CHAPTER I
INTRODUCTION

1.1 Background

Contamination of soil and water by arsenic has grown to be a serious environmental and public health concern. It is harmful to human health and the environment. Rocks, soil, air, and water all naturally contain trace amounts of arsenic, but human activity and natural processes contribute to elevated levels (Gupta, 2022). Arsenic pollution varies in severity from light to very severe, with South Asia, South America, and portions of Africa and Europe having the highest quantities. The majority of arsenic-contaminated locations are found in geological formations that are close to modern geological units and areas that are surrounded by rivers. Because of environmental factors that encourage the release of arsenic from arsenic compounds, tropical climates are more vulnerable to arsenic pollution (Sultan et al., 2025). The contamination of Arsenic can originate from natural sources—such as the weathering of arsenic-bearing rocks, volcanic emissions, and geothermal activity—as well as from anthropogenic activities. Human-induced sources include mining and smelting processes, use of arsenic-based pesticides and herbicides, industrial effluents, coal combustion, and improper disposal of arsenic-containing waste. These activities contribute significantly to the accumulation of arsenic in both soil and water, especially in regions where environmental regulations and waste management are inadequate (Xing et al., 2024).

One of the forms contributing to this contamination is arsenic trioxide (As_2O_3), a trivalent compound representing As(III). This form is highly toxic, readily soluble, and more mobile in the environment, making it a significant threat to groundwater and soil systems (Sinha et al., 2023). Typically, the concentrations of arsenic (As) in uncontaminated soils range from 0.1 to 10 mg/kg, with an average around 5 mg/kg. However, natural geological variations can result in arsenic levels up to 40 mg/kg in some areas. Soils impacted by anthropogenic sources may exhibit much higher concentrations, ranging from 5 to even 3000 mg/kg (Gomez, 2001). These elevated levels can pose severe risks to both environmental and human health, including various forms of cancer (skin, liver, lung, kidney, and bladder), cardiovascular disorders, neurological impairments, and other chronic diseases (Shrivastava & Ghosh, 2015).

Multiple treatment technologies—such as adsorption, coagulation, flocculation, chemical precipitation, membrane filtration, ion exchange, flotation, and electrochemical methods—have been applied to tackle heavy metal contamination. Although these approaches can be effective in specific situations, they often face serious limitations, including the generation of toxic by-products that may lead to secondary pollution (Sadee et al., 2025). With increasing awareness of the dangers posed by heavy metals to both health and the environment, researchers have prioritized the development of cost-effective and sustainable solutions. As a result, newer green biological methods for heavy metal removal are either replacing or supplementing traditional physicochemical techniques (Razzak et al., 2022).

Researchers have investigated biotechnological alternatives to address the shortcomings of traditional techniques, most notably Microbially Induced Carbonate Precipitation (MICP), which has become a practical and sustainable remediation technique. Compared to microbial technologies, traditional treatments are frequently less effective and more expensive over time, even though they can produce quick results in some situations (Razzak et al., 2022). Although the efficacy of traditional cleanup techniques has been assessed in a number of studies, their long-term success has been constrained by their incapacity to completely eliminate contaminants and the high costs involved. As a result, MICP has become well-known for its ability to clean up polluted areas, especially by rendering harmful metals like arsenic immobile (Rajasekar et al., 2021).

MICP's low energy requirements, cost-effectiveness, and environmental compatibility make it a promising bioremediation technique. This method uses microbes to mediate the formation of carbonate minerals, which are fueled by biochemical reactions and impacted by environmental factors. A number of variables, including pH, temperature, microbial species, nutrient availability, and calcium sources, influence the process. MICP is a biogeochemical mechanism that has been used in a number of environmental fields, such as immobilizing heavy metals, preventing corrosion in building materials, and sealing soil cracks.

Compared to conventional treatments, MICP provides several key benefits, including reduced operational costs, simplified procedures, lower energy requirements, and minimal production of hazardous waste (W. Zhang et al., 2023).

The ureolytic bacteria pathway is the most commonly used of the different microbial metabolic pathways that can cause $CaCO_3$ precipitation because of its great controllability and efficiency (Erdmann & Strieth, 2023). By using urease enzymes to hydrolyze urea into ammonium and carbonate ions, ureolytic bacteria play a crucial part in this process. When carbonate ions are released, the pH of the surrounding environment rises, which makes it easier for calcium carbonate to precipitate. In addition to improving soil structure, the resulting $CaCO_3$ also helps to co-precipitate and entrap harmful metals like arsenic, decreasing their mobility and bioavailability (Rajasekar et al., 2024). Urealytic bacteria are very appealing for use in MICP-based soil remediation technologies because of their ease of use, efficiency, and environmental friendliness.

Mangroves are coastal ecosystems that can be found all over the world in tropical and subtropical regions, especially where rivers, seas, and land meet. These ecosystems are renowned for their high levels of productivity and biodiversity for microbes, plants, and animals. The decomposition process and the creation of vital compounds in the carbon cycle in mangrove forest sediments are greatly aided by the high nutrient requirements caused by the diversity of microorganisms in mangrove environments (Holguin et al., 2001). Additionally, the habitat that mangrove environments offer fosters the development of microbial communities that contribute to preserving the ecosystem's ecological function. An oxygenated rhizosphere region with a variety of substrates is formed by mangrove roots, which makes it the perfect place for microbial activity, especially bacteria (Sulastri et al., 2022). Mangrove sediments are a rich source of marine bacterial growth and may be used to isolate ureolytic bacteria and other microorganisms (Ambarsari et al., 2020). Ureolytic bacteria have been successfully isolated from mangrove environments in a number of prior studies, demonstrating their high urease activity and potential for MICP applications (Ambarsari et al., 2020; Leeprasert et al., 2022).

A comprehensive understanding of MICP's mechanisms and influencing factors is necessary in order to fully utilize it for arsenic remediation. The immobilization process is significantly impacted by variables like temperature, pH, arsenic concentration, microbial strains, and arsenic speciation (J. Zhang et al., 2021). MICP has proven to be effective in both laboratory and field studies; however, to maximize its use and enhance its performance as a sustainable remediation technique, a better understanding of arsenic immobilization and the variables influencing its effectiveness is essential. Measurements of optical density, urease activity, specific urease activity, and the mass of $CaCO_3$ formed are among the tests that will be performed to assess these parameters. Finding the ideal circumstances that promote calcium carbonate precipitation—a prerequisite for successfully ensnaring arsenic—is made possible by these tests. Though interest in MICP is growing worldwide, there are still very few studies done in Indonesia, especially when it comes to the isolation and characterization of local ureolytic bacterial species and their unique ability to immobilize arsenic.

Thus, the purpose of this study is to determine whether native ureolytic bacteria from Teluk Buo, Padang's mangrove soil and water exist and to assess their capacity to immobilize arsenic using the MICP process. It is anticipated that this study will advance our understanding of bioremediation technology, particularly with regard to the possible use of MICP in treating arsenic-contaminated soils by utilizing local microbial resources.

1.2 Aim and Objective

This study sets out with the following objectives:

1. To isolate, identify, and analyze bacteria that produce urease
2. To assess the ureolytic bacterial isolates' precipitation potential and tolerance of urease activity in immobilizing arsenic
3. To assess how well actual biocementation treatment works to immobilize arsenic in soil.

1.3 Benefits of The Research

The benefits in this research are:

1. Developing an environmentally friendly remediation technology based on MICP;
2. Reducing the negative impacts of conventional methods on As waste management;
3. Providing a practical solution for mitigating As contamination in real conditions;
4. Serving as preliminary data for future research on the application of MICP in heavy metal immobilization.

1.4 Problem Limitations

1. This study aimed to assess the potential of mangrove soil and water as biocementation materials for immobilizing arsenic (As) in contaminated soil;
2. The biocementation process examined was Microbially Induced Calcite Precipitation (MICP), utilizing ureolytic bacteria found in mangrove soil and water;
3. Ureolytic bacteria played an essential role in stabilizing and immobilizing arsenic in soil, and the study sought to understand how this process might be enhanced for optimal effectiveness;
4. The ureolytic bacterial tests included enrichment culture from mangrove samples, inoculation on Christensen medium to identify urease activity, and isolation on nutrient agar to obtain pure isolates for further characterization and analysis;
5. Arsenic trioxide (As_2O_3) was used as the source of arsenic contamination, representing the trivalent form of arsenic (As(III)), which is highly toxic and readily soluble in soil environments;
6. The effectiveness of arsenic immobilization in this study was evaluated through tolerance tests (including optical density, pH, urease activity, and specific urease activity), biomineralization tests (measured by the mass of $CaCO_3$ precipitates formed), and biocementation tests;

7. All tests were conducted in a controlled laboratory environment to ensure precision in measuring and analyzing the results;
8. The findings were expected to aid in determining the precise conditions under which arsenic immobilization would be most effective.

1.5 Systematization of Writing

CHAPTER I **INTRODUCTION**

This chapter provides the background, aims, objectives, benefits, limitations of the research problems, and significance of the study.

CHAPTER II **LITERATURE REVIEW**

This chapter reviews key theories on arsenic contamination, MICP mechanisms, factors influencing MICP performance in heavy metal immobilization, and biocementation, along with its applications in environmental remediation and engineering.

CHAPTER III **RESEARCH METHODOLOGY**

This chapter describes the research stages conducted, the analysis methods in the laboratory, as well as the location and time of the research.

CHAPTER IV **RESULT AND DISCUSSION**

This chapter discusses the research findings..

CHAPTER V **CONCLUSION AND RECOMMENDATIONS**

This chapter contains conclusions and suggestions based on the discussion that has been described.