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Wah Cantt, Pakistan

To investigate the contaminant removal efficiency using conventional pervious concrete and modified pervious concrete

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Undertaking

It is declared that the work entitled **"To investigate the contaminant removal efficiency using conventional pervious concrete and modified pervious concrete"** presented in this report is an original piece of our own work, except where otherwise acknowledged in text and references. This work has not been submitted in any form for another degree or diploma at any university or other institution for tertiary education and shall not be submitted by us in future for obtaining any degree from this or any other University or Institution.

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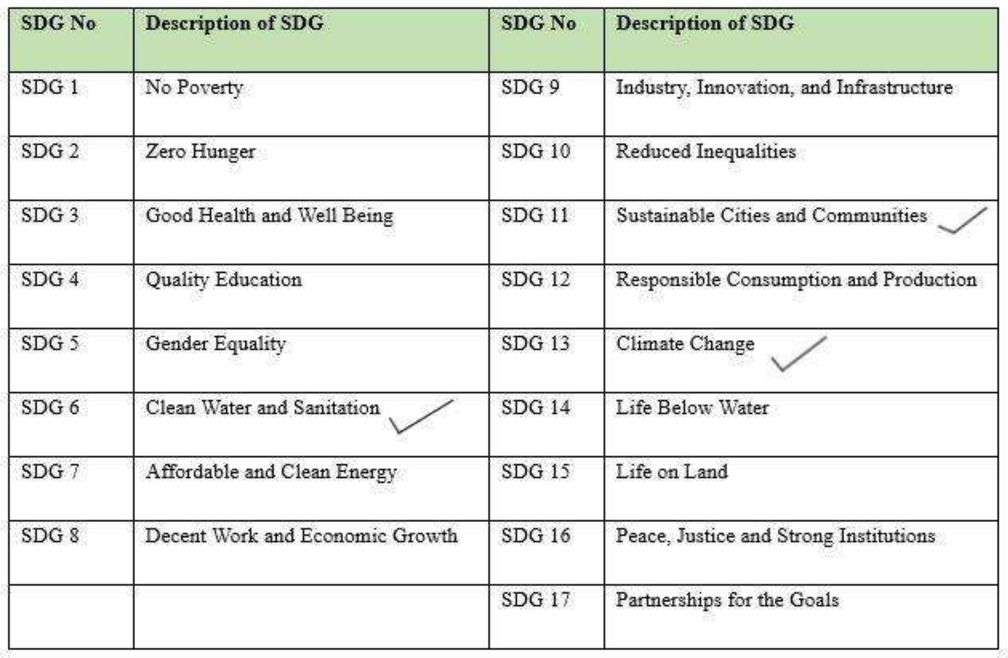
To investigate the contaminant removal efficiency using conventional pervious concrete and modified pervious concrete

Sustainable Development Goals



SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities ✓
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Change ✓
SDG 6	Clean Water and Sanitation ✓	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Abstract

This research study investigates the effectiveness of conventional pervious concrete and graphene oxide-modified pervious concrete in removing zinc and copper, common metals found in urban runoff. Pervious concrete has gained significant attention as an environmentally friendly solution for storm water management due to its ability to promote infiltration and mitigate runoff. However, concerns remain regarding its limited ability to effectively remove contaminants from storm water. This study aims to investigate the contaminant removal efficiency of conventional pervious concrete and compare it with a modified pervious concrete incorporating Graphene Oxide (GO).The objective is to explore the potential of pervious concrete in managing increased runoff caused by climate change and to analyse the influence of graphene oxide and cement quantity on contaminant removal efficiency. Laboratory experiments were conducted to compare the contaminant removal capabilities of conventional and modified pervious concrete. The concentration of metals in the effluents was determined using atomic adsorption spectrometry. The modified pervious concrete was formulated by incorporating graphene oxide into the mix design. Compressive strength tests revealed that the modified pervious concrete exhibited twice the strength of the conventional variant. However, the findings indicated that the conventional pervious concrete exhibited greater metal removal efficiency compared to the modified pervious concrete. Specifically, copper removal demonstrated more promising results than zinc removal. Additionally, the study found that metal removal efficiency was inversely related to the operating head. These results provide valuable insights into the influence of graphene oxide and cement quantity on contaminant removal efficiencies in pervious concrete. Such findings contribute to the development of future pervious concrete mix designs and offer potential solutions for mitigating the impact of urban runoff on the environment.

Keywords: Pervious concrete, contaminant removal, zinc, copper, graphene oxide, urban runoff, climate change, cement quantity, atomic adsorption spectrometry.

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Chapter # 1
Introduction

1. Introduction

Concrete is a widely used construction material in civil infrastructure that has been in use for centuries. It is a composite material made up of coarse aggregate (such as gravel or crushed stone), fine aggregate (such as sand), cement, and water. The aggregates are bound together by the cement paste, resulting in a solid and durable material. Concrete offers several advantages, including high compressive strength, versatility, and fire resistance. It can be molded into various shapes and sizes, making it suitable for a wide range of construction applications. Concrete is commonly used in the construction of buildings, bridges, roads, dams, and many other structures. No-fine concrete is a type of lightweight concrete that differs from traditional concrete by excluding fine aggregates like sand. Instead, it comprises coarse aggregate, cement, and water. While considerable research has been conducted on the physical, chemical, and mechanical aspects of concrete, limited attention has been given to no-fine concrete. This particular form of concrete offers numerous advantages compared to conventional concrete. Its highly porous nature allows for excellent permeability, facilitating easy passage of water. Furthermore, it boasts cost-effectiveness, high thermal insulation, reduced shrinkage, and a lower unit weight. No-fine concrete also exhibits diminished shrinkage, enables early removal of formwork, eliminates the need for mechanical vibrators, and possesses an aesthetically pleasing appearance. Additionally, it proves more economical to produce due to reduced cement and sand content. Various applications have been identified for no-fine concrete, including pavements, internal walls in multi-story housing, retaining walls, damp-proofing sub-base material, and porous structures for drainage pathways. Standards have been established for the casting of in situ no-fine concrete to ensure proper construction practices. Despite its high permeability, the use of no-fine concrete has not been fully optimized due to its lower strength characteristics, typically ranging from 1.4 MPa to about 14 MPa of compressive strength, compared to conventional concrete. This research aims to enhance the strength properties of no-fine concrete by incorporating sustainable additives such as coir fiber (derived from coconut shells) and Nano oxides [1].

As urbanization continues and impervious surface areas increase, the natural percolation of rainfall and snowmelt is hindered, leading to problems such as surface runoff, flooding, erosion, and water pollution. Permeable pavements offer a solution by reducing runoff volume and improving water quality. These pavements can store storm water temporarily, allowing it to infiltrate into the soil or be directed to storm water management systems. Many communities are now considering permeable pavements as a low-impact development strategy for controlling storm water. Portland Cement Pervious Concrete (PCPC) is a specialized type of concrete known for its interconnected pore structure and high void content, typically ranging from 15% to 35% by volume. PCPC offers several benefits, including reducing flood risks, recharging groundwater, minimizing storm water runoff, reducing noise from vehicle tires, and preventing glare and skidding during rainy seasons. Moreover, PCPC is cost-effective, making it an attractive option for sustainable urban drainage systems (SUDS). However, regular maintenance is necessary to prevent clogging of the pores by sediment and vegetation, which can impact its permeability. PCPC may also face durability issues related to abrasion and freeze-thaw cycles, which limit its wider application. Unlike regular concrete, PCPC contains minimal or no fine aggregate and is referred to by various names such as no-fines concrete, permeable concrete, porous concrete, and enhanced porosity concrete. PCPC has been successfully used in various applications, particularly in low-traffic areas such as parking lots, sidewalks, building surroundings, highway shoulders, and medians. Numerous PCPC mixes with different aggregate sizes and types, binder contents, and admixtures have been investigated and documented in the literature. This article provides an overview of PCPC, including its constituent materials, proportions, key properties, durability considerations, and applications.[2]

1.1 Materials of PCPC (Portland Cement Pervious Concrete)

Portland cement pervious concrete (PCPC) utilizes the same materials as regular concrete, but it achieves its porosity by eliminating fine aggregate and using coarse aggregate with a narrow or uniform grading. This promotes relatively low particle packing and allows for the creation of porosity and interconnected pores tailored to specific applications and rainfall intensities. The size and connectivity of the pores in PCPC are influenced by factors such as the type, size, and grading of the aggregate, paste volume, and consolidation energy. Pore size is an important parameter as it affects properties like permeability and sound absorption. Typically, PCPC employs either single-sized coarse aggregate or a grading between 9.5 and 19 mm. PCPC made with single-sized aggregate exhibits high permeability but may have limited strength development. While aggregate with a maximum size of 37.5 mm has been used successfully, a common choice is a maximum size of 20 mm. Single-sized aggregate up to 25 mm has also been employed. The use of single-sized aggregates is crucial to maintain a sufficiently low skeleton packing density, allowing for an adequate number of open pores in the matrix. Generally, a relatively uniform larger aggregate size is preferred for achieving maximum infiltration rates. Larger aggregates result in larger pores and increased permeability. Although adding a small amount of sand can enhance the strength of PCPC compared to single-sized mixes, it reduces permeability. In fact, a small quantity of fine aggregate (< 2.4 mm) has been found to be beneficial for strength and durability. It has been reported that the fine fraction of particles smaller than D10 in the coarse aggregate significantly influences the mechanical properties and hydraulic conductivity of pervious concrete. When fine aggregates are used in PCPC, the paste volume should be adjusted to maintain the desired void content.[3]

1.3 Mixture Design and Proportioning

The design approach for Portland cement pervious concrete (PCPC) primarily involves selecting a narrowly graded coarse aggregate and adjusting the paste volume to achieve the desired properties. The optimal water content for PCPC depends on factors such as the aggregate's gradation, physical characteristics, and the type and amount of cementitious materials used. Typically, a water-to-binder (w/b) ratio ranging between 0.27 and 0.43 is selected, sometimes in combination with water-reducing admixtures, to ensure the desired workability.[6] Workability is considered satisfactory when a handful sample of the mixture can be squeezed and released without crumbling or becoming void-free. Table 1 provides a summary of the reported ranges of mixture proportions in various studies. A successful PCPC mix design should achieve a balanced composition of materials to ensure optimal performance in terms of permeability, strength, and durability. The key consideration in PCPC design is to maintain the continuity of cement paste with embedded coarse aggregate, ensuring the presence of continuous voids. Generally, the aggregate-to-cement ratios (A/C) range from 4 to 6 by mass, resulting in aggregate contents between 1300 kg/m3 and 1800 kg/m3. In laboratory studies, higher A/C ratios have been used, but they lead to a significant reduction in strength.[3]

1.4 Application of Graphene Oxide

Graphene has garnered considerable attention in recent years due to its remarkable properties and potential applications. It consists of a single layer of carbon atoms arranged in a hexagonal lattice, making it the thinnest and strongest material known. One of the most notable characteristics of graphene is its exceptional mechanical strength. It exhibits a tensile strength approximately 200 times greater than that of steel, while remaining incredibly lightweight. This unique combination of strength and low weight makes it a promising material for various industries, including aerospace, automotive, and structural engineering. In addition to its mechanical properties, graphene also possesses excellent electrical conductivity. It enables electrons to move through it at a much faster rate compared to other materials, making it a potential candidate for electronic and optoelectronic devices. Researchers are exploring the use of graphene-based transistors, sensors, batteries, and solar cells for their superior performance. Graphene's thermal conductivity is another notable aspect. It has the ability to efficiently conduct heat, which makes it suitable for thermal management applications in electronics, batteries, and energy storage systems. Furthermore, graphene exhibits unique optical properties. It is nearly transparent and can absorb up to 2.3% of visible light. This characteristic makes it well-suited for applications in transparent conductive films, touchscreens, and photovoltaic devices. Despite its exceptional properties, the widespread use of graphene faces certain challenges. One major obstacle is the large-scale production of high-quality graphene at an affordable cost. Various methods, such as mechanical exfoliation, chemical vapor deposition, and epitaxial growth, have been developed for synthesizing graphene. Each method has its own advantages and limitations in terms of scalability, cost, and quality control. Another challenge lies in integrating graphene into existing technologies. Its unique properties often require customized fabrication techniques and manufacturing processes. Compatibility issues with other materials, such as substrates and electrodes, need to be addressed for successful integration. Moreover, the commercial adoption of graphene is influenced by regulatory and safety considerations. As a relatively new material, its health and environmental impacts are still being studied, and regulations may evolve accordingly. In conclusion, graphene possesses exceptional properties that make it highly attractive for a wide range of applications. However, realizing its full potential requires advancements in large-scale production, integration into existing technologies, and addressing regulatory and safety concerns. Through continued research and development efforts, graphene's capabilities can be further harnessed in diverse industries.[4]

1.5 Application of pervious concrete

- Pervious concrete, also known as permeable or porous concrete, is a specialized type of concrete that possesses high porosity, enabling water to permeate through it. This unique characteristic makes it a valuable solution for managing storm water in urban areas. Pervious concrete finds applications in various areas, including:
- Pavements and Parking Lots: Pervious concrete is suitable for constructing driveways, sidewalks, parking lots, and low-traffic roadways. Its porous structure facilitates the infiltration of rainwater directly into the ground, reducing the need for extensive drainage systems and minimizing the risk of flooding.
- Sustainable Landscaping: Pervious concrete is an ideal choice for landscaping projects such as pathways, patios, and outdoor recreational areas. By allowing rainwater to seep into the soil, it aids in replenishing groundwater and supporting the natural hydrological cycle.
- These applications demonstrate the versatility and effectiveness of pervious concrete in mitigating storm water runoff and promoting sustainable water management in urban environments.[5]

1.6 Combination of Pervious Concrete and Graphene Oxide

The incorporation of graphene oxide (GO) into pervious concrete has the potential to enhance its properties and performance. GO is a derivative of graphene comprising oxygen-functionalized graphene sheets. Here are some possible effects and benefits of introducing GO into pervious concrete:

- Increased Strength: Studies have reported that GO can improve the mechanical properties, such as compressive and flexural strength, of concrete. By adding GO to pervious concrete, its overall strength and durability can be enhanced, resulting in increased resistance to cracking and deformation. Enhanced Water Permeability: Pervious concrete is designed to allow water to infiltrate through its porous structure. The addition of GO can further improve water permeability due to the unique properties of graphene-based materials. GO's hydrophilic nature and interconnected nanostructure can facilitate the movement of water through the concrete matrix, enhancing its permeability.

- Increased Chemical Resistance: GO has shown promise in enhancing the chemical resistance of concrete. Its impermeable nature can restrict the penetration of harmful substances, such as chloride ions, into the concrete matrix. This can improve the durability of pervious concrete, especially in aggressive environments. Improved Thermal Properties: Graphene-based materials, including GO, exhibit excellent thermal conductivity. Incorporating GO into pervious concrete can enhance its thermal properties, leading to better heat dissipation and temperature regulation. It is important to note that research on the combination of pervious concrete with GO is still ongoing, and the optimal dosage and dispersion techniques of GO in concrete require further investigation. Therefore, it is advisable to refer to specific research studies and consult with experts in the field for more detailed information and guidance regarding the application of graphene oxide in pervious concrete.[7]

1.7 Problem Statement

The escalating challenges of climate change, intensified rainfall patterns, and increased anthropogenic activities have significantly contributed to non-point source pollution in urban areas, leading to elevated levels of metal contaminants in urban runoff. This growing issue calls for urgent attention and the development of effective solutions to mitigate the environmental impact caused by metal-laden runoff.

1.8 Statement of Project

The purpose of this investigation is to investigate the effect of cement quantity on the contaminant removal efficiency of conventional pervious concrete and modified pervious concrete.

1.9 Aims & Objective

- The objective of this study is to examine the impact of varying cement content in pervious concrete on the efficiency of contaminant removal.
- To conduct a comparative analysis of the contaminant removal efficiencies of the conventional and modified pervious concrete.

Chapter # 2

Literature Review

2. Literature Review

Concrete is a versatile and widely used construction material that is composed of several components. It is a composite material made up of coarse aggregate (such as gravel or crushed stone), fine aggregate (such as sand), cement, and water. These ingredients are combined in specific proportions to create a mixture that solidifies and hardens over time, forming a durable and strong material. The coarse and fine aggregates provide the bulk and fill the voids within the concrete, giving it its structural strength. They make up the majority of the volume and provide stability and support to the structure. The cement acts as a binder that holds the aggregates together. When mixed with water, the cement undergoes a chemical reaction known as hydration, which forms a paste that binds the aggregates and hardens over time. Water is an essential component in the concrete mixture. It reacts with the cement during hydration and enables the paste to flow and be workable. The water-to-cement ratio plays a crucial role in determining the strength and durability of the concrete. The correct proportion of water is necessary to achieve a proper balance between workability and strength. Once the concrete mixture is prepared, it can be poured into molds or formwork to give it the desired shape. It then undergoes a curing process, where it is allowed to harden and gain strength over time. Curing is important to ensure that the concrete develops its full potential strength and durability. Concrete offers several advantages as a construction material. It has high compressive strength, meaning it can withstand heavy loads and pressures. It is also fire-resistant, providing a level of protection in case of fire. Concrete is versatile and can be molded into various shapes and sizes, allowing for a wide range of applications in construction, such as buildings, bridges, roads, dams, and more. Its durability and longevity make it a popular choice for long-lasting structures.[3]

Pervious concrete, also known as porous concrete or permeable concrete, is a specialized type of concrete that allows water to pass through it. Unlike traditional concrete, which is dense and non-permeable, pervious concrete is designed to have a highly porous structure, enabling water to infiltrate and drain through the material. Pervious concrete is typically composed of the same basic ingredients as traditional concrete, including coarse aggregate, fine aggregate, cement, and water. However, it is specifically engineered with a lower paste content and a higher proportion of voids within the mixture. This creates a network of interconnected voids or pores throughout the concrete, allowing water to flow through. The voids within pervious concrete can be achieved by using larger aggregate sizes, reducing the amount of fine aggregate or sand, and adjusting the water-to-cement ratio. During the mixing and placement process, special care is taken to avoid over compaction, as excessive compaction would close off the pores and reduce the permeability of the concrete. The primary advantage of pervious concrete is its ability to promote storm water management and mitigate the effects of urban runoff. When rainfall or water comes into contact with pervious concrete surfaces, it can percolate through the pavement, filtering out impurities and recharging the groundwater table. This helps to reduce storm water runoff, minimize the strain on storm water drainage systems, and improve water quality by removing pollutants. Pervious concrete is commonly used in a range of applications, including parking lots, sidewalks, driveways, pedestrian areas, and low-traffic roadways. It is also utilized in sustainable construction practices, green infrastructure projects, and environmentally sensitive areas where water management is crucial. While pervious concrete offers excellent permeability, it typically has lower structural strength compared to traditional concrete. Therefore, it is commonly used in areas with lighter loads or where the structural requirements are less demanding. Overall, pervious concrete provides an innovative solution for managing storm water and promoting sustainable development by allowing water to infiltrate the surface and replenish groundwater resources.[6]

Pervious concrete has various applications in construction and landscaping where effective storm water management and water infiltration are desired. Some common applications of pervious concrete includes, pervious concrete is frequently used for parking lots, particularly in areas with strict storm water regulations. It allows rainwater to infiltrate the ground, reducing runoff and minimizing the need for elaborate drainage systems. Pervious concrete is an excellent choice for sidewalks, pathways, and pedestrian areas. It provides a safe and durable surface for foot traffic while allowing water to permeate and prevent puddling. Pervious concrete driveways are becoming increasingly popular due to their eco-friendly nature and ability to prevent rainwater from pooling on the surface. They provide a stable and permeable surface for vehicles while reducing storm water runoff. Pervious concrete can be utilized in parks and recreational areas to create porous walkways, plazas, and gathering spaces. This allows rainwater to be absorbed into the ground, promoting healthier vegetation and minimizing erosion. Pervious concrete can be used in low-traffic roadways, such as residential streets or parking lanes, where it's porous nature aids in water infiltration and reduces the strain on drainage systems. Pervious concrete is an integral component of sustainable drainage systems (SuDS) or low-impact development (LID) practices. It can be used in rain gardens, bios wales, infiltration basins, and other features designed to manage and treat storm water runoff. Pervious concrete can be utilized in sports courts, such as tennis or basketball courts, to allow for better drainage and minimize the accumulation of water on the surface. It can also be used in playgrounds to create safe and permeable play surfaces. Pervious concrete can be employed in landscaping projects, such as retaining walls or decorative features, where water permeability is desired.[7]

Graphene oxide is a derivative of graphene, which is a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice. Graphene itself possesses exceptional electrical, mechanical, and thermal properties, making it a highly sought-after material. Graphene oxide is obtained by the oxidation of graphene, resulting in the introduction of oxygen-containing functional groups, such as hydroxyl and epoxy groups, onto the graphene structure. The oxidation process of graphene involves treating it with strong oxidizing agents, such as sulfuric acid, nitric acid, or potassium permanganate. These agents disrupt the carbon-carbon bonds in graphene, leading to the formation of oxygen-containing functional groups. The resulting graphene oxide retains the two-dimensional structure of graphene but with increased hydrophilicity and improved dispersibility in water and other solvents. Graphene oxide exhibits unique properties that differ from pure graphene due to the presence of oxygen functional groups. These functional groups introduce polarity and enhance the interaction of graphene oxide with other materials and substances. This property makes graphene oxide suitable for a wide range of applications, particularly in areas such as electronics, energy storage, composites, biomedical engineering, and environmental remediation. The oxygen functional groups on graphene oxide enable it to be easily dispersed in water or organic solvents, making it compatible with various processing techniques. This dispersion characteristic allows graphene oxide to be used as a precursor for the synthesis of reduced graphene oxide (rGO) by the removal of a portion of the oxygen functional groups through reduction processes. The unique properties of graphene oxide, such as its high surface area, mechanical strength, thermal stability, and electrical conductivity, make it an attractive material for various applications. It has been investigated for use in electronics and optoelectronics, as a reinforcing additive in composites to enhance mechanical properties, as a catalyst support, in energy storage devices like supercapacitors and batteries, as well as for biomedical applications such as drug delivery, tissue engineering, and bio sensing. Graphene oxide's versatility and ability to be easily functionalized and modified have contributed to its growing importance in scientific research and technological advancements. Researchers continue to explore and develop new applications and techniques involving graphene oxide to harness its unique properties for a wide range of practical applications. [5]

Graphene oxide has shown promise in the field of environmental remediation, particularly in the removal of heavy metals from urban runoff. Urban runoff refers to the water that flows over urban surfaces, such as roads, parking lots, and rooftops, and carries pollutants, including heavy metals, into water bodies. Here are some applications of graphene oxide:

- Adsorption: Graphene oxide possesses a large surface area and abundant functional groups, making it an excellent adsorbent for heavy metals. Its high adsorption capacity allows it to effectively bind heavy metal ions in water and remove them from the runoff. Graphene oxide-based adsorbents can be used in filters or integrated into storm water treatment systems to capture heavy metals.
- Filtration Membranes: Graphene oxide membranes can be engineered to selectively filter out heavy metal ions from water. The unique properties of graphene oxide, such as its nanoscale thickness, high mechanical strength, and controlled permeability, enable the creation of membranes that allow water to pass through while effectively trapping heavy metal contaminants.
- Functionalized Nanocomposites: Graphene oxide can be functionalized or combined with other materials to enhance its heavy metal removal capabilities. For example, it can be modified with specific functional groups or incorporated into nanocomposite materials to improve its selectivity and affinity towards heavy metal ions. This approach can enhance the efficiency and effectiveness of heavy metal removal from urban runoff.
- Catalysis: Graphene oxide can also be used as a catalyst in advanced oxidation processes for the degradation and detoxification of organic pollutants in urban runoff. By utilizing the unique properties of graphene oxide, such as its large surface area and redox properties,

it can participate in catalytic reactions to break down organic pollutants and facilitate the removal of heavy metals.

The application of graphene oxide in removing heavy metals from urban runoff is still an area of active research. While its potential is evident, further studies are needed to optimize the synthesis and modification of graphene oxide-based materials, evaluate their long-term performance, and assess their environmental impact. However, the unique properties of graphene oxide make it a promising candidate for developing efficient and sustainable solutions to address heavy metal pollution in urban environments.[8]

Urbanization has significant effects on the environment, and one of the key impacts is the generation of urban runoff. Here are some of the effects of urbanization on the environment and how they contribute to urban runoff. Urbanization involves the conversion of natural land into built-up areas with impervious surfaces like roads, parking lots, and buildings. These surfaces prevent water from infiltrating into the ground, leading to increased surface runoff. Rainwater that would have been absorbed by vegetation or soaked into the soil now flows over these impervious surfaces, collecting pollutants such as heavy metals, oil, pesticides, and fertilizers along the way. Urbanization disrupts the natural hydrological cycle. Green spaces and natural vegetation are replaced by concrete and asphalt, reducing the amount of water that can be absorbed into the ground. This alteration in the hydrological cycle results in increased runoff volumes and faster flow rates during rainfall events. Urbanization can exacerbate flooding due to the reduced capacity of the land to absorb and store water. The increased runoff from impervious surfaces overwhelms natural drainage systems, leading to flash floods and damage to infrastructure. Urban runoff can also overload sewer systems, causing combined sewer overflows and further contributing to flooding and water pollution. Urban runoff carries various pollutants from the built environment into water bodies. The runoff picks up contaminants such as heavy metals, bacteria, sediments, nutrients, and chemicals, and transports them into streams, rivers, lakes, and coastal areas. These pollutants can have detrimental effects on aquatic ecosystems, causing water quality degradation, harming aquatic life, and impairing human health if the contaminated water is used for drinking or recreation. Urbanization involves clearing natural habitats to make way for buildings, roads, and other infrastructure. This leads to the loss of vegetation, wildlife habitat, and biodiversity. The destruction of natural habitats disrupts ecosystems and reduces the ability of vegetation to absorb and filter runoff, exacerbating the negative impacts of urban runoff on water quality and the environment. Addressing the effects of urbanization on the environment and mitigating the impacts of urban runoff requires implementing sustainable urban planning and design practices. These may include incorporating green infrastructure, such as rain gardens, bioswales, permeable pavements, and rooftop gardens, to promote infiltration and reduce runoff volumes. Additionally, implementing proper storm water management practices, such as detention ponds and treatment systems, can help capture and treat urban runoff before it reaches water bodies.[6]

Surface water and groundwater contamination refers to the presence of pollutants or contaminants in bodies of water, including rivers, lakes, streams, and underground aquifers. Contamination can occur as a result of human activities, industrial processes, agricultural practices, improper waste disposal, and natural processes. Some common causes and sources of surface water and groundwater contamination. Industrial processes can release various pollutants into water bodies. Factories and industrial facilities may discharge untreated or inadequately treated wastewater containing heavy metals, toxic chemicals, solvents, oils, and other pollutants. Accidental spills and leaks from industrial sites can also lead to contamination of nearby surface water and groundwater sources. Agricultural activities contribute to water contamination through the use of fertilizers, pesticides, and herbicides. These chemicals can enter surface water and groundwater through runoff and leaching. Excessive nutrient runoff, such as nitrogen and phosphorus, can lead to eutrophication, causing harmful algal blooms and degrading water quality. Improper disposal of waste, including household waste, sewage, and hazardous materials, can contaminate surface water and infiltrate into groundwater. Inadequate sewage treatment, septic system failures, and illegal dumping of waste can introduce pathogens, nutrients, chemicals, and other pollutants into water sources. Mining operations can release various contaminants into nearby water bodies. Acid mine drainage, for example, occurs when sulfide minerals are exposed to air and water, leading to the formation of sulfuric acid and the release of heavy metals into surface water and groundwater. Extraction activities, such as oil and gas drilling and production, can result in the release of pollutants into surface water and groundwater. Spills, leaks from storage tanks, and improper disposal of produced water or fracking fluids can introduce hydrocarbons, chemicals, and heavy metals into water sources. Landfills can contribute to water contamination through the leaching of hazardous substances and pollutants into groundwater. Contaminants from decomposing waste can infiltrate the underlying soil and reach groundwater sources. Inadequate waste management practices, such as open dumping or poorly designed landfills, can exacerbate the risks of contamination. Some areas may naturally contain contaminants in the groundwater, such as high levels of naturally occurring arsenic or radon. These natural contaminants can pose risks to human health if they exceed safe levels. The contamination of surface water and groundwater has significant environmental and public health implications. It can affect aquatic ecosystems, impair water quality, threaten drinking water supplies, harm aquatic life, and pose risks to human health through the consumption of contaminated water or contact with polluted water sources. Preventing and addressing surface water and groundwater contamination require effective pollution prevention measures, proper wastewater treatment, responsible waste management practices, and sustainable agricultural practices. Regular monitoring, enforcement of regulations, and the implementation of remediation strategies are vital for protecting water resources and ensuring safe and clean water supplies.[9]

The most common pollutants found in urban runoff are nutrients, sediments, and heavy metals. Heavy metals, in particular, are highly toxic and can cause severe health issues. Copper (Cu), lead (Pb), and zinc (Zn) are the most common heavy metals found in urban runoff, primarily originating from traffic-related sources. These heavy metals pose a risk to human health, especially when multiple heavy metals are present. The concentration of heavy metals in storm water varies due to factors such as weather, land use patterns, and antecedent dry periods. Specific treatment schemes should consider site-specific data acquisition. The behavior of porous concrete in removing heavy metals, especially Cu, Pb, and Zn.[10]

Heavy metals pose a significant threat to human health, as they have no biological role and can have toxic effects on the body. These metals can interfere with metabolic processes and accumulate in the body and food chain, leading to chronic toxicity. Public health measures have been implemented to control and prevent metal toxicity from occupational exposure, accidents, and environmental factors. The severity of metal toxicity depends on factors such as the dose, route, and duration of exposure, whether acute or chronic. Exposure to heavy metals can cause various disorders and oxidative stress due to the formation of free radicals. Heavy metals are well-known environmental pollutants that can have long-lasting effects and accumulate in the human body through bioaccumulation. Pollution of terrestrial and aquatic ecosystems with toxic heavy metals is a major concern for public health. While some heavy metals occur naturally, others are derived from human activities. These metals have a high atomic mass and can be highly toxic to living organisms. They can contaminate water, soil, and air, and enter the human body through the food chain. [9]

Porous concrete offers an attractive solution for urban runoff treatment without the need for additional land acquisition or open water storage. In terms of heavy metal treatment, the fixation of heavy metals in porous concrete involves physical and chemical processes, with the dominant process depending on the characteristics of the influent. Both aggregates and cement paste in the porous concrete matrix have the capacity to fix heavy metals, with the aggregate's ability being significant when it has a high calcium content, such as limestone aggregates. The main processes involved in heavy metal removal are precipitation, through the formation of heavy metal hydroxides, and sorption, via cation exchange. The dominant removal mechanism is dictated by the initial concentration of heavy metals, with precipitation dominating at high initial concentrations and sorption dominating at low initial concentrations. To identify the strategic pollutants in urban runoff, evaluate the efficacy of porous concrete in removing these pollutants, discuss the mechanisms involved in pollutant removal, evaluate existing modifications of porous concrete, and suggest areas for further enhancements in storm water treatability using porous concrete. Porous concrete, also known as pervious or permeable concrete, offers promising potential for the removal of heavy metals from water due to its unique structure and composition. The mechanisms through which heavy metals are removed can be categorized into physical and chemical processes, each playing a crucial role in pollutant removal. To address these issues, there has been a focus on storm water management and the treatment of urban runoff. Conventional methods, such as detention and retention basins, have been used, but they require engineered treatment and have disadvantages such as drowning hazards, malodour, limited groundwater recharge, and the need for significant land uptake. Porous concrete has emerged as an alternative storm water management method. It allows runoff attenuation, pollutant reduction, and water infiltration. The pollutants are removed through chemical and physical reactions between the porous concrete and microorganisms present in the pores. Many research studies have been conducted to improve the pollutant removal efficiency of porous concrete. Physical processes involve water trapping and diffusion within the porous structure of the concrete. When water containing heavy metals comes into contact with porous concrete, it infiltrates the interconnected voids or pores present in the material. The trapped water physically holds the heavy metal ions within the concrete, preventing their immediate release. Over time, diffusion occurs, allowing the heavy metal ions to migrate through the porous network of the concrete.[11]

Chemical processes in porous concrete involve various interactions between the heavy metal ions and the components of the concrete. Sorption is a prominent chemical mechanism where heavy metal ions adhere to the surface of the concrete. The chemical composition of the concrete, such as the presence of calcium-based compounds, can provide reactive sites for the adsorption of heavy metal ions. Complexation is another important chemical process. It involves the formation of chemical complexes between the heavy metal ions and the constituents of the concrete, such as hydroxides or oxides. These complexes can reduce the mobility and bioavailability of heavy metals, contributing to their removal from the water. Precipitation is a chemical process that occurs when heavy metal ions react with compounds present in the concrete, leading to the formation of insoluble precipitates. The alkaline nature of the cement paste in porous concrete, resulting from cement hydration, can facilitate precipitation or sorption of heavy metals through reactions with hydration products. In addition to physical and chemical processes, biological purification can also occur in porous concrete. Microbes residing within the pores of the concrete can contribute to the removal of heavy metals through biological mechanisms. These microorganisms, including bacteria and fungi, can interact with heavy metal ions, potentially immobilizing or transforming them into less toxic forms.[2]

Aggregates in porous concrete, such as limestone, can also play a role in pollutant removal. Aggregates containing high quantities of lime have been found to exhibit higher removal capacities compared to other aggregates. These aggregates contribute to removal through adsorption mechanisms, where heavy metal ions adhere to their surfaces, as well as by increasing the pH of the water, which can enhance the precipitation of heavy metal ions. The removal efficiency of heavy metals by porous concrete can be influenced by various factors. The composition of the concrete, including the type and proportion of cementitious materials and aggregates, can significantly impact its pollutant removal capabilities. Aggregates with larger surface areas and higher porosity tend to exhibit greater removal efficiencies. It is important to note that the effectiveness of porous concrete in removing heavy metals can vary depending on the specific conditions and characteristics of the concrete and the pollutants involved. Factors such as pH, temperature, flow rate, and the presence of competing ions can influence the overall removal efficiency. To explore and optimize the removal capabilities of porous concrete for different heavy metals and operating conditions, ultimately enhancing its potential as a sustainable and effective method for water treatment and pollution mitigation. The initial concentration of pollutants in the water also plays a role in determining the dominant mechanism of removal. Higher initial concentrations may lead to the formation of precipitates, while lower concentrations may rely more on adsorption mechanisms. The contact time between the water and the porous concrete is another critical factor. Generally, maximum removal efficiency is achieved within a relatively short contact time, as the available reactive sites within the concrete become saturated over time. Both components of permeable concrete, namely cement paste and aggregates, have the ability to remove contaminants from the solution. The adsorption capacity of the porous concrete is significantly influenced by the adsorption capacity of the cement paste. The highly alkaline conditions resulting from cement hydration, with a pH above 12, cause metals to precipitate or bind with cement hydration products such as calcium-silica-hydrate (C-S-H) gel. Physical fixation and sorption have been identified as the main mechanisms of metal removal. The presence of competing ions or changes in the ionic strength of the solution can affect the adsorption of pollutants.[7]

The maximum removal efficiency of heavy metals using porous concrete is typically achieved within 18 minutes. However, current treatment methods with porous concrete require the storage of runoff due to its high infiltration capacity. Decalcification, resulting from the displacement of calcium ions, can lead to the degradation of porous concrete. Leaching of adsorbed heavy metals from porous concrete requires low pH values below 2, and the effluent pH of water passing through porous concrete often needs additional treatment to lower its pH, as it tends to be above 8.5 in most studies. The individual capacity of the cement paste and aggregates in porous concrete to remove contaminants has been a subject of research. Cement paste, being highly alkaline, can cause heavy metals to precipitate or sorb with hydration products. The calcium-silicate hydrate (C-S-H) gel in the cement paste has a significant cation exchange capacity, allowing it to readily exchange heavy metal ions. Permeable concrete, consisting of cement paste and aggregate, possesses inherent capabilities to remove contaminants from solutions. The adsorption capacity of the concrete paste plays a crucial role in its water purification efficiency. The alkaline conditions resulting from cement hydration, with a pH above 12, lead to the precipitation of metals or the sorption of heavy metal ions by cement hydration products such as calcium-silica-hydrate (C-S-

H) gel. Previous studies have demonstrated the physical fixation and sorption as the primary mechanisms for contaminant removal. The ionic strength of the solution also influences the adsorption process by affecting the surface potential of the adsorbents or acting as competing ions. In hydrated cement paste, the presence of ions such as Na+, K+, Ca2+, Mg2+, Cl-, SO42-, and OH- results in an observed ionic strength ranging from approximately 0.23 to 0.17 mol/L. Different ions exhibit varying behaviors in terms of adsorption. For instance, increasing the initial ionic strength of the solution from 0.05 mol/L to 2 mol/L using Ca(NO3)2 was found to decrease Pb adsorption by over 45% in thermally modified waste concrete, whereas increasing the ionic strength through NaNO3 addition led to an approximate 10% increase in Pb removal. However, no specific studies addressing the impact of ionic strength on the removal of heavy metals using porous concrete were found in the available literature. Cement hydration primarily results in the formation of calcium-silicate hydrate (C-S-H) and calcium hydroxide (CH) compounds, with C-S-H exhibiting notable cation exchange capacity. Heavy metal ions exhibit a stronger affinity towards C-S-H compared to alkali metal ions like Ca2+, Al3+, and Si4+ in the solidified cement matrix. Understanding the primary mechanisms involved in the removal of metals is crucial when exploring ways to modify porous concrete. The processes through which heavy metals are eliminated by porous concrete can be broadly categorized as physical (water trapping and diffusion) and chemical processes (sorption, complexation, and precipitation). Additionally, microbes residing in the pores of pervious concrete can contribute to biological purification. The effectiveness of pollutant removal by porous concrete depends on the characteristics of the concrete and the pollutants.[6]

In hydrated cement paste, the ionic strength is influenced by various ions such as Na+, K+, Ca2+, Mg2+, Cl−, SO4 2−, and OH−. Different ions behave differently in terms of pollutant adsorption. For example, the adsorption of lead (Pb) by thermally modified waste concrete decreased by more than 45% when the initial ionic strength of the solution was increased using Ca (NO3)2. However, when the ionic strength was increased by the addition of NaNO3, Pb removal increased by approximately 10%. However, there is a lack of studies specifically focusing on the effect of ionic strength on the removal of heavy metals using porous concrete.[12]

Cement hydration primarily results in the formation of calcium-silicate hydrate (C-S-H) and calcium hydroxide (CH). C-S-H has significant cation exchange capacity and heavy metal ions have a higher affinity for C-S-H compared to other cations present in the cement matrix. Therefore, cation exchange easily occurs between C-S-H and heavy metal ions. The migration of Ca2+ ions in the cement matrix contributes to the co-precipitation of metal species on the surface of the concrete particles. Isomorphic substitution, where Pb2+ ions replace Ca2+ ions in the cement matrix, can occur during adsorption. Ettringite, a mineral found in Portland cement paste, also has an electronegative surface that attracts metal ions.[5]

Decalcification refers to the degradation process in cementitious materials, primarily caused by the leaching of calcium and hydroxide ions from the cement matrix. This decalcification adversely affects the mechanical strength and durability of concrete, leading to its deterioration. The rate of decalcification is influenced by the type of exposure, with concrete taking longer to undergo decalcification when exposed to freshwater compared to aggressive agents. Porous concrete's long-term performance and service life are highly dependent on the characteristics of the water it comes into contact with. Acidic wastewater, for example, can rapidly decalcify the hydrates (such as portlandite, C-S-H, and ettringite) and unhydrated cement in porous concrete, resulting in the leaching of immobilized heavy metals and rendering the concrete non-functional. Researchers have also observed a significant loss of strength in the uppermost layer of porous concrete, attributed to the displacement or diffusion of calcium by heavy metals. This degradation compromises the structural integrity of the porous concrete. Additionally, the leaching of calcium ions from the cement paste increases the porosity of the material, further promoting its degradation. Studies have shown that increased porosity and high capillary adsorption in porous concrete can enhance the removal of contaminants. However, there is currently no evidence available in the literature regarding the potential benefits of increased porosity resulting from decalcification on the removal of heavy metals.[1]

Nanotechnology has shown promise in the analysis and removal of heavy metals from complex matrices. Various nanomaterials, including graphene and its derivatives, magnetic nanoparticles, metal oxide nanoparticles, and carbon nanotubes, have been utilized for the removal of heavy metals. Nanotechnology offers several advantages over traditional methods, such as a wide linear range, low detection and quantification limits, high sensitivity, and selectivity. This review aims to examine the environmental consequences of heavy metals, their toxicity to human health, and the development of novel therapeutic approaches using natural resources. Additionally, it explores the applications of nanotechnology and nanomedicine in treating heavy metal toxicity. Extensive experimental studies have been conducted to explore potential treatment options using natural products, as well as advancements in nanotechnology-based treatments. The discovery of graphene, consisting of carbon atoms arranged in a hexagonal structure with atomic layers of sp2 hybridization, has captured the attention of researchers from various fields. Graphene oxide (GO), a derivative of graphene, has gained significant interest in the development of effective pollution treatment due to its large specific surface area and abundant functional groups. Recently, there have been advancements in synthesizing novel GO-based nanomaterials by combining them with other nanomaterials, resulting in efficient removal of different types of pollutants. Nanoparticles, such as TiO2, are being explored for their ability to remove heavy metals due to their high surface area and reactive properties. They can also improve the mechanical properties of cement-based products. Research on improving heavy metal removal using porous concrete has mainly focused on enhancing removal efficiency. Some approaches include the addition of pozzolanic materials like pumice, fly ash, silica fume, and natural zeolites, which decrease pH due to pozzolanic reactions without reducing overall removal efficiency. The addition of materials such as reduced graphene oxide (RGO) and iron oxide increases heavy metal removal, while RGO also reduces heavy metal leaching due to acidic influent. However, the homogeneous embedding of photocatalytic nanoparticles throughout porous concrete may lower the photocatalytic efficiency. The addition of Fe2O3 nanoparticles marginally increased lead (Pb) removal in one study, but the exact removal mechanism was not identified. Future research should focus on identifying the mechanisms of removal following nanoparticle modification and optimizing the mixing of photocatalytic materials to maximize their beneficial effects on mechanical properties and pollutant removal. Additionally, new photocatalytic materials and incorporation strategies need to be explored, and the release of photocatalytic materials during wear from abrasion should be investigated, especially for porous concrete. The synthesis process, characteristics of the adsorption process, and interaction mechanisms of the adsorbent are emphasized and discussed. Additionally, the effects of different environmental conditions on the removal process are outlined. Finally, a brief summary, perspective, and outlook are presented. The purpose of this review is to offer exciting information that can contribute to the design and production of GO-based nanomaterials for the effective elimination of heavy metal ions from wastewater in environmental pollution management. The fabrication of graphene oxide (GO) has undergone several modifications and improvements over the years. Initially, Brodie's method involved heating the substance at 60°C until no more yellow vapors were produced. It was then mixed with deionized water, washed to remove salt and acid, and dried in a water bath. The oxidizing process was repeated using potassium chlorate and nitric acid until no further changes occurred. The obtained GO was finally dried under vacuum at 100°C. Staudenmaier later enhanced this method by using fuming nitric acid and concentrated sulfuric acid, and adding potassium chlorate in multiple portions during the reaction. Although this alteration provided similar oxidation levels to Brodie's method, it was found to be hazardous and time-consuming. Hummers and Offeman introduced a commonly used method in 1958, which involved mixing graphite, sodium nitrate, and concentrated sulfuric acid in a cooled flask. Potassium permanganate was slowly added while vigorously agitating the suspension. The temperature was then raised and maintained at specific levels, followed by treatment with hydrogen peroxide. The resulting filter cake was washed and dispersed in distilled water. These three methods, despite some variations by other researchers, represent the main pathways for GO synthesis and have remained largely unchanged. It is important to note that the prepared GO materials can exhibit significant differences depending on the reaction conditions, oxidants used, and graphite sources. Despite the notable progress made, achieving a cost-effective, high-quality, and environmentally friendly manufacturing process for GO remains a challenging task in the field.[5]

Both conventional pervious concrete and pervious concrete modified with graphene oxide have emerged as effective solutions for removing heavy metals from urban runoff. These innovative materials possess inherent capabilities that contribute to the successful elimination of heavy metal pollutants. In the case of conventional pervious concrete, the process of cement hydration plays a crucial role. During hydration, cementitious materials undergo chemical reactions, resulting in the formation of hydration products. These hydration products exhibit remarkable adsorption properties, making them effective adsorbents for heavy metals present in urban runoff. The unique structure and composition of these hydration products allow them to attract and retain heavy metal ions, thereby facilitating their removal from the runoff water. This adsorption mechanism plays a vital role in the efficient cleansing of the urban runoff, making conventional pervious concrete a valuable tool in combating heavy metal pollution. However, to further enhance the heavy metal removal capabilities of pervious concrete, researchers have explored the incorporation of graphene oxide into the material. Graphene oxide, with its exceptional properties, serves as a promising additive for modifying pervious concrete. When graphene oxide is introduced into the concrete matrix, it imparts additional adsorptive capacity to the material, enabling it to selectively adsorb heavy metals. The graphene oxide, with its large surface area and unique surface chemistry, interacts with heavy metal ions, capturing them and effectively eliminating them from the urban runoff. This additional adsorption mechanism enhances the overall efficiency of heavy metal removal in modified pervious concrete, providing an advanced and sustainable approach for mitigating the detrimental effects of heavy metal contamination in urban runoff. By employing both conventional pervious concrete and modified pervious concrete, urban planners and environmental engineers can effectively combat the issue of heavy metal pollution in urban runoff. The adsorption mechanisms inherent to cement hydration products, combined with the supplementary adsorptive capacity offered by graphene oxide in modified pervious concrete, ensure the successful removal of heavy metals, safeguarding the quality of receiving water bodies and protecting the environment from the adverse impacts of urban runoff contamination. Through the adoption of these innovative materials, urban environments can be better equipped to address the challenges posed by heavy metal pollutants and promote the sustainable management of water resources.[5]

Chapter # 3

Research Methodology

3. Research Methodology

For this study, the methodology is composed of five main stages, represented in figure 1.The following section describe each stage in detail.

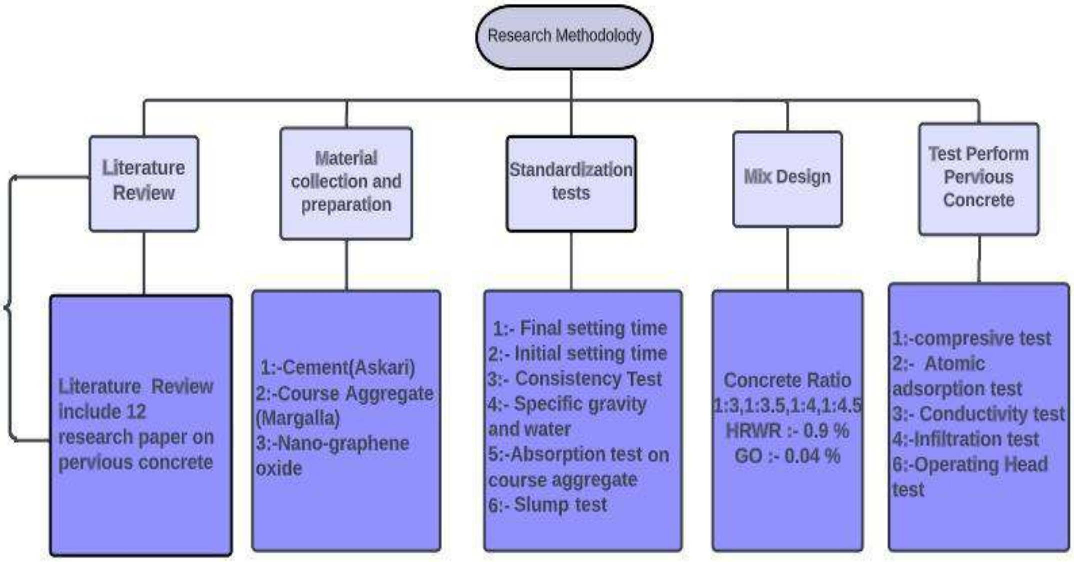


Figure 1: Research methodology followed throughout the project

3.1 Material collection and preparation

3.1.1 Collection of Cement (Askari):

The cement was collected from the Askari cement factory. Askari Cement Limited (ACL) is one of the leading manufacturers in the Pakistan's Cement Industry. Askari Cement has its two plants located at Wah (Punjab) and Nowshera (KPK). It originated back in 1921.

3.1.2 Collection of coarse aggregates (Margalla Hills):

The Coarse aggregate was collected from the Margalla hills. Margalla crushed stone aggregate refers to the crushed stone that is sourced from the Margalla Hills region in Pakistan. This type of aggregate is known for its high quality and strength, which makes it a popular choice for construction projects in the region. Margalla crushed stone aggregates is typically produced by crushing granite or limestone rock found in the Margalla Hills. The crushing process produces aggregate of various sizes, ranging from small stones to larger rocks. The aggregate is then sorted and graded based on its size, shape, and quality, and can be used for a variety of construction applications.

3.2 Formation of Nano graphene oxide:

The Nano graphene oxide formation was done through Hammers process explained below.

- Add 360 ml sulphuric acid to dry beaker.
- Then slowly add 40 ml phosphoric Acid.
- Add 3g graphite and start stirring at 300 rpm for 10 minutes.
- Then slowly add 12 ml DI (Deionized) water.
- Then slowly add 18 gm kmno4 and keep watching the temperature.
- Then cover the beaker with aluminum foil and stir for 24 hours.
- Then add 9ml hydrogen peroxide and maintain a temperature less than 30 ℃.
- Then Centrifuge and sonicate the solution.

Figure 2: Synthesis of graphene oxide in laboratory

3.3 Formation of pervious concrete:

- Aggregate of the desired diameter is obtained by sieving.
- Mixing of aggregate in a mixer.
- Placing aggregate in 6×6×6 Cubes, temping in three layers.
- Placed in a water tank for curing, for 7 or 28 days.
- Checking for minimum compressive strength of cubes.

Figure 3: Formation of pervious concrete in lab

3.4 Standardization Tests:

3.4.1 Final setting time:

Final setting time refers to the period of time it takes for cement paste to fully harden and achieve a certain level of rigidity. It is a crucial property of cement that impacts its workability, handling, and strength development during construction. The final setting time is determined through standardized testing methods, such as the Vicat apparatus, which measures the point at which the cement paste can no longer be penetrated by a needle-like plunger.

3.4.2 Initial setting time:

The term "initial setting" refers to the early stage in the hardening process of cement when it transitions from a plastic, workable state to a semi-solid state. It is a critical property of cement that affects its handling and workability during construction.

During the initial setting stage, the cement paste, which is a mixture of cement and water, undergoes a chemical reaction known as hydration. In this process, the cement particles react with water, forming chemical compounds that contribute to the strength and durability of the resulting concrete or mortar.

The initial setting is determined by the amount of time it takes for the cement paste to reach a specific level of stiffness and lose its plasticity. It is typically measured using the Vicat apparatus, where a needle-like plunger is lowered onto the surface of the cement paste. The initial setting time is defined as the point at which the needle no longer penetrates the paste and leaves a visible mark on its surface.

3.4.3 Consistency Test:

The consistency test is a procedure used to determine the workability and fluidity of cement paste, mortar, or concrete. It provides an indication of the amount of water needed to achieve a desired consistency for proper mixing, placing, and finishing of the material during construction.

3.4.4 Adsorption test on Coarse Aggregate:

ASTM C 127-15

The adsorption test is conducted on coarse aggregates to determine the amount of water it can absorb when immersed in water for a specific duration. This test provides information about the porosity and moisture content of the aggregates, which can impact the properties of concrete or other construction materials. Range: 0.1% to 2%.The water adsorption test was 1.11%.

3.4.5 Mix Design:

To identify a control sample for our testing processes we made mix sample of mix design 1:3,1:3.5,1:4,1:4.5,1:7,1:7.5.[6]

Superplasticizer was used 0.9% of cement and GO 0.04%. Control sample was 1:4.5

3.4.6 Compressive Strength Test:

ACI 522 Compressive strength refers to the ability of a material to withstand compressive forces without breaking or undergoing permanent deformation. In the context of construction materials, compressive strength is an important property of materials such as concrete, masonry, and rock.

Figure 4: Compressive strength on pervious concrete using UTM (universal testing machine)

3.4.7 Atomic Adsorption Test:

The technique used to perform atomic adsorption test was flame atomic adsorption spectrophotometer. A flame atomic adsorption spectrophotometer (AAS) is an analytical instrument used to measure the concentration of specific elements in a sample. It utilizes the principle of atomic adsorption spectroscopy to detect and quantify the presence of elements in a liquid sample by measuring the adsorption of light at specific wavelengths.

3.4.8 Electrical Conductivity test as an indirect indicator for adsorption:

The electrical conductivity test is an indirect indicator used to evaluate metal adsorption. It involves measuring the conductivity of a solution with a conductivity meter, which is influenced by the presence of adsorbed metals. Metal ions can enhance or inhibit conductivity based on the adsorption process. By comparing conductivity before and after adsorption, the extent of metal adsorption can be determined. In this study, copper and zinc samples in different concrete mix ratios underwent the electrical conductivity test at 15-minute, 5-minute, and 1-minute intervals. Minimal variation was observed at 1 minute, while noticeable differences were seen at 15 minutes, emphasizing the need for sufficient time to stabilize conductivity. Longer intervals, like 15 minutes, are critical for accurately assessing copper and zinc behavior in different concrete mixes.

Figure 5: Electricity conductivity test on pervious concrete

3.4.9 Operating water head test

An operating water head test was conducted to investigate the adsorption behavior of metals at different heights within pervious concrete. The test was carried out at four distinct heights: 7.5cm, 10cm, 20cm, and 30cm. Conductivity meter was utilized as an indirect indicator to evaluate metals adsorption at different water heads. These findings contribute valuable insights to our understanding of metals adsorption in pervious concrete and have implications for optimizing concrete mix designs in applications where metal removal is a priority.

Figure 6: Operating water head test on pervious concrete

3.4.10 Infiltration rate test (ASTM 1701)

The purpose of an infiltration rate test is to evaluate how quickly water can infiltrate and permeate through pervious concrete. This test is essential for assessing the concrete's porosity and permeability, which are critical factors in its ability to effectively manage storm water runoff and prevent surface flooding. To conduct the test, the ASTM 1701 standard is commonly followed. During the infiltration rate test, the concrete mix ratio and the time gap between sample passings are varied to gather comprehensive data. By manipulating these variables, it was investigated how different concrete mixtures and time intervals impact the infiltration rate. Infiltration rate test was performed by varying both time and ratio. Infiltration rate test was performed at 1- minute, 5 – minutes and 15 – minutes gap by using different ratios of pervious concrete i-e 1:3, 1:3.5, 1:4, 1:4.5.

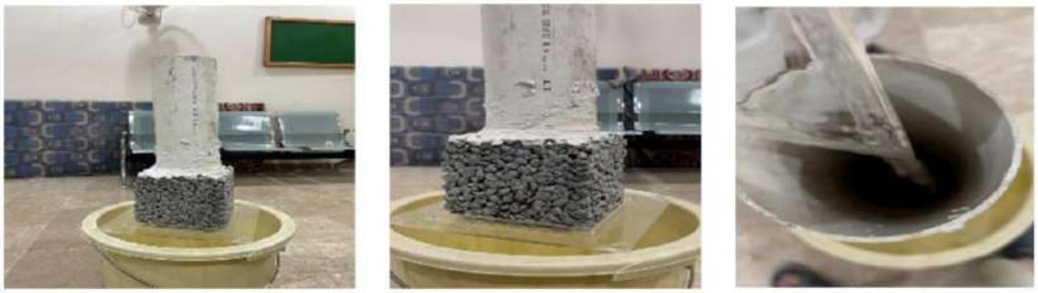


Figure 7: infiltration rate test on pervious concrete

Chapter # 4
Results and Discussions

4. Results and Discussions

4.1 Compressive strength test

4.2.1 Compressive strength test for conventional pervious concrete

The experimental results obtained from the compressive strength test is shown in table 1, which reveal a direct relationship between the cement quantity and the compressive strength of conventional pervious concrete. As the amount of cement increases, the compressive strength of the concrete also increases. The compressive strength test was conducted by varying the cement quantity while keeping the water-cement ratio, aggregate size, and super-plasticizer constant. This experimental setup allowed for the isolation of the cement quantity as the influencing factor on compressive strength. The compressive strength test was conducted on conventional pervious concrete specimens after a curing period of 7 days. This specific testing duration was chosen to evaluate the compressive strength properties of the concrete at an early stage of curing.

Table 1: Compressive strength test values for conventional pervious concrete

SR#	Concrete Mix	W/C Ratio	Cement (Kg/m3)	Aggregate (Kg/m3)	HRWR (% by wt. of binder)	Compressive strength (MPa)
1.	(1:3)	0.28	410	1425	0.9	9
2.	(1:3.5)	0.28	410	1425	0.9	8
3.	(1:4)	0.28	410	1425	0.9	7.3
4.	(1:4.5)	0.28	410	1425	0.9	6

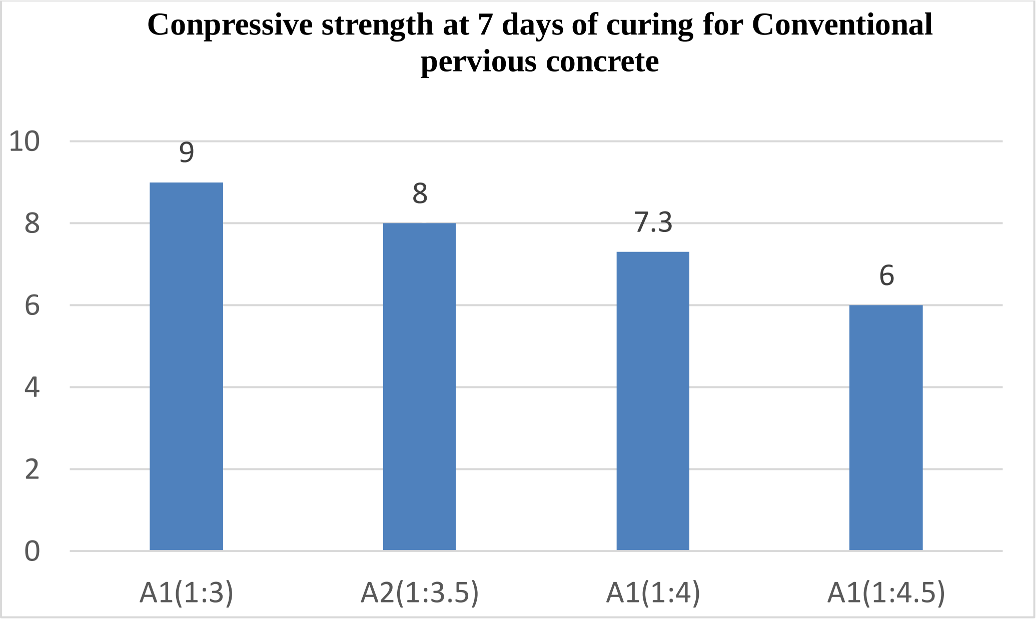


Figure 8: Compressive strength test results of conventional pervious concrete

The findings from the compressive strength test, as depicted in Fig. 8 illustrate a positive correlation between the quantity of cement and the compressive strength of conventional pervious concrete. Increasing the cement content results in higher compressive strength values for the concrete. This controlled experimental design allowed for the isolation of the cement quantity as the primary influencing factor on compressive strength. It is evident that the 1:4.5 mix ratio exhibits the lowest value of compressive strength among the tested mix proportions. This can be attributed to the relatively lower quantity of cement used in this particular mixture. The graph clearly illustrates that as the cement quantity increases, the compressive strength of the conventional pervious concrete also increases. Therefore, it can be concluded that the cement content plays a significant role in determining the compressive. Furthermore, the compressive strength test was performed on conventional pervious concrete specimens after a curing period of 7 days.

In regions where Copper contamination is reported and the site load is relatively low, we recommend the use of conventional pervious concrete. While the load-bearing capacity of conventional pervious concrete is half that of modified pervious concrete, it exhibits higher copper adsorption. This makes it a suitable choice for areas with low site loads and a specific concern for copper contamination.

For regions where Zinc contamination is reported, the use of conventional pervious concrete is recommended. Conventional pervious concrete demonstrates good zinc adsorption capabilities. Therefore, it is a suitable choice for areas specifically affected by zinc contamination.

4.2.2 Compressive strength test for modified pervious concrete

The experimental results obtained from the compressive strength test for modified pervious concrete is shown in table 2, which reveal a direct relationship between the cement quantity and the compressive strength of modified pervious concrete. As the amount of cement increases while keeping the graphene oxide percentage constant, the compressive strength of the concrete also increases. The compressive strength test was conducted by varying the cement quantity while keeping the water-cement ratio, aggregate size, and super-plasticizer constant. This experimental setup shows that graphene oxide and cement quantity are the influencing factors on compressive strength. The compressive strength test was conducted on modified pervious concrete specimens after a curing period of 7 days. This specific testing duration was chosen to evaluate the compressive strength properties of the concrete at an early stage of curing.

Table 2: Compressive strength test values for conventional pervious concrete

SR#	Concrete Mix	W/C ratio	Cement (kg/m3)	GO percentage %	Aggregate (kg/m3)	HRWR (% by wt. of binder)	Compressive strength (MPa)
1.	A1(1:3)	0.28	410	0.04	1425	0.9	18
2.	A2(1:3.5)	0.28	410	0.04	1425	0.9	16
3.	A1(1:4)	0.28	410	0.04	1425	0.9	15
4.	A1(1:4.5)	0.28	410	0.04	1425	0.9	8

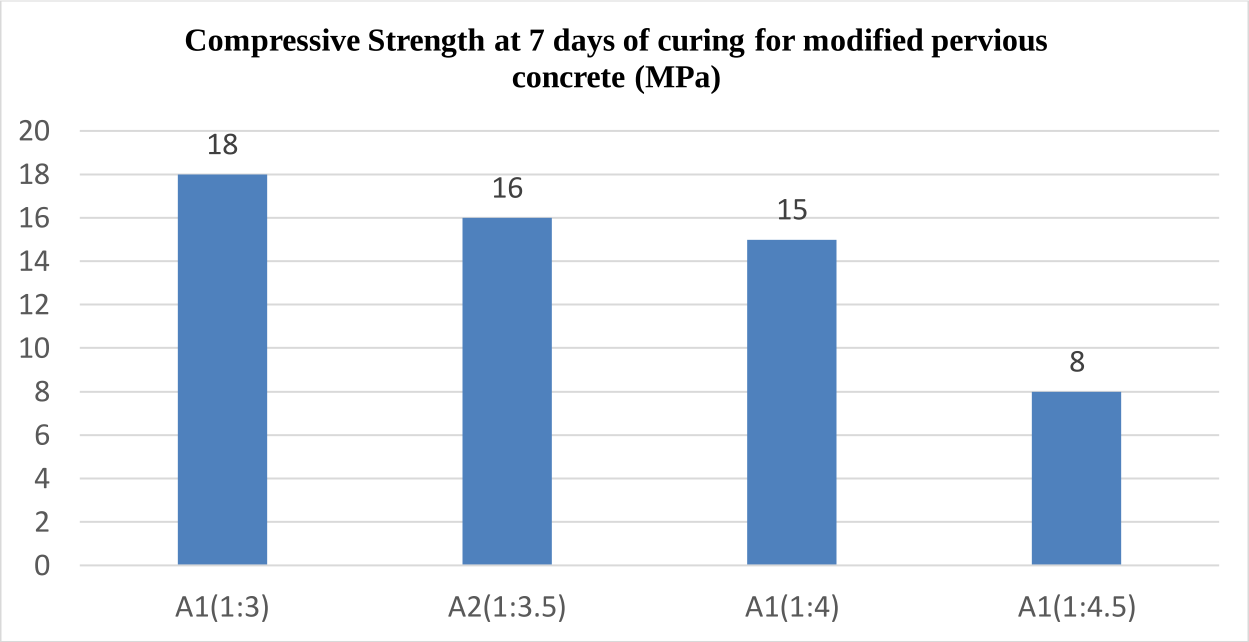


Figure 9: Compressive strength test results of conventional pervious concrete

The findings in Fig. 9 shows a positive correlation between cement quantity and compressive strength in modified pervious concrete. Increasing cement content enhances compressive strength. Graphene oxide and cement quantity are influential factors. The 1:4.5 mix ratio exhibits the lowest strength due to lower cement quantity. In conclusion, cement content and graphene oxide significantly impact compressive strength.

In regions where Copper contamination is reported and the site load is comparably high, we recommend the use of codified pervious concrete (modified pervious concrete). Modified pervious concrete provides twice the strength compared to conventional pervious concrete, making it more suitable for areas with higher site loads and a concern for copper contamination.

In regions where a higher infiltration rate is required, conventional pervious concrete is recommended. This is because the infiltration rate in conventional pervious concrete is higher compared to modified pervious concrete. Therefore, it is a suitable choice for areas where rapid water infiltration is desired.

4.1 Atomic adsorption test

4.1.1 Flame Atomic Adsorption Spectrophotometer (FAAS) test, of copper in conventional pervious concrete.

The experimental results obtained from the Flame Atomic Adsorption Spectrophotometer (FAAS) test, focusing on the adsorption of copper metal in conventional pervious concrete, are presented in table 3. The findings demonstrate a positive correlation between the quantity of cement used in the conventional pervious concrete mixture and its adsorption capacity. Notably, the highest concentration of copper adsorption was observed in the 1:3 mix ratio. The FAAS test, a widely employed analytical technique for quantifying trace metal concentrations, was specifically employed to evaluate the adsorption capabilities of copper within the conventional pervious concrete samples.

Table 3: Flame Atomic Adsorption Spectrophotometer (FAAS) test of copper concentration in conventional pervious concrete

S. No	Sample Name	Cu mg/L (ppm)
1	Initial Concentration	71.3000
2	1:4.5 conventional	48.0355
3	1:4 conventional	41.8998
4	1:3.5 conventional	35.7642
5	1:3 conventional	29.6286

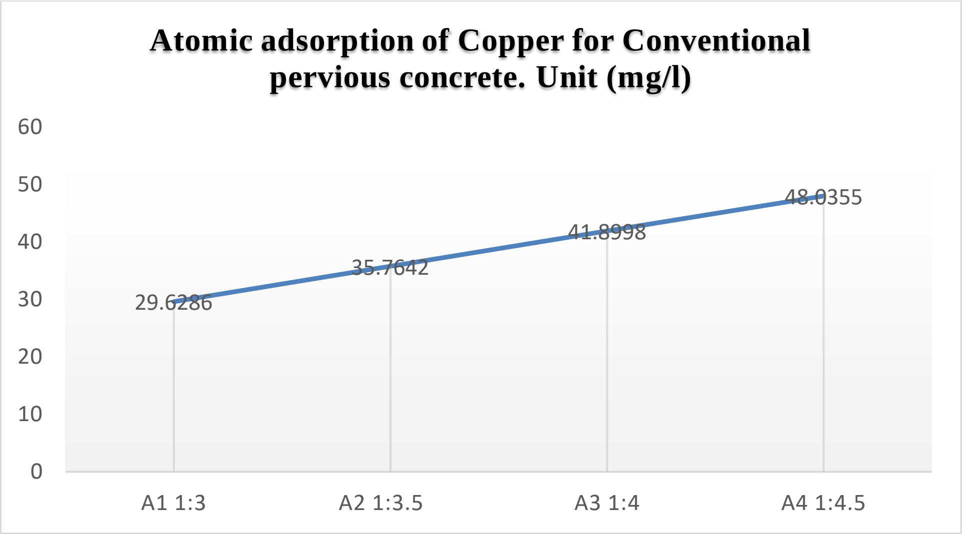


Figure 10: Flame Atomic Adsorption Spectrophotometer (FAAS) test results of copper concentration in conventional pervious concrete

The results depicting the atomic adsorption values of copper in conventional pervious concrete are illustrated in Fig 10. The data reveals a direct relationship between the concentration of cement in conventional pervious concrete and the atomic adsorption of copper. Notably, the highest copper adsorption concentration was observed in the 1:3 mixture ratio, surpassing all other mixtures. These findings indicate that increasing the cement content enhances the adsorption capacity of the concrete for copper. This information was obtained through the use of atomic adsorption measurements, a commonly employed technique for quantifying trace metal concentrations in samples of interest.

4.1.2 Flame Atomic Adsorption Spectrophotometer (FAAS) test of copper in modified pervious concrete

The experimental data obtained from the Flame Atomic Adsorption Spectrophotometer (FAAS) test, focusing on the adsorption of copper metal in modified pervious concrete, is presented in table 4. The results indicate that increasing the cement quantity in modified pervious concrete, with the addition of 0.04% Graphene oxide, leads to an enhanced adsorption capacity. This suggests that in the modified pervious concrete 1:3 has a highest ability to adsorb copper compared to the other mixes counterpart.

Table 4: Flame Atomic Adsorption Spectrophotometer (FAAS) test of copper concentration in modified pervious concrete

S#	Sample Name	Cu mg/L (ppm)
1	Initial Concentration	71.3000
2	1:4.5 modified	58.2220
3	1:4 modified	56.9192
4	1:3.5 modified	54.9804
5	1:3 modified	50.7388

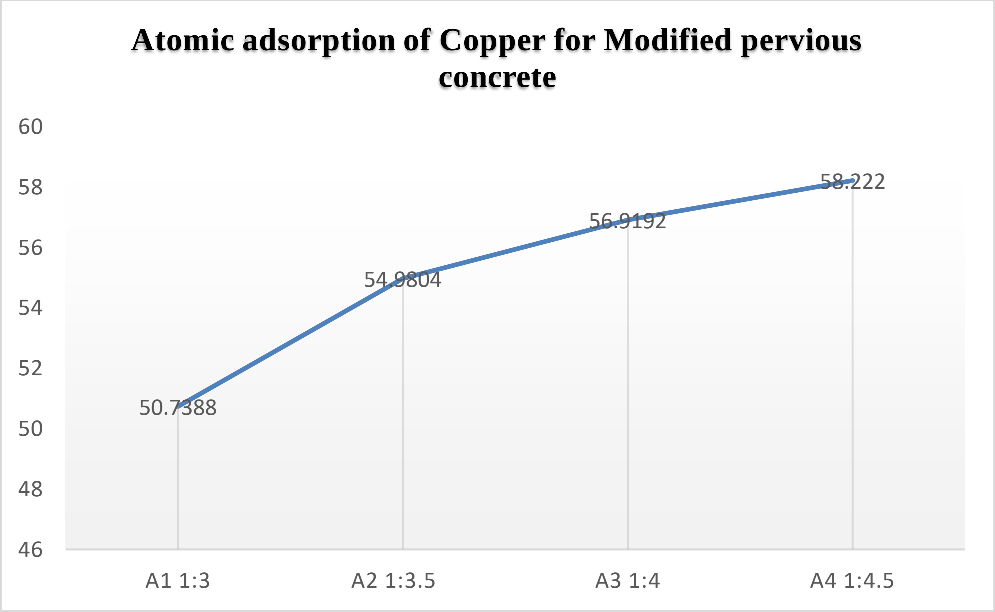


Figure 11: Flame Atomic Adsorption Spectrophotometer (FAAS) test results of copper concentration in modified pervious concrete

The results depicting the atomic adsorption values of copper in modified pervious concrete are illustrated in Fig. 11. The data reveals a direct relationship between the concentration of cement in modified pervious concrete and the atomic adsorption of copper. Notably, the highest copper adsorption concentration was observed in the 1:3 mixture ratio, surpassing all other mixtures. These findings indicate that increasing the cement content enhances the adsorption capacity of the concrete for copper. This information was obtained through the use of atomic adsorption measurements, a commonly employed technique for quantifying trace metal concentrations in samples of interest.

4.1.3 Flame Atomic Adsorption Spectrophotometer (FAAS) test of zinc in conventional pervious concrete

The experimental outcomes from the Flame Atomic Adsorption Spectrophotometer (FAAS) test, aimed at investigating the adsorption of zinc metal in conventional pervious concrete, are presented in table 5. The results indicate a positive relationship between the cement quantity in the conventional pervious concrete mixture and its adsorption capacity. Significantly, the highest zinc adsorption concentration was observed in the 1:3 mix ratio. The FAAS test, a widely utilized analytical technique for quantifying trace metal concentrations, was specifically employed to assess the zinc adsorption capabilities of the conventional pervious concrete samples.

Table 5: Flame Atomic Adsorption Spectrophotometer (FAAS) test values of zinc concentration in conventional pervious concrete

S#	Sample Name	Zn mg/L (ppm)
1	Initial Concentration	60.5601
2	1:4.5 conventional	46.3791
3	1:4 conventional	42.5648
4	1:3.5 conventional	38.7506
5	1:3 conventional	35.6081

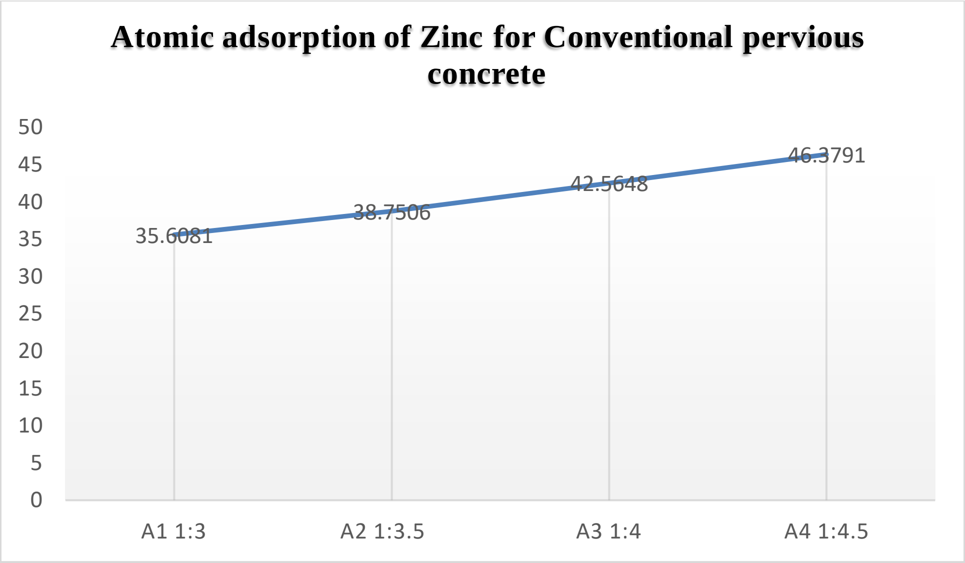


Figure 12: Flame Atomic Adsorption Spectrophotometer (FAAS) test results of zinc concentration in conventional pervious concrete

The results depicting the atomic adsorption values of zinc in conventional pervious concrete are illustrated in Fig. 12. The data reveals a direct relationship between the concentration of cement in conventional pervious concrete and the atomic adsorption of zinc. Notably, the highest zinc adsorption concentration was observed in the 1:3 mixture ratio, surpassing all other mixtures. These findings indicate that increasing the cement content enhances the adsorption capacity of the concrete for zinc. This information was obtained through the use of atomic adsorption measurements, a commonly employed technique for quantifying trace metal concentrations in samples of interest.

4.1.4 Flame Atomic Adsorption Spectrophotometer (FAAS) test of Zinc in Modified pervious concrete

The experimental findings obtained from the Flame Atomic Adsorption Spectrophotometer (FAAS) test, conducted to investigate the adsorption of zinc metal in modified pervious concrete, have been tabulated in table 6. The results reveal a positive correlation between the quantity of cement employed in the modified pervious concrete mixture and its adsorption capacity. Notably, the 1:3 mix ratio exhibited the highest concentration of zinc adsorption. The FAAS test, a widely employed analytical technique for quantifying trace metal concentrations, was specifically employed to evaluate the zinc adsorption capabilities of the conventional pervious concrete samples.

Table 6: Flame Atomic Adsorption Spectrophotometer (FAAS) test values of zinc concentration in modified pervious concrete

Sr. No	Sample name	Zn mg/L (ppm)
1	Initial Concentration	60.5601
2	1:4.5 modified	60.2220
3	1:4 modified	59.9192
4	1:3.5 modified	57.9804
5	1:3 modified	56.7388

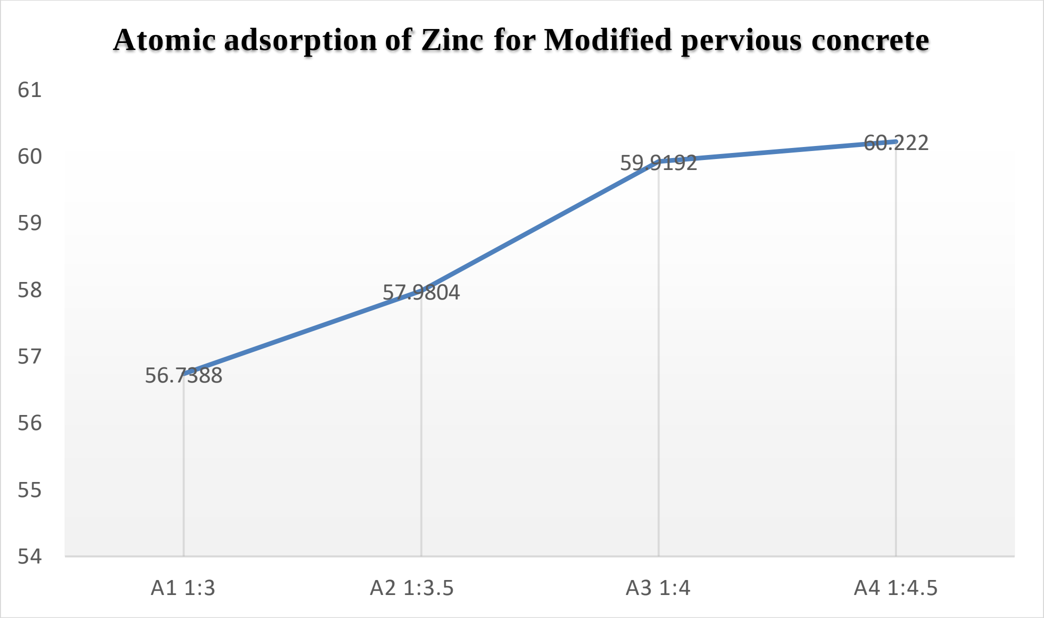


Figure 13: Flame Atomic Adsorption Spectrophotometer (FAAS) test results of zinc concentration in modified pervious concrete

The results depicting the atomic adsorption values of zinc in modified pervious concrete are illustrated in Fig. 13. The data reveals a direct relationship between the concentration of cement in modified pervious concrete and the atomic adsorption of zinc. Notably, the highest zinc adsorption concentration was observed in the 1:3 mixture ratio, surpassing all other mixtures. These findings indicate that increasing the cement content enhances the adsorption capacity of the concrete for zinc. This information was obtained through the use of atomic adsorption measurements, a commonly employed technique for quantifying trace metal concentrations in samples of interest.

4.3 Electrical conductivity test

The electrical conductivity test was used as an indirect indicator to evaluate metal adsorption. It involves measuring the conductivity of a solution with a conductivity meter, which is influenced by the presence of adsorbed metals. Metal ions can enhance or inhibit conductivity based on the adsorption process. By comparing conductivity before and after adsorption, the extent of metal adsorption can be determined. In this study, copper and zinc samples in different concrete mix ratios underwent the electrical conductivity test at 15-minute, 5-minute, and 1-minute intervals. Minimal variation was observed at 1 minute, while noticeable differences were seen at 15 minutes, emphasizing the need for sufficient time to stabilize conductivity. Longer intervals, like 15 minutes, are critical for accurately assessing copper and zinc behavior in different concrete mixes.

4.3.1 Conductivity test result for copper conventional pervious concrete after 15 minutes interval

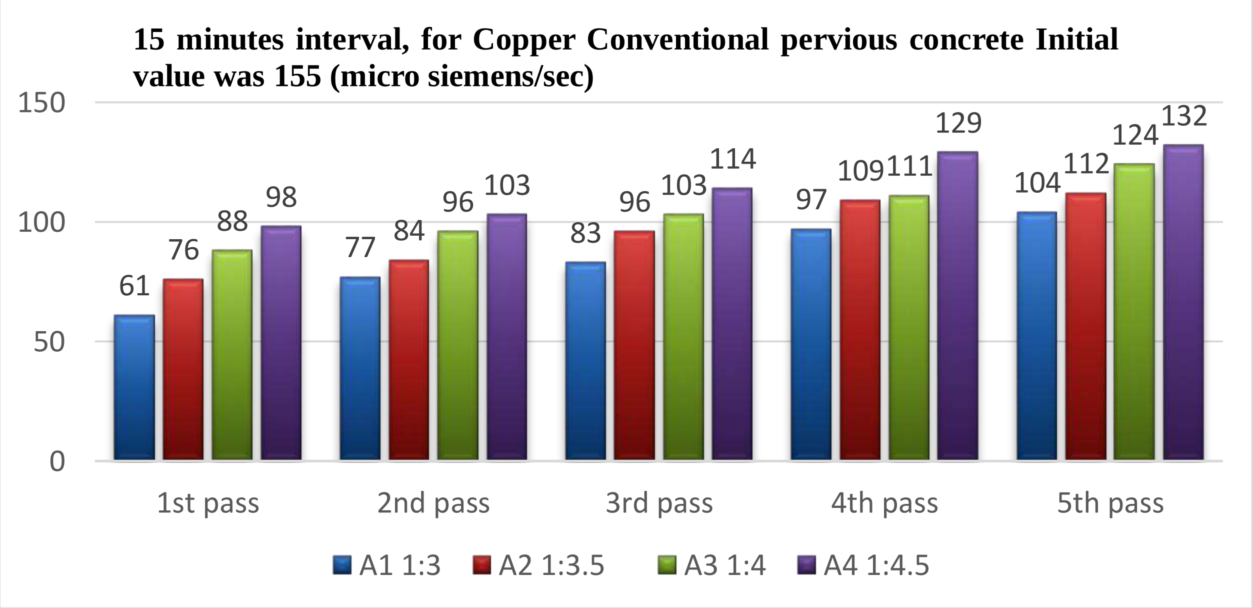


Figure 14: Conductivity test result for copper conventional pervious concrete after 15 minutes of interval

Fig. 14 displays the 15-minute electrical conductivity test results for the copper conventional pervious concrete. Increasing cement quantity leads to decreased conductivity, which ultimately shows that more metals are adsorbed as cement quantity increases, with the lowest value observed for the 1:3 mix ratio. Conductivity increases with each subsequent pass, reaching a peak at the 5th pass, indicating decreased adsorption capacity over time. These findings highlight the influence of cement quantity on conductivity and adsorption properties in conventional pervious concrete.

4.3.2 Conductivity test result values for copper modified pervious concrete after 15 minutes of interval

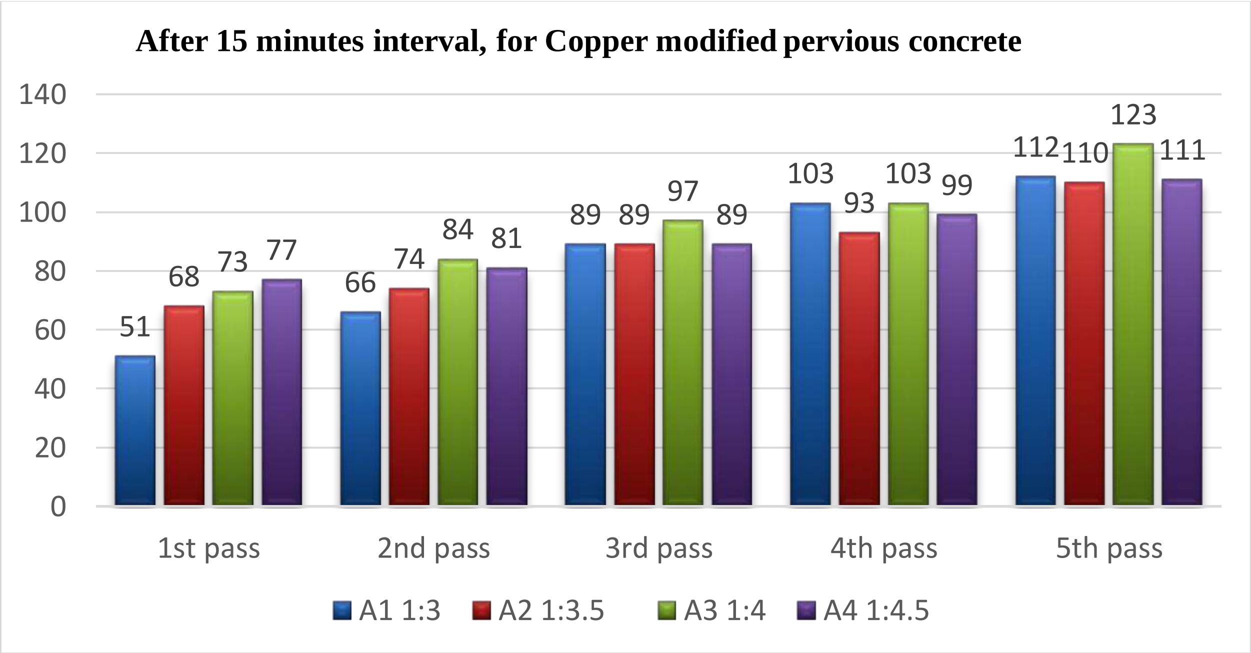


Figure 15: Conductivity test result values for copper modified pervious concrete after 15 minutes of interval

Fig. 15 displays the 15-minute electrical conductivity test results for the copper modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide. Increasing cement quantity leads to decreased conductivity, which ultimately shows that more metals are adsorbed as cement quantity increases, with the lowest value observed for the 1:3 mix ratio. Conductivity increases with each subsequent pass, reaching a peak at the 5th pass, indicating decreased adsorption capacity over time. These findings highlight the influence of cement quantity on conductivity and adsorption properties in modified pervious concrete.

4.3.3 Conductivity test result values for copper conventional pervious concrete after 5 minutes of interval

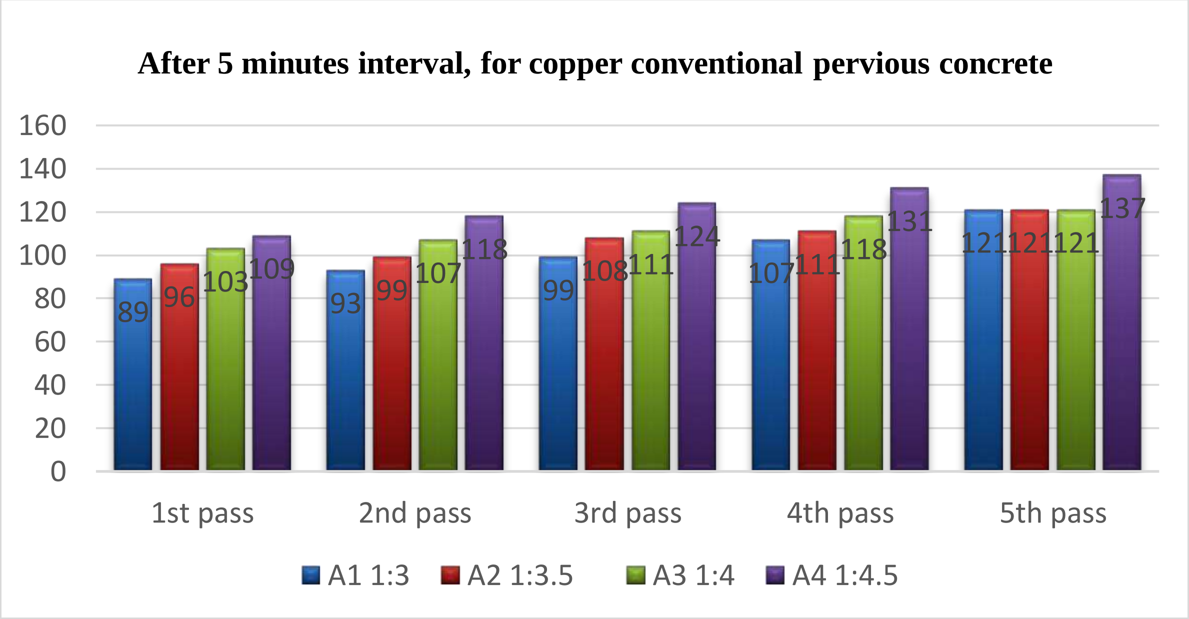


Figure 16: Conductivity test result for copper conventional pervious concrete after 5 minutes of interval

The findings of electrical conductivity presented in Fig. 16 illustrate the results of the 5-minute electrical conductivity test conducted on the copper conventional pervious concrete. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of conventional pervious concrete.

4.3.4 Conductivity test result for copper modified pervious concrete after 5 minutes of interval

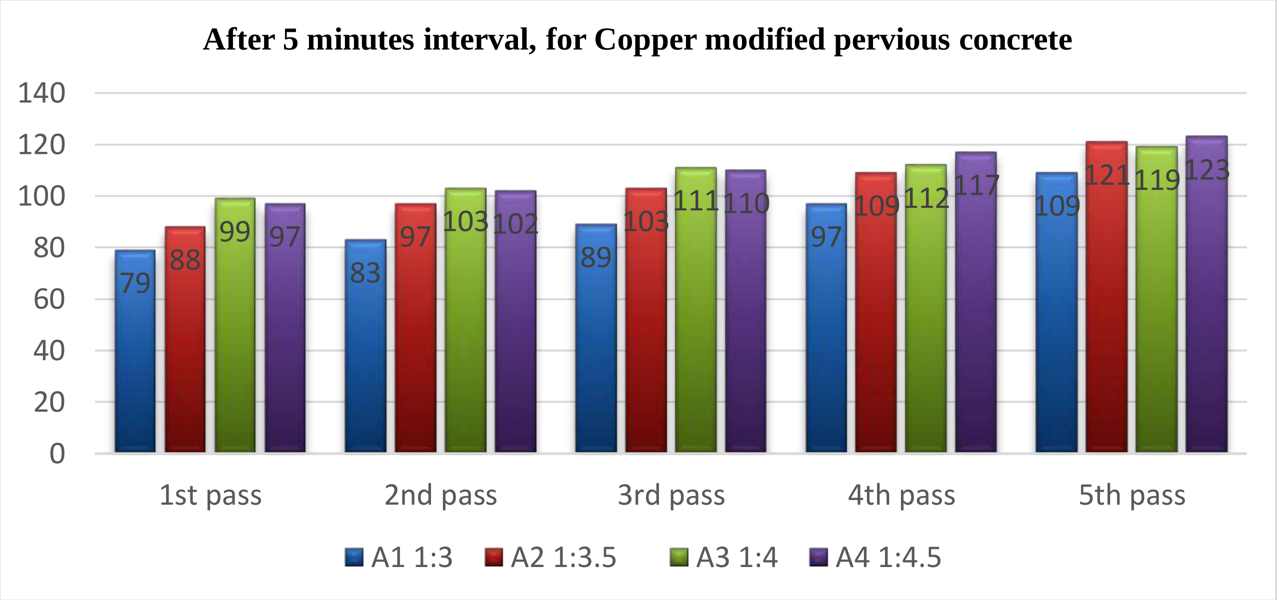


Figure 17: Conductivity test result for copper modified pervious concrete after 5 minutes of interval

The results presented in Fig. 17 depict the outcomes of the 5-minute electrical conductivity test conducted on the copper modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide. The data reveals a clear inverse relationship between cement quantity and conductivity, suggesting that higher cement quantities lead to increased metal adsorption. Notably, the 1:3 mix ratio displays the lowest conductivity value, indicating a higher capacity for metal adsorption. Furthermore, the conductivity gradually rises with each subsequent pass, reaching its peak at the 5th pass, implying a decrease in adsorption capacity over time. These findings emphasize the crucial role of cement quantity in influencing the conductivity and adsorption properties of modified pervious concrete.

4.3.5 Conductivity test result for copper conventional pervious concrete after 1 minute of interval

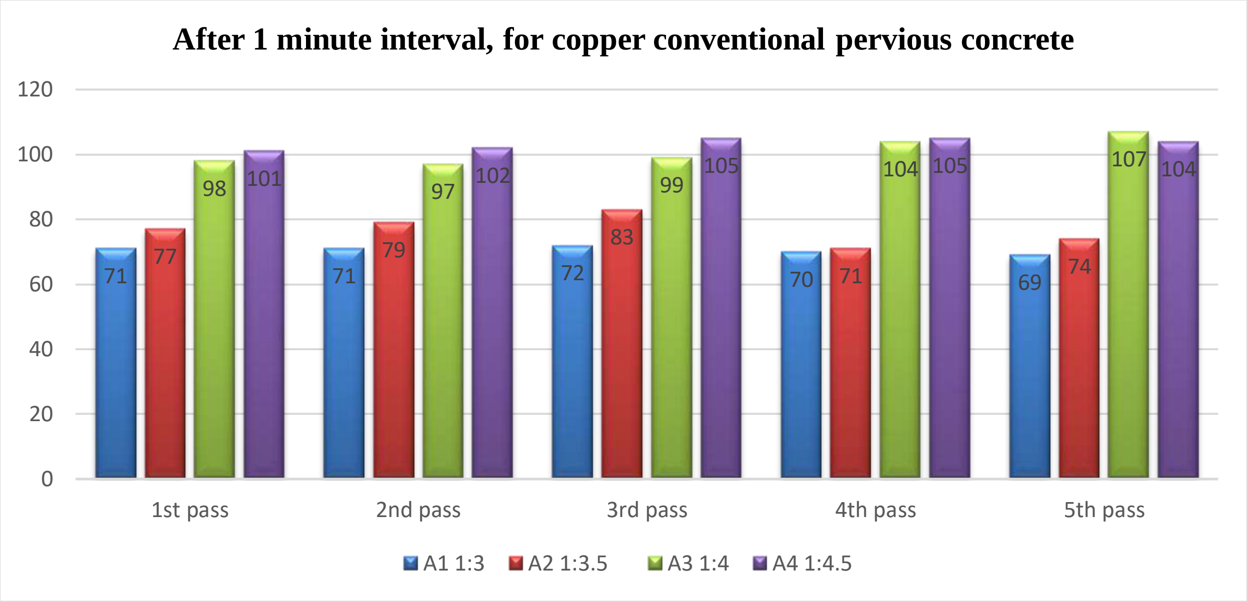


Figure 18: Conductivity test result values for copper conventional pervious concrete after 1 minute of interval

The findings of electrical conductivity presented in Fig. 18 illustrate the results of the 1-minute electrical conductivity test conducted on the copper conventional pervious concrete. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. The uncertain values suggest that in order to obtain more reliable and accurate adsorption results, a longer time interval should be provided. By allowing for a longer time interval between measurements, the system can reach a more stable state, leading to more consistent and dependable adsorption measurements. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of conventional pervious concrete.

4.3.6 Conductivity test result for copper modified pervious concrete after 1 minute of interval

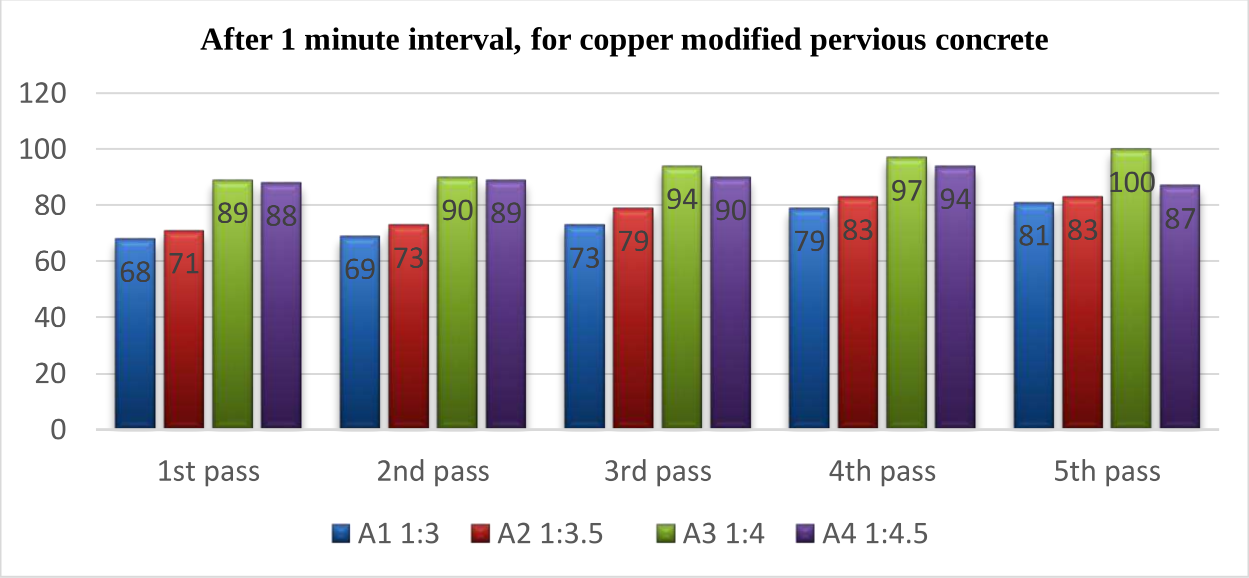


Figure 19: Conductivity test result for copper modified pervious concrete after 1 minute of interval

The findings of electrical conductivity presented in Fig. 19 illustrate the results of the 1-minute electrical conductivity test conducted on the copper modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. The uncertain values suggest that in order to obtain more reliable and accurate adsorption results, a longer time interval should be provided. By allowing for a longer time interval between measurements, the system can reach a more stable state, leading to more consistent and dependable adsorption measurements. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of modified pervious concrete.

4.3.7 Conductivity test result for zinc conventional pervious concrete after 15 minutes of interval

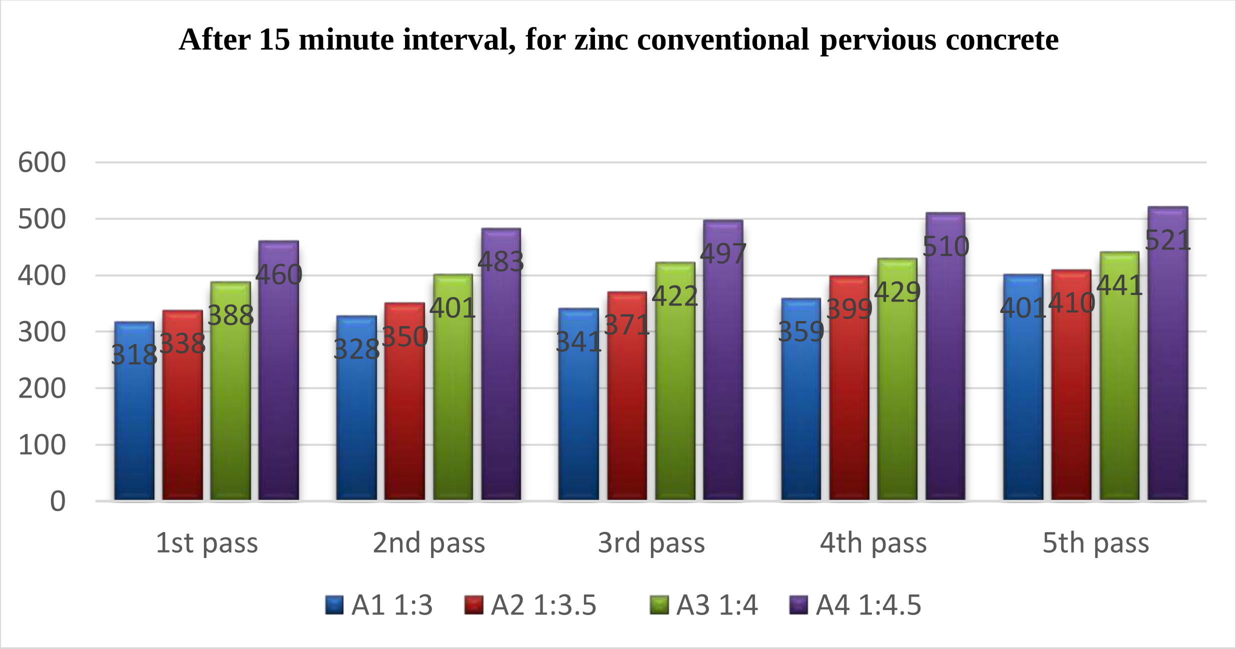


Figure 20: Conductivity test result for zinc conventional pervious concrete after 15 minutes of interval

The findings of electrical conductivity presented in Fig. 20 illustrate the results of the 15-minutes electrical conductivity test conducted on the zinc conventional pervious concrete. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. The uncertain values suggest that in order to obtain more reliable and accurate adsorption results, a longer time interval should be provided. By allowing for a longer time interval between measurements, the system can reach a more stable state, leading to more consistent and dependable adsorption measurements. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of conventional pervious concrete.

4.3.8 Conductivity test result for zinc modified pervious concrete after 15 minutes of interval

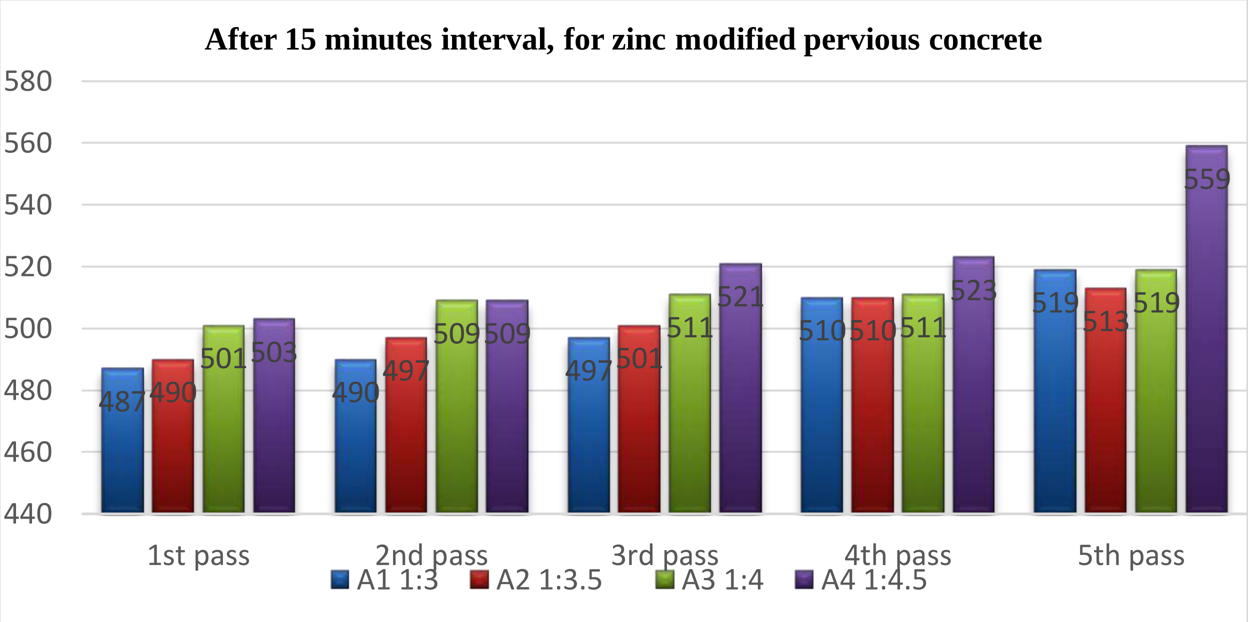


Figure 21: Conductivity test result for zinc modified pervious concrete after 15 minutes of interval

The findings of electrical conductivity presented in Fig. 21 illustrate the results of the 15-minute electrical conductivity test conducted on the zinc modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. The uncertain values suggest that in order to obtain more reliable and accurate adsorption results, a longer time interval should be provided. By allowing for a longer time interval between measurements, the system can reach a more stable state, leading to more consistent and dependable adsorption measurements. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of modified pervious concrete.

4.3.9 Conductivity test result for zinc conventional pervious concrete after 5 minutes of interval

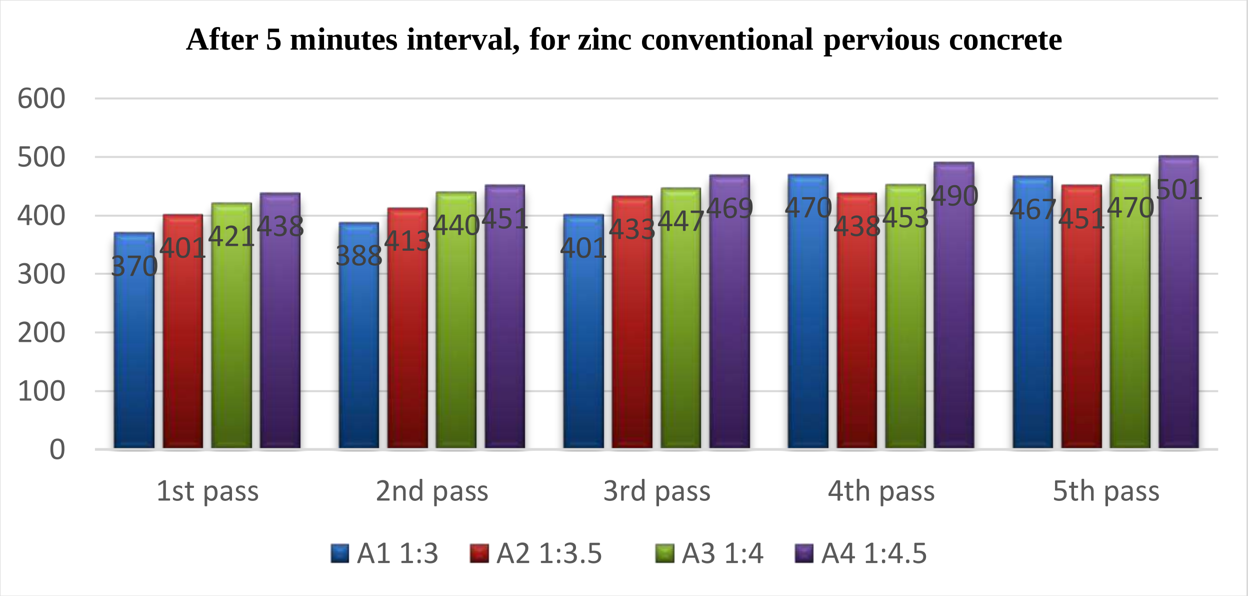


Figure 22: Conductivity test result for zinc conventional pervious concrete after 5 minutes of interval

The findings of electrical conductivity presented in Fig.22 illustrate the results of the 5-minutes electrical conductivity test conducted on the zinc conventional pervious concrete. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. The uncertain values suggest that in order to obtain more reliable and accurate adsorption results, a longer time interval should be provided. By allowing for a longer time interval between measurements, the system can reach a more stable state, leading to more consistent and dependable adsorption measurements. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of conventional pervious concrete.

4.3.10 Conductivity test result for zinc modified pervious concrete after 5 minutes of interval

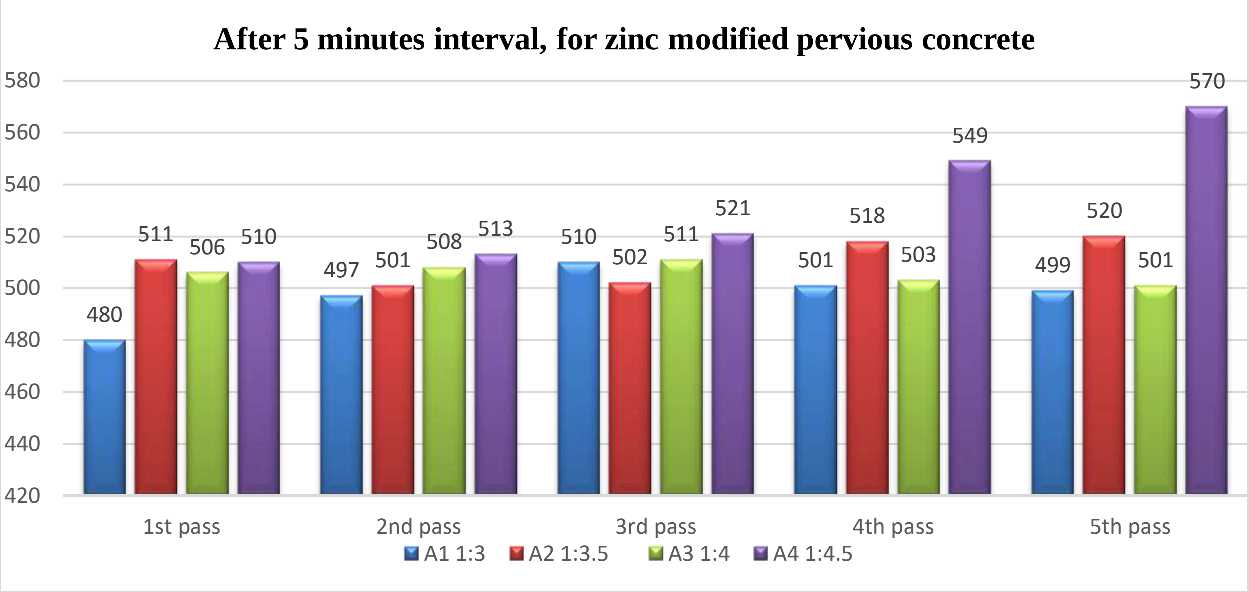


Figure 23: Conductivity test result for zinc conventional pervious concrete after 5 minutes of interval

The findings of electrical conductivity presented in Fig. 23 illustrate the results of the 5-minute electrical conductivity test conducted on the zinc modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. The uncertain values suggest that in order to obtain more reliable and accurate adsorption results, a longer time interval should be provided. By allowing for a longer time interval between measurements, the system can reach a more stable state, leading to more consistent and dependable adsorption measurements. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of modified pervious concrete.

4.3.11 Conductivity test result for zinc conventional pervious concrete after 1 minute of interval

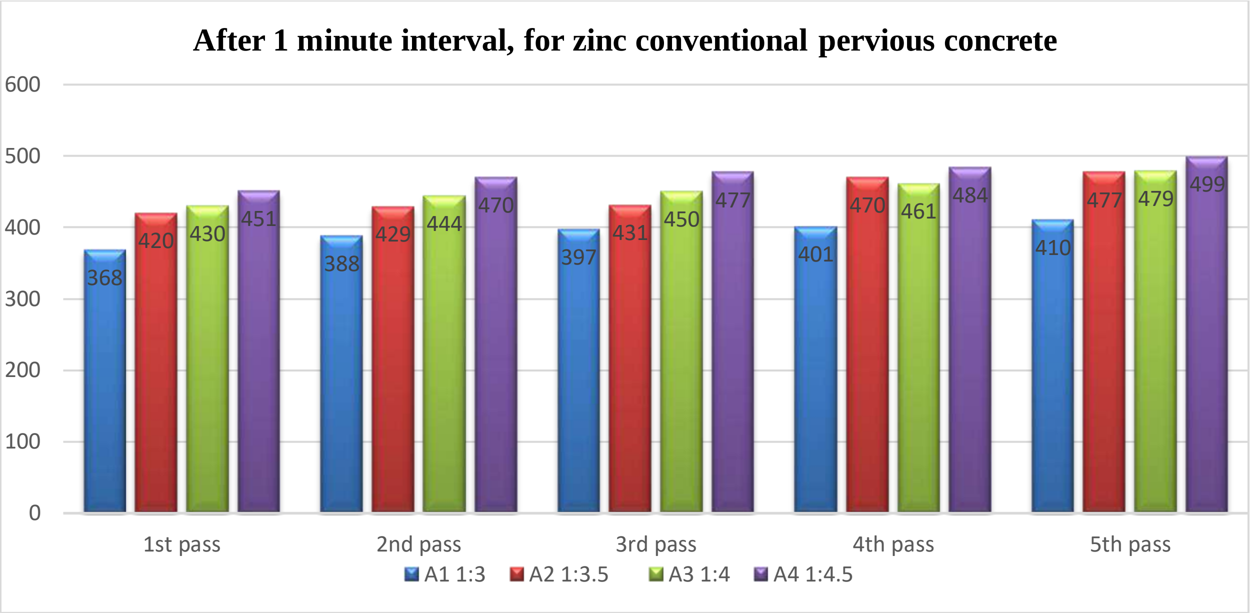


Figure 24: Conductivity test result for zinc conventional pervious concrete after 1 minute of interval

The findings of electrical conductivity presented in Fig. 24 illustrate the results of the 1-minute electrical conductivity test conducted on the zinc conventional pervious concrete. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. The uncertain values suggest that in order to obtain more reliable and accurate adsorption results, a longer time interval should be provided. By allowing for a longer time interval between measurements, the system can reach a more stable state, leading to more consistent and dependable adsorption measurements. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of conventional pervious concrete.

4.3.12 Conductivity test result for zinc modified pervious concrete after 1 minute of interval

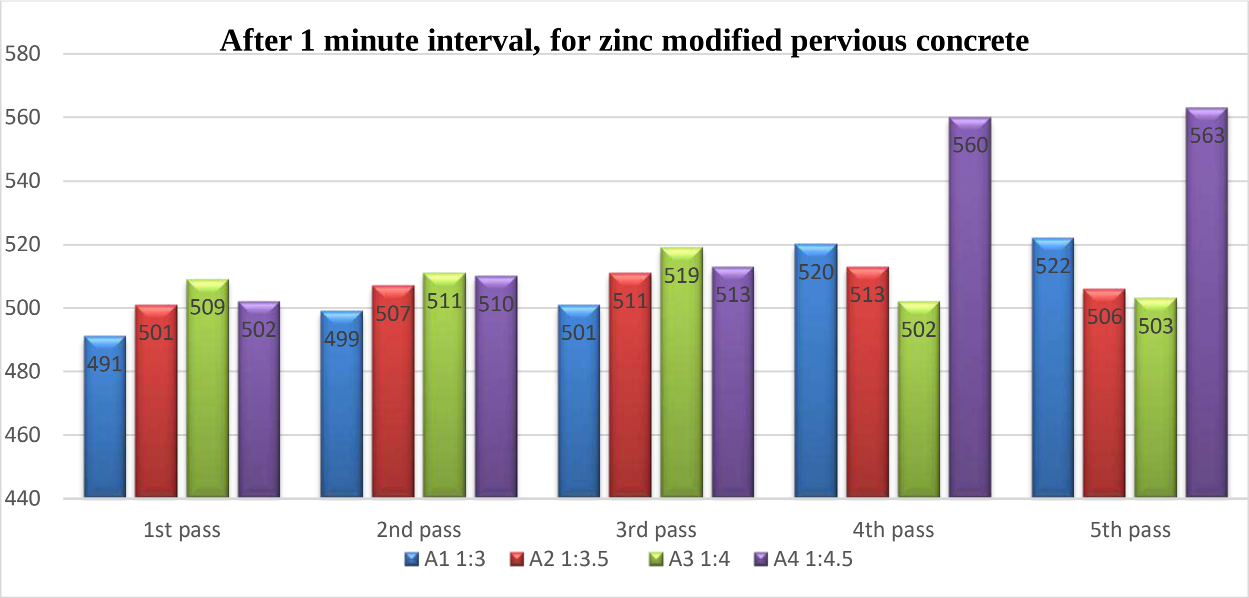


Figure 25: Conductivity test result for zinc modified pervious concrete after 1 minute of interval

The findings of electrical conductivity presented in Fig. 25 illustrate the results of the 1-minute electrical conductivity test conducted on the zinc modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide. The data demonstrates a negative correlation between cement quantity and conductivity, suggesting that higher cement quantities result in increased adsorption of metals. The uncertain values suggest that in order to obtain more reliable and accurate adsorption results, a longer time interval should be provided. By allowing for a longer time interval between measurements, the system can reach a more stable state, leading to more consistent and dependable adsorption measurements. Notably, the 1:3 mix ratio exhibits the lowest conductivity value, indicating enhanced metal adsorption. Additionally, conductivity gradually increases with each subsequent pass, peaking at the 5th pass, indicating a decline in adsorption capacity over time. These observations underscore the significant role of cement quantity in influencing the conductivity and adsorption properties of modified pervious concrete.

4.4 Operating Water Head test

An Operating Water Head test was conducted to investigate the adsorption behavior of metals at different heights within pervious concrete. The test was carried out at four distinct heights: 7.5cm, 10cm, 20cm, and 30cm. The results demonstrated a clear trend where a decrease in the water head corresponded to an increase in the adsorption of metals. Notably, the highest level of metal adsorption was recorded at the 7.5cm height. The test incorporated variations in both the water head and concrete mix ratios to comprehensively assess the adsorption characteristics. Conductivity meter was utilized as an indirect indicator to evaluate metals adsorption at different water heads. These findings contribute valuable insights to our understanding of metals adsorption in pervious concrete and have implications for optimizing concrete mix designs in applications where metal removal is a priority.

4.4.1 Operating Water Head test for 1:4.5 mix conventional and modified pervious concrete for copper

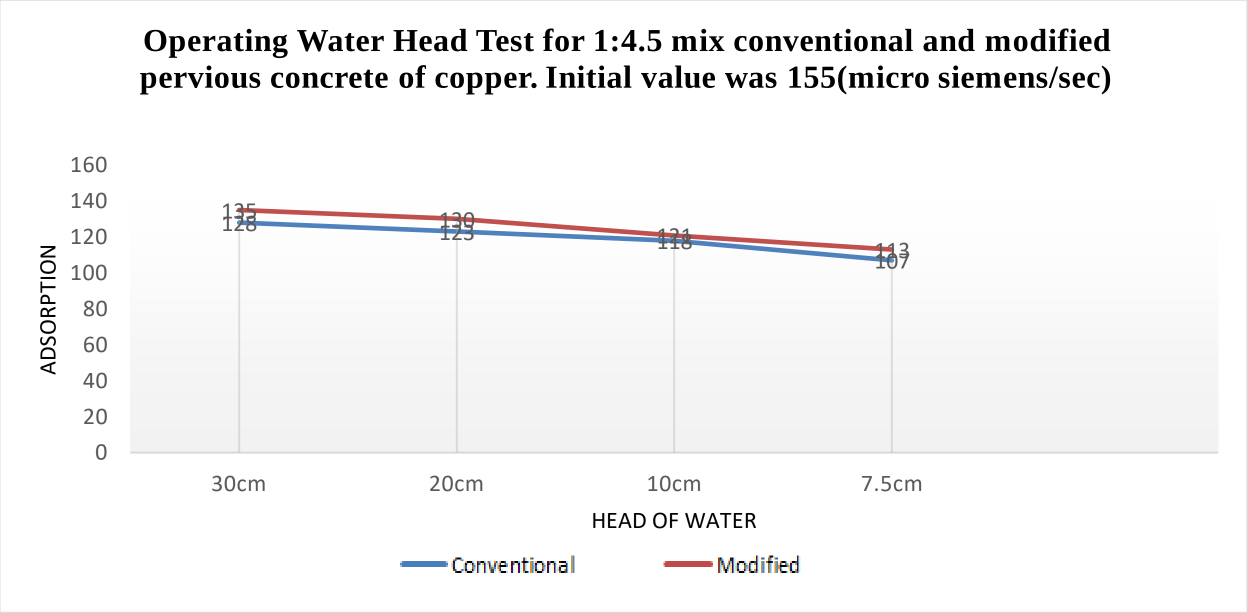


Figure 26: Operating Water Head Test results of 1:4.5 mix for Conventional and modified pervious concrete of Copper

Fig. 26 show the results of the Operating Water Head Test conducted on the 1:4.5 mix samples of conventional and modified pervious concrete, specifically focusing on copper adsorption. The data clearly illustrates a direct relationship between water head level and the adsorption capacity of copper in both concrete types. As the water head decreases, indicating a lower release height, the adsorption of copper metal increases in both conventional and modified pervious concrete. This finding highlights the significance of water head as a critical factor influencing the adsorption performance of pervious concrete in relation to copper metal contaminants.

4.4.2 Operating Water Head test for 1:4.5 mix conventional and modified pervious concrete of zinc

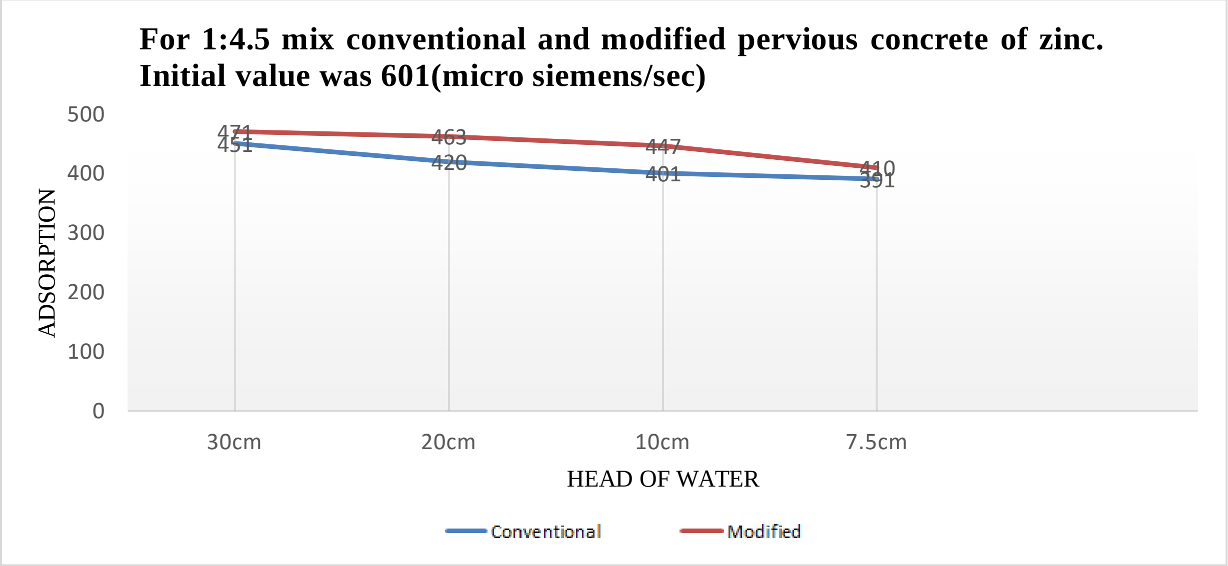


Figure 27: Operating Water Head Test results of 1:4.5 mix for conventional and modified pervious concrete of zinc

Fig. 27 showcases the results of the Operating Water Head test conducted on the 1:4.5 mix samples of conventional and modified pervious concrete, specifically focusing on zinc adsorption. The data clearly illustrates a direct relationship between water head level and the adsorption capacity of zinc in both concrete types. As the water head decreases, indicating a lower release height, the adsorption of zinc metal increases in both conventional and modified pervious concrete. This finding highlights the significance of water head as a critical factor influencing the adsorption performance of pervious concrete in relation to zinc metal contaminants.

4.4.3 Operating Water Head test for 1:4 mix conventional and modified pervious concrete of copper

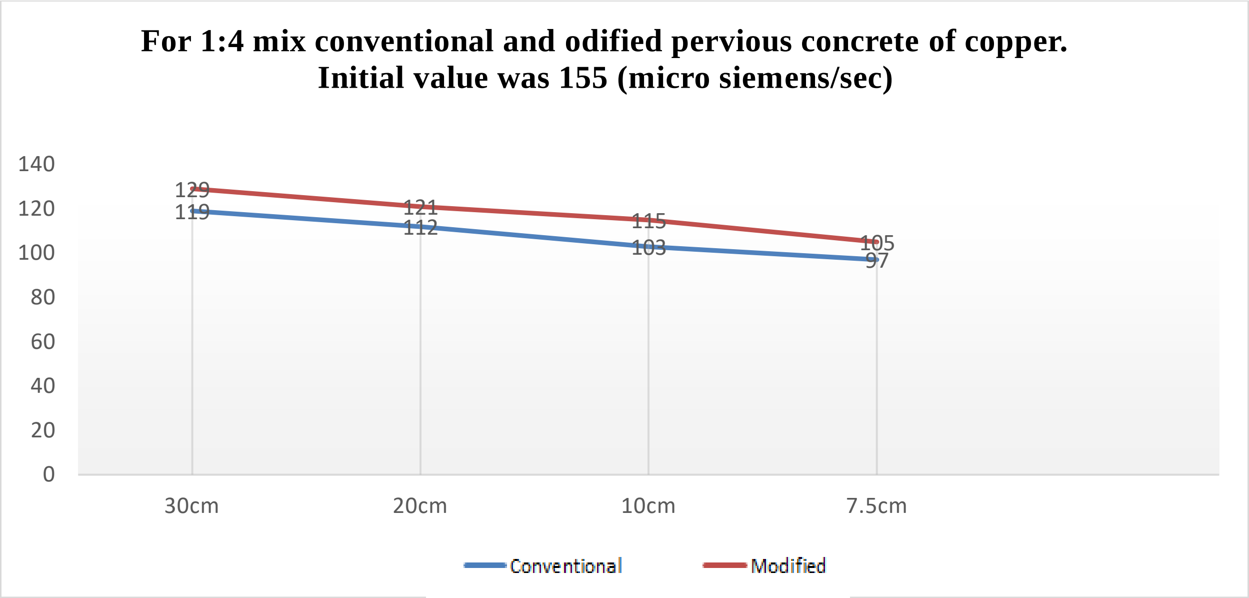
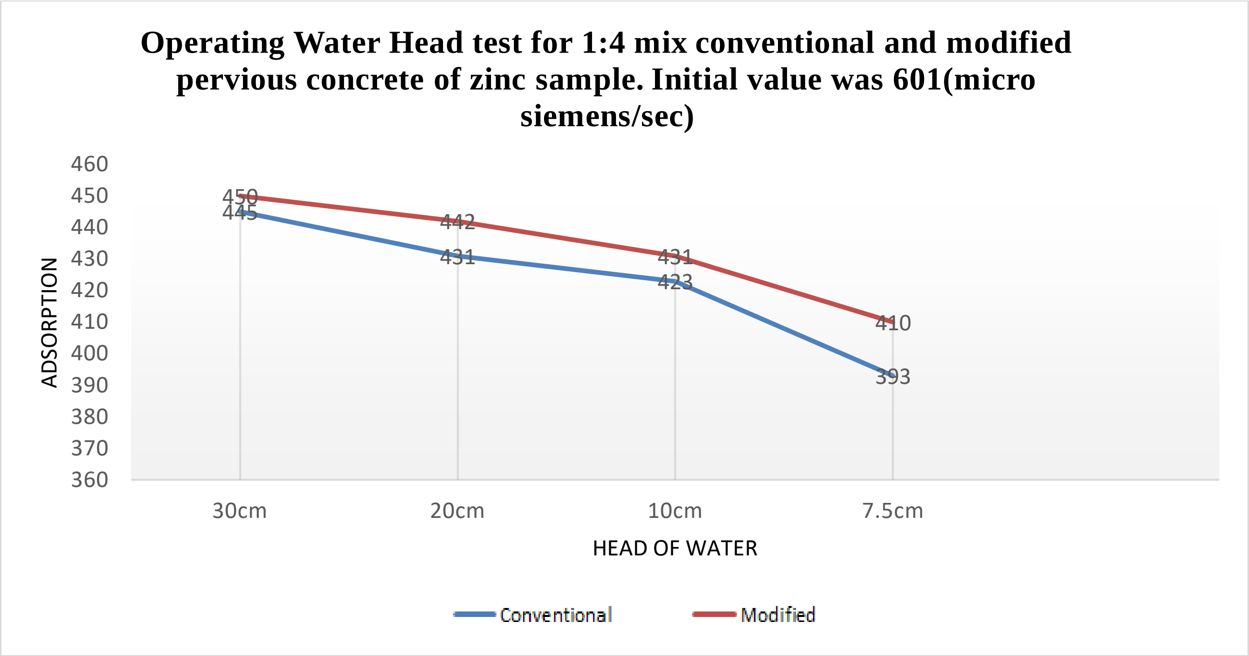


Figure 28: Operating Water Head test results of 1:4 mix for conventional and modified pervious concrete of copper

The findings presented in Fig. 28 depict the outcomes of the Operating Water Head test conducted on the 1:4.5 ratio samples of conventional and modified pervious concrete, with a specific focus on copper adsorption. The data clearly demonstrates a direct correlation between water head level and the adsorption capacity of copper in both types of concrete. A decrease in water head, indicating a lower release height, corresponds to an increase in the adsorption of copper metal in both conventional and modified pervious concrete. These results emphasize the crucial role of water head as a significant factor influencing the adsorption performance of pervious concrete in the context of copper metal contaminants.

4.4.4 Operating Water Head test for 1:4 mix conventional and modified pervious concrete of zinc



Operating Water Head test for 1:4 mix conventional and modified pervious concrete of zinc sample. Initial value was 601(micro siemens/sec)

Figure 29: Operating Water Head Test results of 1:4 mix for Conventional and modified pervious concrete of zinc

The findings presented in Fig. 29 depict the outcomes of the Operating Water Head test conducted on the 1:4 ratio samples of conventional and modified pervious concrete, with a specific focus on zinc adsorption. The data clearly demonstrates a direct correlation between water head level and the adsorption capacity of zinc in both types of concrete. A decrease in water head, indicating a lower release height, corresponds to an increase in the adsorption of zinc metal in both conventional and modified pervious concrete. These results emphasize the crucial role of water head as a significant factor influencing the adsorption performance of pervious concrete in the context of zinc metal contaminants.

4.4.5 Operating Water Head test for 1:3.5 mix conventional and modified pervious concrete of copper

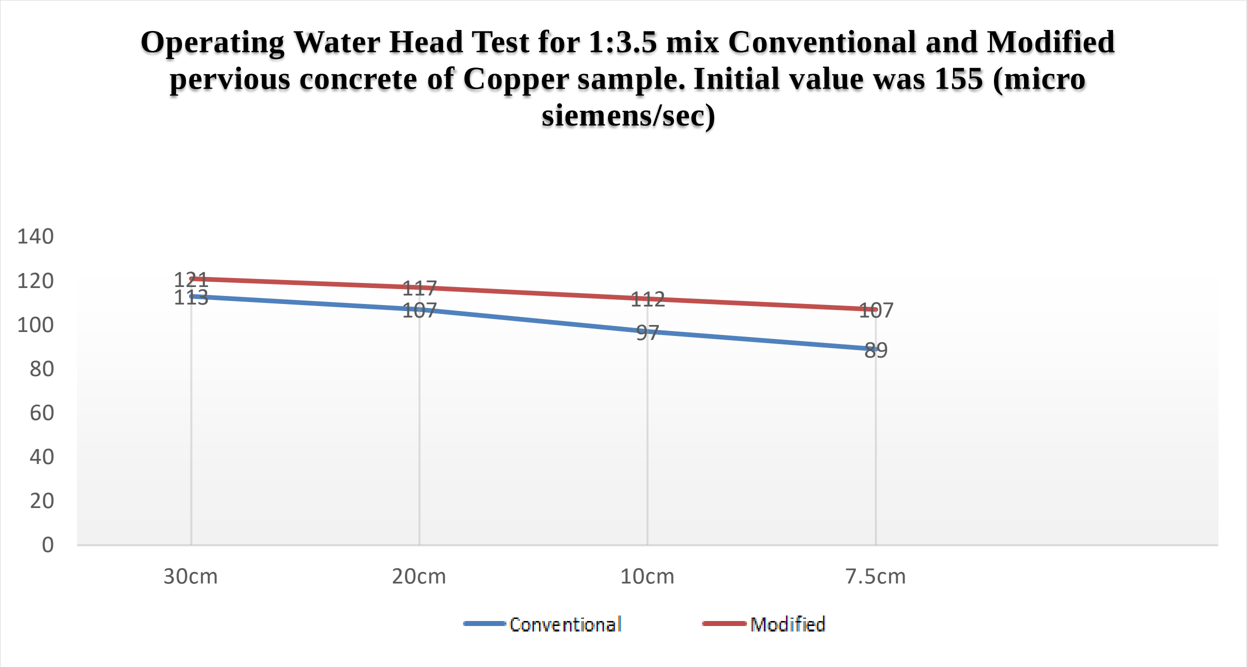


Figure 30: Operating Water Head Test results of 1:3.5 mix for conventional and modified pervious concrete of copper

The results presented in Fig. 30 illustrate the findings of the Operating Water Head test conducted on the 1:4 ratio samples of conventional and modified pervious concrete, focusing specifically on copper adsorption. The data clearly shows a direct relationship between the water head level and the adsorption capacity of copper in both types of concrete. Decreasing the water head, indicating a lower release height, leads to an increase in the adsorption of copper metal in both conventional and modified pervious concrete. These results highlight the significant role of water head as a key factor influencing the adsorption performance of pervious concrete in the presence of copper metal contaminants.

4.4.6 Operating Water Head Test for 1:3.5 mix conventional and modified pervious concrete of zinc

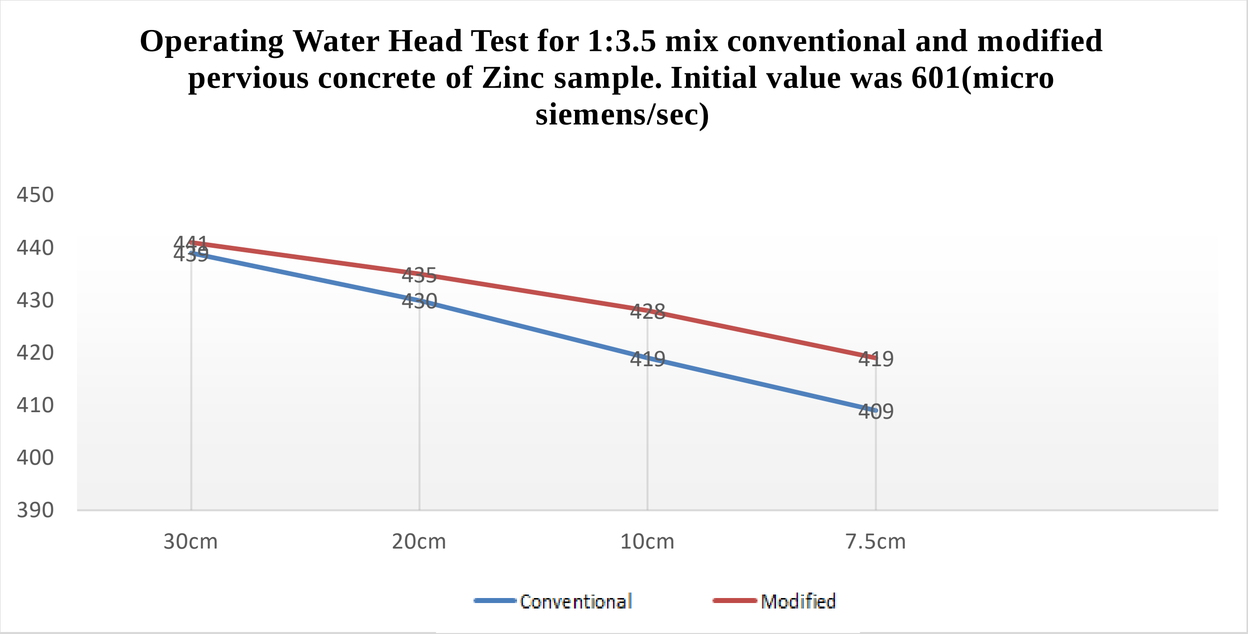


Figure 31: Operating Water Head Test results of 1:3.5 mix for conventional and modified pervious concrete of zinc

The results presented in Fig. 31 illustrate the findings of the Operating Water Head Test conducted on the 1:3.5 ratio samples of both conventional and modified pervious concrete, specifically focusing on zinc adsorption. The data clearly exhibits a direct relationship between water head level and the adsorption capacity of zinc in both types of concrete. As the water head decreases, indicating a lower release height, the adsorption of zinc metal increases in both conventional and modified pervious concrete. These findings highlight the significant influence of water head as a key factor affecting the adsorption performance of pervious concrete in relation to zinc metal contaminants.

4.4.7 Operating Water Head test for 1:3 mix conventional and modified pervious concrete of copper

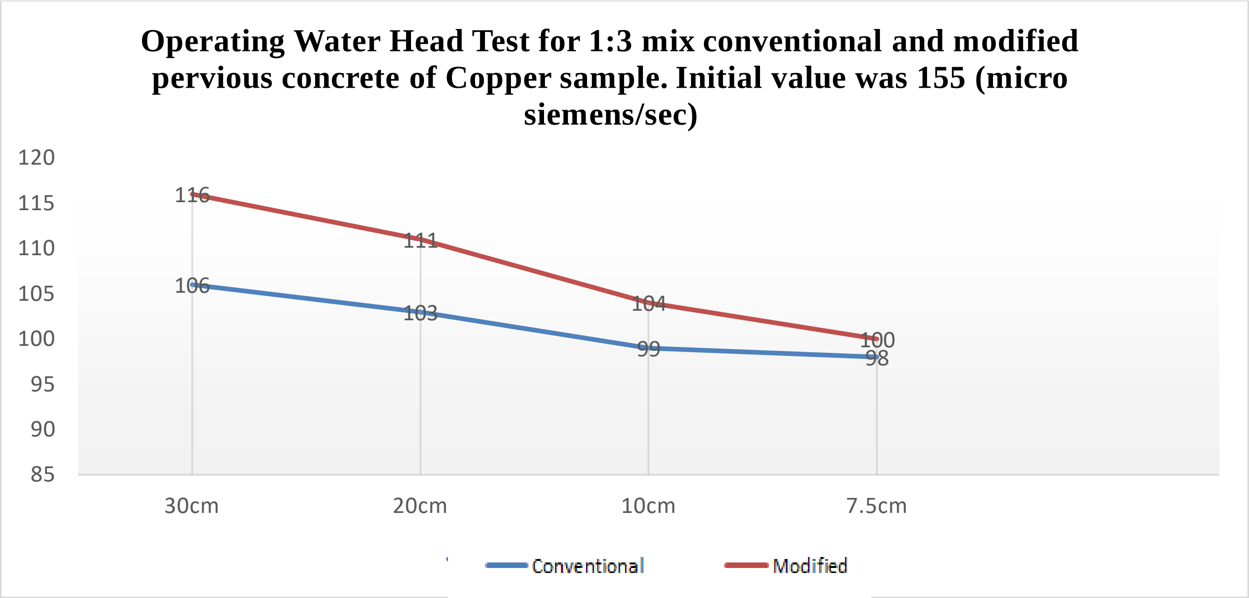


Figure 32: Operating Water Head Test results of 1:3 mix for conventional and modified pervious concrete of copper

The results depicted in Fig. 32 illustrate the findings of the Operating Water Head test conducted on the 1:3 ratio samples of conventional and modified pervious concrete, focusing on copper adsorption. The data clearly demonstrates a direct relationship between water head level and the adsorption capacity of copper in both types of concrete. A decrease in water head, indicating a lower release height, leads to an increase in the adsorption of copper metal in both conventional and modified pervious concrete. These findings highlight the significant role of water head as a critical factor influencing the adsorption performance of pervious concrete in the presence of copper metal contaminants.

4.4.8 Operating Water Head test for 1:3 mix conventional and modified pervious concrete of zinc

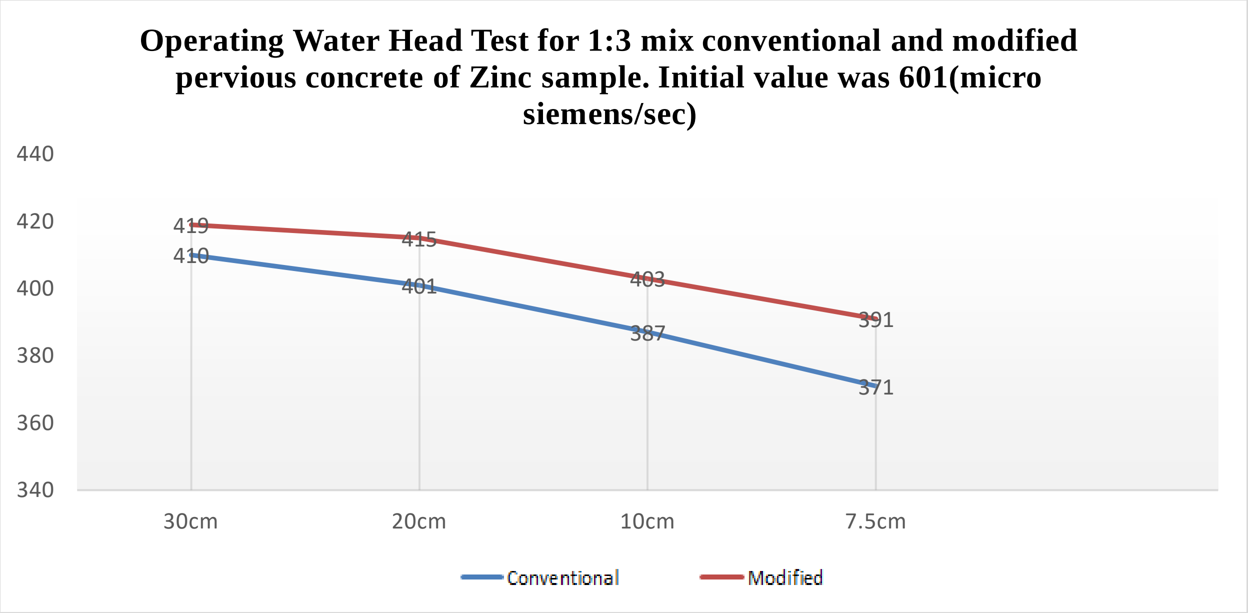


Figure 33: Operating Water Head Test results of 1:3 mix for conventional and modified pervious concrete of zinc

The experimental findings presented in Fig. 33 provide insights into the results of the Operating Water Head test conducted on the 1:3 ratio samples of conventional and modified pervious concrete, specifically focusing on zinc adsorption. The data clearly exhibits a direct relationship between the water head level and the adsorption capacity of zinc in both types of concrete. As the water head decreases, indicating a lower release height, there is an observed increase in the adsorption of zinc metal in both conventional and modified pervious concrete. These results underscore the significant influence of water head as a critical factor impacting the adsorption performance of pervious concrete concerning zinc metal contaminants.

4.5 Infiltration rate test

The purpose of an infiltration rate test is to evaluate how quickly water can infiltrate and permeate through pervious concrete. This test is essential for assessing the concrete's porosity and permeability, which are critical factors in its ability to effectively manage storm water runoff and prevent surface flooding. To conduct the test, the ASTM 1701 standard is commonly followed. During the infiltration rate test, the concrete mix ratio and the time interval between sample passings are varied to gather comprehensive data. By manipulating these variables, it was investigated how different concrete mixtures and time intervals impact the infiltration rate.

4.5.1 Infiltration rate test of 1 minute interval for conventional pervious concrete

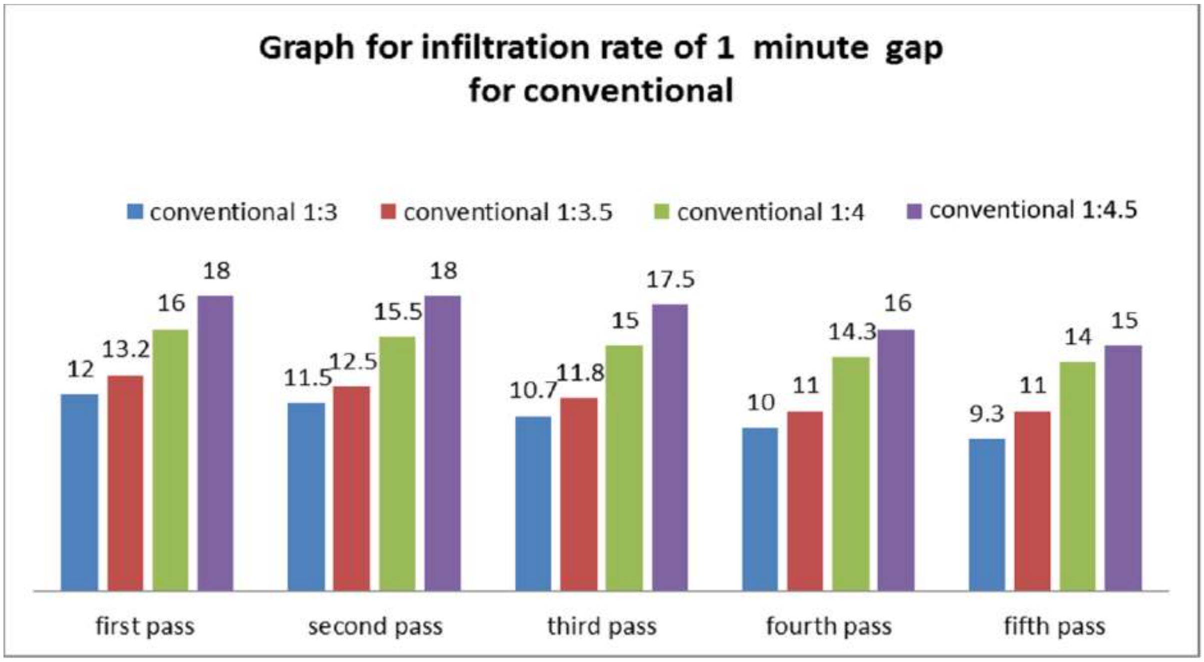


Figure 34: Infiltration rate test results of conventional pervious concrete for 1 minute interval

The results of the infiltration rate test for conventional pervious concrete is shown in Fig. 34 indicate a consistent decrease in the infiltration rate with each subsequent passing of the sample. Notably, the lowest infiltration rate was observed during the fifth pass. This trend suggests that as the number of sample passes increases, the permeability of the pervious concrete decreases.

Furthermore, the results demonstrate that the infiltration rate is inversely related to the cement quantity in the concrete mixture. Specifically, the lowest infiltration rate was recorded for the concrete mix ratio of 1:3, indicating that as the amount of cement in the mixture increases, the infiltration rate decreases.

4.5.2 Infiltration rate test of 1 minute interval for modified pervious concrete

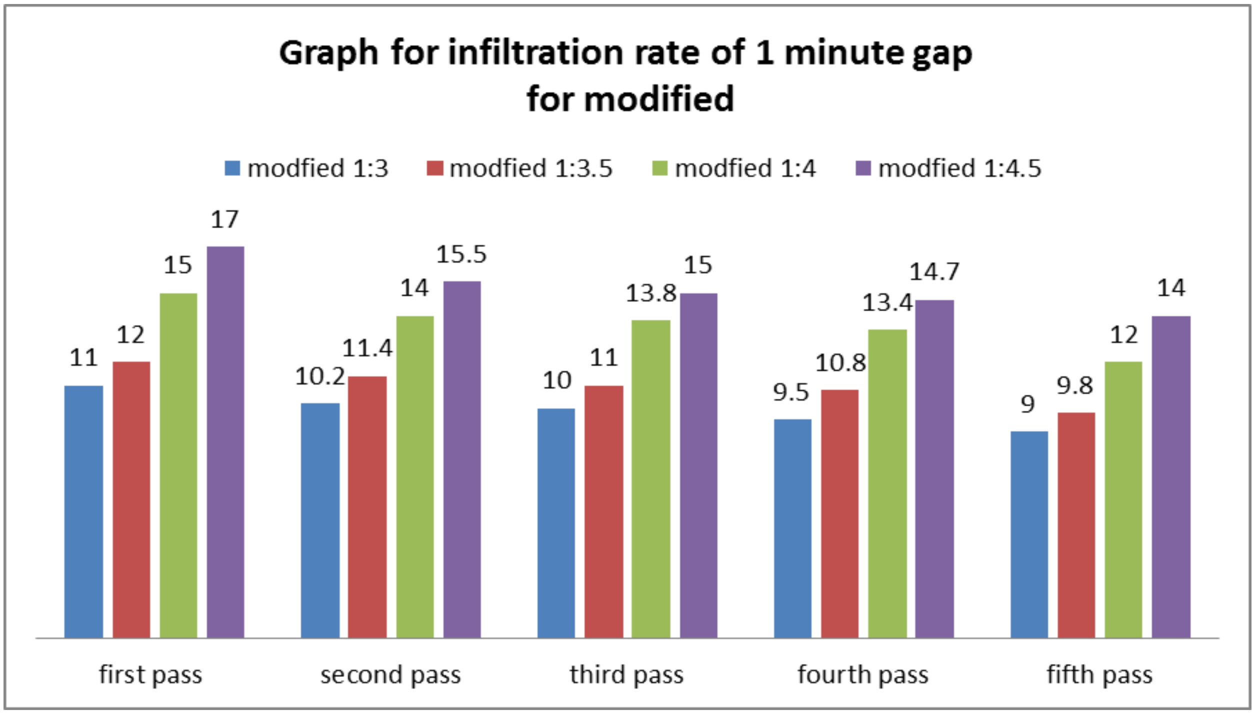


Figure 35: Infiltration rate test results of modified pervious concrete for 1 minute interval

The results of the infiltration rate test result for modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide is shown in Fig. 35 indicate a consistent decrease in the infiltration rate with each subsequent passing of the sample. Notably, the lowest infiltration rate was observed during the fifth pass. This trend suggests that as the number of sample passes increases, the permeability of the pervious concrete decreases.

Furthermore, the results demonstrate that the infiltration rate is inversely related to the cement quantity in the concrete mixture. Specifically, the lowest infiltration rate was recorded for the concrete mix ratio of 1:3, indicating that as the amount of cement in the mixture increases, the infiltration rate decreases.

4.5.3 Infiltration rate test of 5 minutes interval for conventional pervious concrete

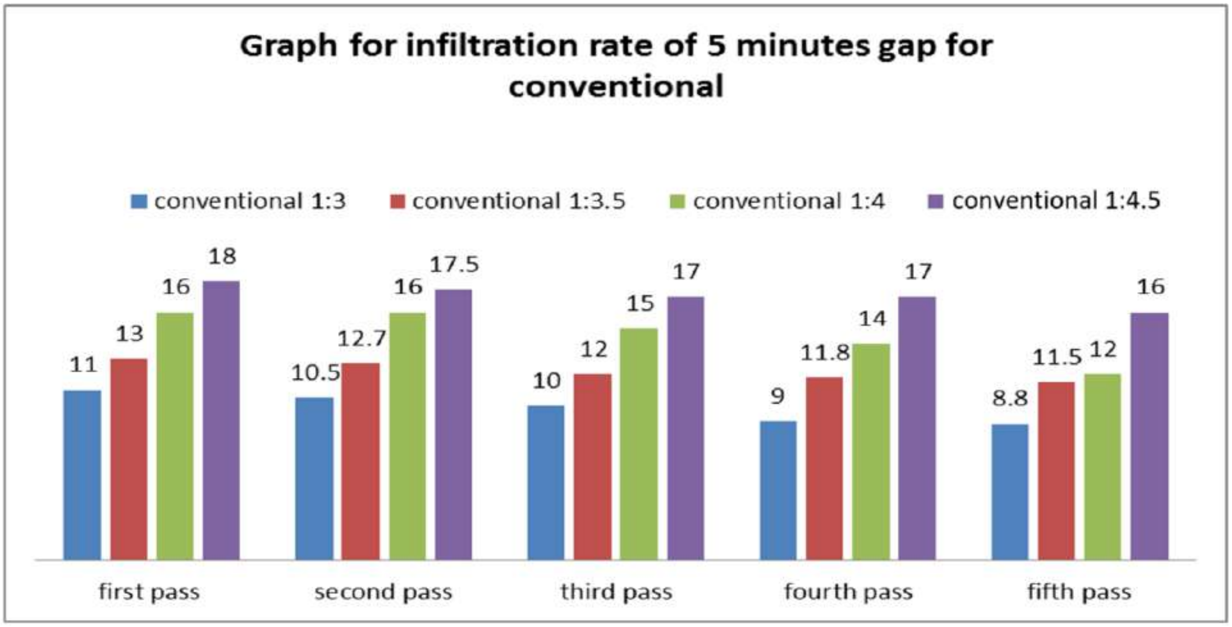


Figure 36: Infiltration rate test results of conventional pervious concrete for 5 minutes interval

The results of the infiltration rate test for conventional pervious concrete is shown in Fig. 36 indicate a consistent decrease in the infiltration rate with each subsequent passing of the sample. Notably, the lowest infiltration rate was observed during the fifth pass. This trend suggests that as the number of sample passes increases, the permeability of the pervious concrete decreases.

Furthermore, the results demonstrate that the infiltration rate is inversely related to the cement quantity in the concrete mixture. Specifically, the lowest infiltration rate was recorded for the concrete mix ratio of 1:3, indicating that as the amount of cement in the mixture increases, the infiltration rate decreases.

4.5.4 Infiltration rate test of 5 minutes interval for modified pervious concrete

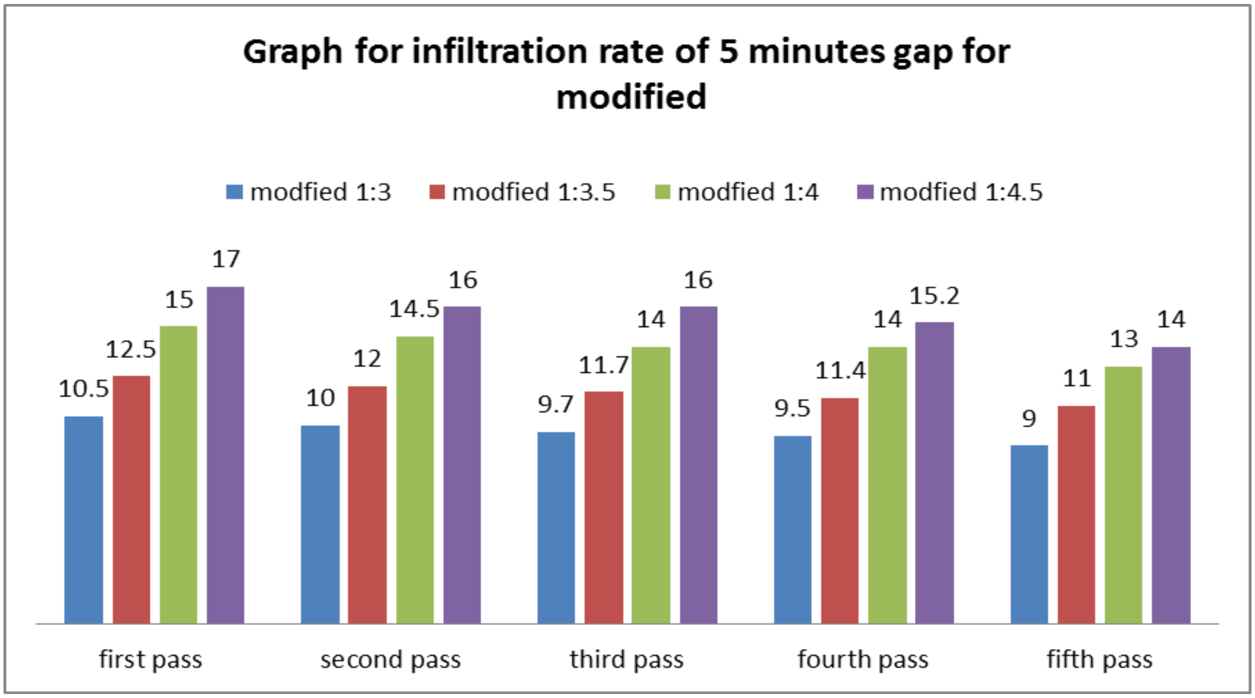


Figure 37: Infiltration rate test results of modified pervious concrete for 5 minutes interval

The results of the infiltration rate test result for modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide is shown in Fig. 37 indicate a consistent decrease in the infiltration rate with each subsequent passing of the sample. Notably, the lowest infiltration rate was observed during the fifth pass. This trend suggests that as the number of sample passes increases, the permeability of the pervious concrete decreases.

Furthermore, the results demonstrate that the infiltration rate is inversely related to the cement quantity in the concrete mixture. Specifically, the lowest infiltration rate was recorded for the concrete mix ratio of 1:3, indicating that as the amount of cement in the mixture increases, the infiltration rate decreases.

4.5.5 Infiltration rate test of 15 minutes interval for conventional pervious concrete

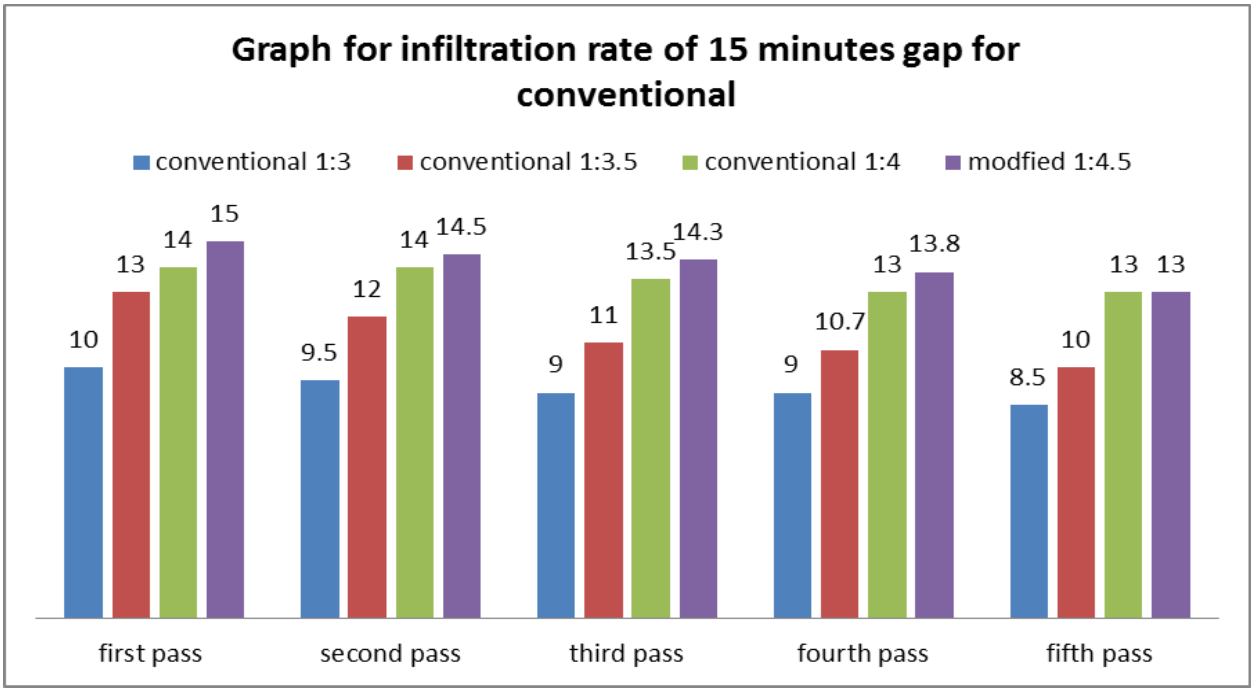


Figure 38: Infiltration rate test results of conventional pervious concrete for 15 minutes interval

Fig. 38 illustrates the findings of the infiltration rate test conducted on conventional pervious concrete. The results reveal a consistent reduction in the infiltration rate as each subsequent sample pass is performed. Notably, the fifth pass yielded the lowest infiltration rate, indicating a diminishing permeability trend with increasing sample passes.

Additionally, the results highlight an inverse relationship between the infiltration rate and the cement content within the concrete mixture. Specifically, the infiltration rate was found to be at its lowest point for the concrete mix ratio of 1:3. This observation suggests that as the proportion of cement in the mixture increases, the infiltration rate diminishes.

4.5.6 Infiltration rate test of 15 minutes interval for modified pervious concrete

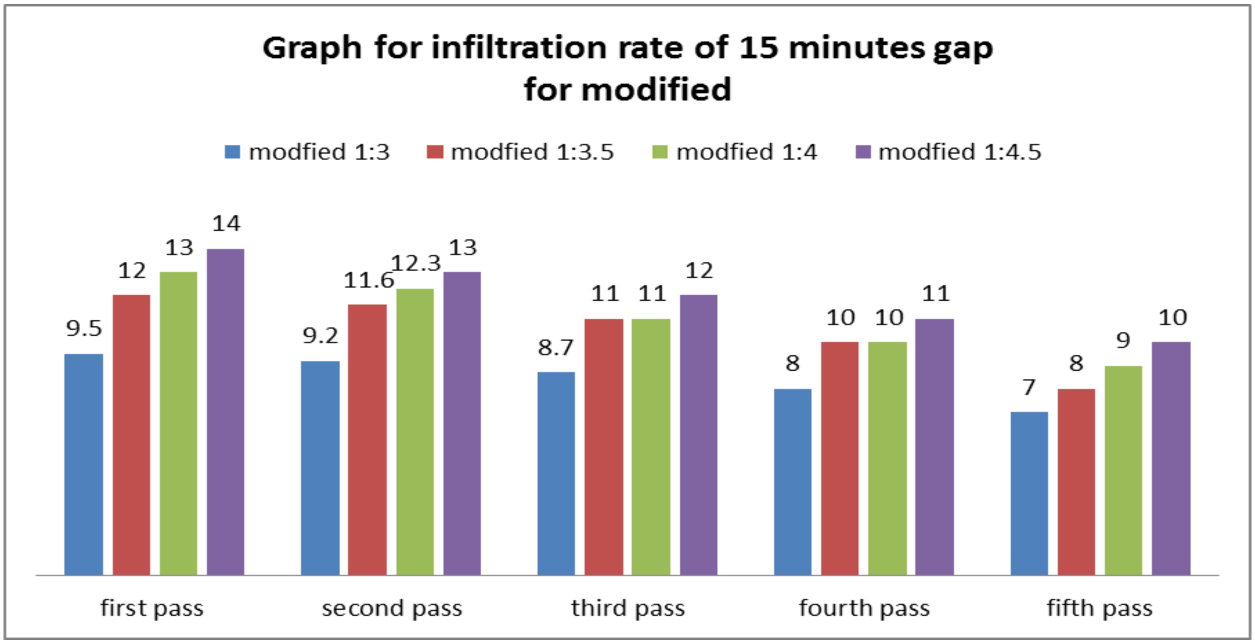


Figure 39: Infiltration rate test results of modified pervious concrete for 15 minutes interval

The results of the infiltration rate test result for modified pervious concrete, which underwent modification through the inclusion of 0.04% graphene oxide is shown in Fig. 39 indicate a consistent decrease in the infiltration rate with each subsequent passing of the sample. Notably, the lowest infiltration rate was observed during the fifth pass. This trend suggests that as the number of sample passes increases, the permeability of the pervious concrete decreases.

Furthermore, the results demonstrate that the infiltration rate is inversely related to the cement quantity in the concrete mixture. Specifically, the lowest infiltration rate was recorded for the concrete mix ratio of 1:3, indicating that as the amount of cement in the mixture increases, the infiltration rate decreases.

Chapter # 5

Conclusions and Recommendations

5. Conclusions and Recommendations

5.1 Conclusions

- Variation in cement quantity significantly influences the adsorption capacity of both copper and zinc in conventional pervious concrete. Increasing the amount of cement leads to an increase in the adsorption capacity of the sample.
- In modified pervious concrete, with a constant percentage of Graphene Oxide (GO), an increase in cement quantity results in enhanced adsorption capacity for copper. However, the adsorption capacity for zinc does not exhibit substantial changes.
- The conductivity test, used as an indirect indicator for metal adsorption, demonstrates that as cement quantity increases in both conventional and modified pervious concrete, the adsorption of copper increases. This is evidenced by the decrease in conductivity values, indicating higher copper adsorption.
- The conductivity test reveals that increasing cement quantity enhances the adsorption of zinc in conventional pervious concrete, while the adsorption capacity of zinc in modified pervious concrete remains relatively unchanged.
- Comparatively, conventional pervious concrete exhibits superior contaminant removal efficiency compared to modified pervious concrete.
- The results of the operating water head test demonstrate an inverse relationship between the operating water head (the height from which water is released) and the adsorption of heavy metals, including copper and zinc. As the operating water head decreases, the adsorption of these metals increases, and conversely, as the operating water head increases, the adsorption decreases.
- The infiltration rate test reveals a consistent decrease in the infiltration rate of both conventional pervious concrete and modified pervious concrete with each successive sample. This indicates that the permeability of the concrete decreases over time, leading to a slower rate of water infiltration.

- Furthermore, the infiltration rate test highlights that the modified pervious concrete exhibits a lower infiltration rate compared to the conventional pervious concrete. This indicates that the modifications implemented in the concrete composition result in a reduced permeability, leading to a slower rate of water infiltration.

5.2 Recommendations

- In light of the significant influence of pH on heavy metal adsorption, further research is recommended to explore the optimal pH ranges for zinc and copper metals and adsorbent materials (cement and graphene oxide), investigate the underlying mechanistic aspects of pH-dependent adsorption, consider adsorbent (cement and graphene oxide), modification to enhance performance under specific pH conditions, apply the findings to real-world scenarios, and investigate the behavior of heavy metals in multi-metal systems. Addressing these recommendations will contribute to the development of efficient water treatment strategies and advance our understanding of pH-dependent adsorption processes, ultimately aiding in the mitigation of heavy metal contamination in various environmental settings.
- In light of the significant impact of temperature on heavy metals adsorption, further research is recommended to determine optimal operating temperatures for zinc and copper metals and adsorbent materials (cement and graphene oxide), conduct thermodynamic analysis to assess the feasibility of adsorption processes under varying temperature conditions, develop kinetic models to understand temperature-dependent adsorption rates, explore the stability and regeneration of adsorbents at elevated temperatures, and validate the findings in real-world water treatment scenarios. Addressing these recommendations will advance our understanding of temperature's influence on heavy metal adsorption and aid in the development of efficient and sustainable strategies for water treatment and environmental remediation.

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