# ECOTECHNOLOGICAL AND SUSTAINABLE APPROACH TO MITIGATE EROSION-INDUCED SHALLOW LANDSLIDE

***Project Reference No.:*** *47S_BE_0631*


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## Introduction:

Soil erosion in the form of landslides poses a threat to the sustainability of some regions globally. People and resources are suffering greatly from landslides and other geo- disasters. Rainfall is one of the most prevalent causes of soil erosion. It can generate four different types of erosion: gully, splash, sheet, and rill. The initial stage of splash erosion is the breakdown of soil aggregates brought on by rains. Sheet erosion occurs when the soil mass is saturated or when the rate of rainfall is greater than the rate at which water seeps into the soil. The loose soil particles are subsequently carried down the slope by surface runoff. Landslides are a significant issue because of topographic differences, brittle lithology, dense overburden material, seismic activity, steep slope angles, high monsoon precipitation rates, and human activity. (Patial *et al.*, 2022) Slope instability may be a result of change in stress conditions, rise in groundwater table and rainfall. Similarly, many slopes that have been stable for several years can abruptly fail due to changes in geometry, weak soil shear strength or as an external forces effect. (Ali Mangnejo *et al.*, 2019) By enhancing the soil's shear strength and managing its properties, stabilization can increase a soil's ability to sustain pavements and foundations. Numerous soil types, including expansive clays and granular minerals, can be remedied via stabilization. (Jan and Kumar, 2022). One of the most often used biotechnological methods for stabilizing soil is microbially induced calcite precipitation (MICP), which significantly enhances the geotechnical characteristics of soil. Through soil solidification, the MICP process has a definite potential to increase residual strength. (Gowthaman *et al.*, 2019)

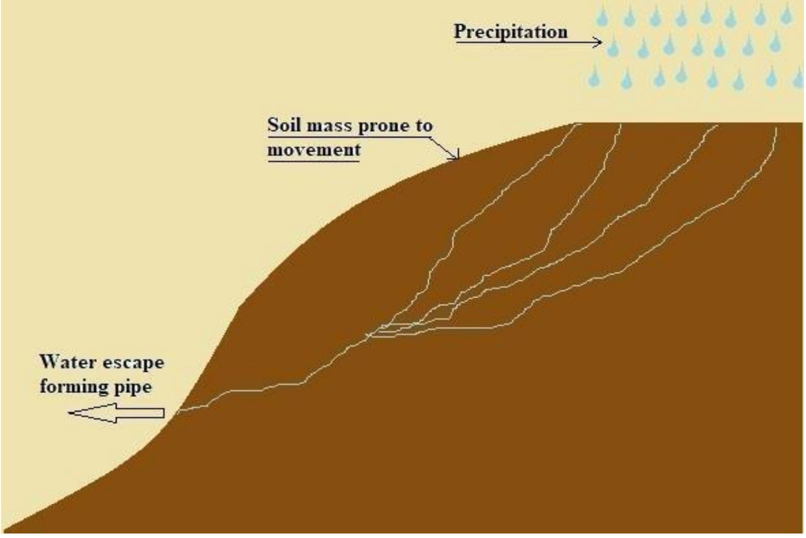



**Fig. 1 Pictorial representation of landslide**

**Objectives**:

Landslides are one of the catastrophic hazards and are an important component of the natural disturbance regime in most mountainous regions of the world and could strongly alter the environmental gradients. Landslides are among one of the major and widely spread natural disasters that strike life and property almost perennially year after year.

A classic morphological cause of landslides is erosion, which poses significant threats to communities, infrastructure, and ecosystems worldwide. Traditional mitigation measures often involve costly engineering solutions that may not be sustainable in the long term. In recent days promoting environmental harmony has been a key theme and thus ecotechnological approaches had considerable scientific interest. There are various ecotechnological strategies such as vegetation and soil stabilization, bioengineering techniques, geotextiles, hydroseeding, gabion structures, grassed swales, etc. Integrating these approaches can foster resilience and sustainable development in landslide-prone regions.

The main objective of this study is to investigate how bacterial strain affects the geotechnical characteristics of soil to reduce erosion and stabilize slopes.

- To study the mechanism of calcite precipitation in enhancing slope stability.
- To determine the performance of the biotechnological approach in mitigating landslides.
- Comparison between different bacterial strains in reducing soil erosion leading to slope failure.

**Methodology**:

This study aims to explore the impact of bacterial strains on the geotechnical properties of soil to mitigate erosion and stabilize slopes. The study also seeks to advance the understanding of how bacterial strains can be harnessed to enhance soil stability and mitigate the risks associated with erosion and slope instability.

**Materials**

**Soil**

The utilization of clayey soil from the Bagalkot area, Karnataka, in the current study signifies a deliberate selection process aimed at capturing representative soil characteristics. By collecting soil samples from a depth of 0.5 meters below the ground Surface, the study ensures the exclusion of potentially variable and contaminated top surface layers. The choice of locally available Grade-II silica sand for experimentation enhances the study's relevance and applicability to the local context. Laboratory testing conducted according to IS 2720 standards plays a pivotal role in characterizing the soil and sand samples. These standardized tests encompass a range of parameters, including particle size distribution, Atterberg limits, and compaction characteristics, among others. By adhering to established testing protocols, the study ensures consistency, reliability, and comparability of results, thereby enhancing the credibility of its findings. The properties of clay, black cotton soil, and sand are presented in Tables 4.1 and 4.2 respectively.

**Table 4.1 Properties of Clay**

| Property | Value |
|---|---|
| Specific gravity | 2.68 |
| ***Grain size distribution*** | |
| Sand | 4 % |
| Silt | 70 % |
| Clay | 26 % |
| ***Atterberg Limits*** | |
| Liquid limit | 49.5 % |
| Plastic limit | 21.5 % |
| Plasticity index | 28 % |
| IS classification | CL |
| ***Compaction characteristics*** | |
| Maximum dry density | 1.7 g/cm$^3$ |
| Optimum moisture content | 18.5 % |

**Table 4.2 Properties of Sand**

| Property | Value |
|---|---|
| Specific gravity | 2.64 |
| ***Grain size distribution*** | |
| D10 | 0.5 |
| D30 | 0.7 |
| D60 | 1.1 |
| Uniformity Coefficient | 3.2 |
| Curvature Coefficient | 0.89 |
| ***Density characteristics*** | |
| Maximum unit weight | 1.62 g/cm$^3$ |
| Friction angle | 34° |

**Bacterial strains**

Microbially Induced Calcium Carbonate Precipitation (MICP) is a biotechnological process that harnesses the metabolic activities of urease-producing bacteria to induce the precipitation of calcium carbonate in soil matrices. In the present study, two different types of bacterial strains are chosen to know their effect on stabilizing the slope. Bacillus subtilis (MTCC 7755), known also as the hay bacillus or grass bacillus, is a gram-positive, catalase-positive bacterium, found in soil and the gastrointestinal tract of ruminants, humans, and marine sponges. Sporosarcina pasteurii (ATCC 11895) formerly known as Bacillus pasteurii from older taxonomies, bacterium have the ability to precipitate calcite and solidify sand given a calcium source and urea; through the process of microbiologically induced calcite precipitation (MICP) or biological cementation. Figures 4.1 and 4.2 show the mother culture of B.subtilis and S.pasteurii.

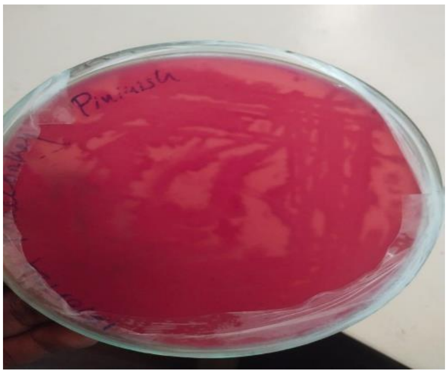


**Fig. 4.1 B.subtilis mother culture**

**Fig. 4.2 S.pasteurii mother culture**

**Cementitious Solution**

The cementitious solution should provide an optimal environment for bacterial growth and activity. The formulated cementation solution, is comprised of Calcium chloride, urea, and a carefully calibrated concentration of nutritional broth at 3.5 g/L. In the MICP process, the cementation solution acts as the catalyst for biomineralization, a natural phenomenon wherein microorganisms induce the precipitation of calcium carbonate, effectively cementing particles together. Central to this process are urease-active bacteria, which play a pivotal role in initiating and facilitating bio cementation.

**Slope model**

At the core of the model lies the acrylic container, meticulously crafted to dimensions of 300 x 200 x 100 mm. The primary component of the model is the 88 mm thick layer of compacted clay, meticulously compacted to a density of 1.7 g/cm³. Beneath the soil layer rests a 12 mm thick bed of sand, meticulously chosen to serve as a drainage medium. This container serves as the foundational structure for creating a miniature representation of a soil slope. The soil slope model described offers a comprehensive platform for investigating soil behavior under controlled conditions.

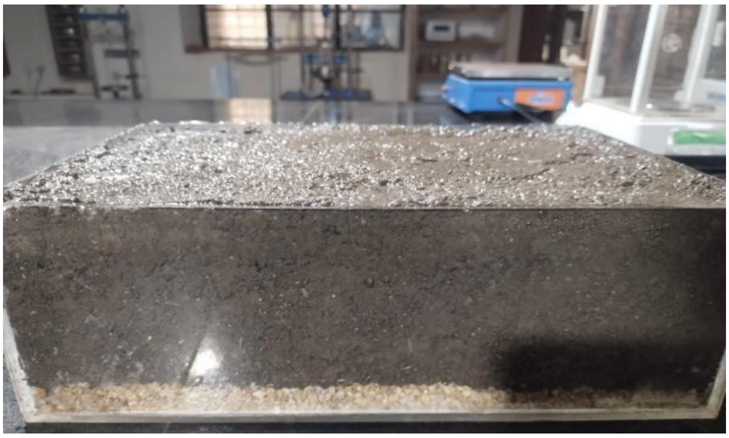


**Fig. 4.3 Soil mould**

The flowchart depicted in Figure 4.4 delineates a meticulously designed sample treatment and testing procedure tailored to emulate the intricate processes of natural weathering, specifically focusing on the cyclical patterns of rainfall and drought. The methodology commences with subjecting all soil samples to a series of wetting-drying cycles, mimicking the alternating wet and dry phases experienced in nature. Each wetting cycle involves the precise application of 100 mL of water onto the soil sample, followed by exposure to stable room conditions (maintained at 30 ± 2 ◦C) for drying. The drying phase is terminated when the observed weight change remains below 0.2 g for three consecutive measurements. Following the initial wetting-drying phase, samples labeled S0 to S2 undergo a series of five cycles of Microbially Induced Calcium Carbonate Precipitation (MICP) treatment. MICP is a process recognized for its potential to augment soil strength and stability through the formation of calcium carbonate bonds within the soil matrix. Each MICP treatment cycle involves the application of a 100 mL bacterial solution onto the soil surface, followed by the subsequent spraying of a cementing solution after a specified interval of 6 hours. To facilitate a complete MICP reaction, an 18-hour gap is maintained between successive treatment cycles. Subsequently, the treated samples are left to air dry following the completion of the MICP treatment.

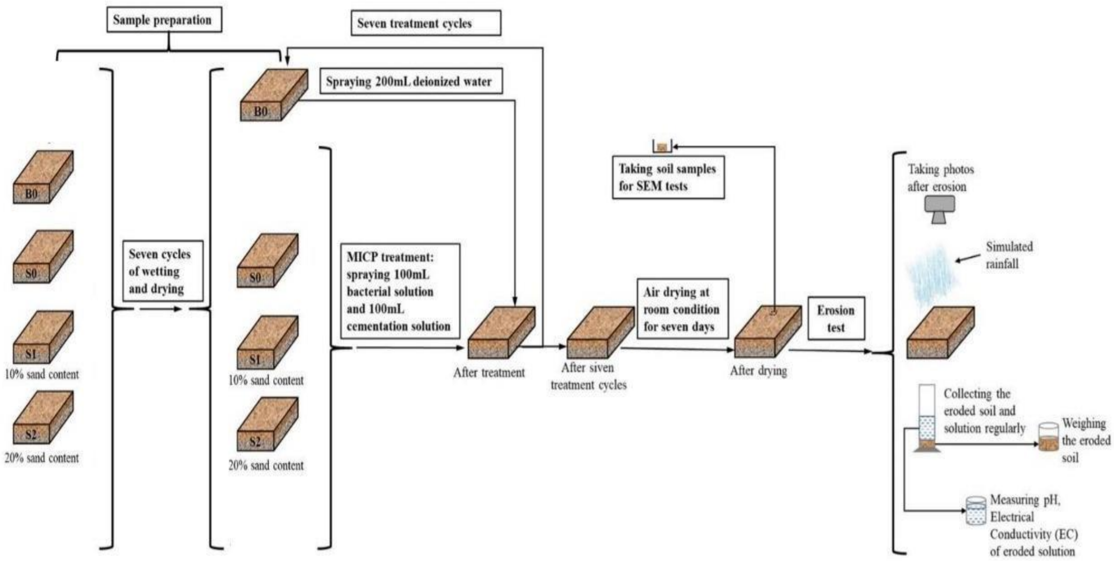



**Fig. 4.4 Schematic representation of the testing procedure**

The simulated rainfall erosion test stands as a cornerstone method in the realm of soil science, offering a robust means to evaluate soil erosion resistance under controlled laboratory conditions. This methodological approach provides researchers with invaluable insights into soil stability and erosion susceptibility by replicating the erosive forces typically encountered in natural environments. At the outset of the test, soil samples are securely mounted in a mould onto a platform tilted at a precise 45° angle. This angle mirrors sloping terrain by situating the sample on a tilted platform, researchers ensure uniform exposure of the entire surface to the simulated rainfall, thereby fostering consistent testing conditions essential for accurate evaluation. The generation of artificial rainfall is achieved by positioning a sprayer approximately

30 cm above the soil sample. To emulate extreme rainfall events, a high intensity of 45 mm/h is maintained throughout the test. Throughout the rainfall simulation, eroded soil particles and surface runoff are meticulously collected in a replaceable vessel positioned beneath the sample. Additionally, measurements of pH and electrical conductivity may be conducted to evaluate any alterations in soil properties induced by erosion.

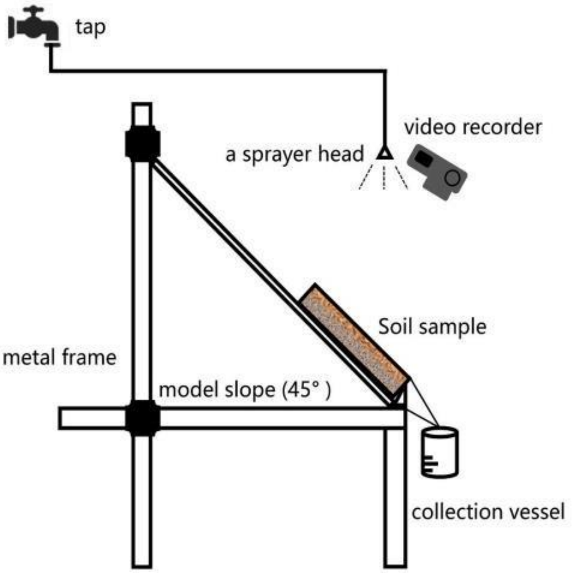
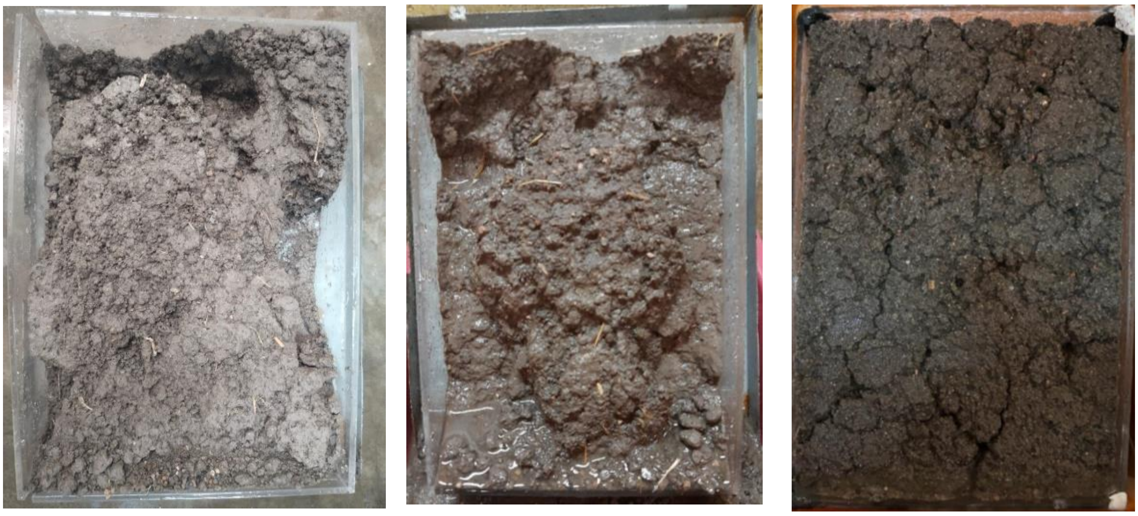



**Fig. 4.5 Schematic view of slope model and rainfall simulation devic**

**Fig 4.6 Rainfall simulation (slope subjected to rainfall intensity of 45 mm/hr)**

## Results and Conclusions

All the samples, treated and untreated, are subjected to a simulated rainfall erosion test. Correspondingly the pH, electrical conductivity, and erosion rate of the outflow solutions were measured. Deep gully erosion, the severe erosion type, can be observed in sample B0, while samples treated with both bacterial strains, S0–S2 exhibit strong erosion resistance.



(a) (b) (c)

**Fig. 5.1 Samples after subjecting to simulated rainfall (a) B0 (b) S0 (c) S2**

For sample B0, the eroded soil mass after 10 min was around 49.37 g, and the peak erosion rate was 12 g/min, while for sample S0 only treated with S.pasteuri, the eroded soil mass was only 7.25 g, and the peak erosion rate was 2.1 g/min and the sample treated with B.subtilis it was around 14.2 g with a peak erosion rate of 7.3 g/min. The pH and EC values of the water used in the rain erosion test are 7.59 and 0.65 ms/cm, respectively. For treated soil samples (S0–S2) with S.pasteuri, the pH values of the effluent solution are generally lower than the pH of water and increase rapidly as the erosion time increases during the first 5 min. This low pH can be attributed to the redissolution of residual salts ($CaCl_2$ and $NH_4Cl$) from the MICP process on the sample surface. In the case of soil treated with B.subtilis, the pH value increased. This can be attributed to the fact that when Bacillus subtilis spores germinate, the core releases Na+ and K+ ions. These ions react with $Cl^-$ present in the residual salts, due to which pH is increased. With the increase in the time of erosion at the beginning of the test, the EC of the solution in sample S0 decreased significantly from a rather high value (78 ms/cm, treated with S.pasteuri; 55 ms/cm, treated with B.subtilis) while mixed sand-clay samples

(S1 ~ S2) generally exhibited EC values much lower (<19ms/cm) in both treated samples. After 3 min, the EC of outflow solution in all MICP-treated samples reduces gradually until approaching the EC of water. To study the microstructure of the samples, SEM images of B0, S0, and S2 were considered. These images show a significant reduction in the pore size of the surface soil after applying the MICP treatment, the subsurface soil layer was also cemented by CaCO3 precipitation as for the soil mixture samples clay-sand (S1 ~ S2).

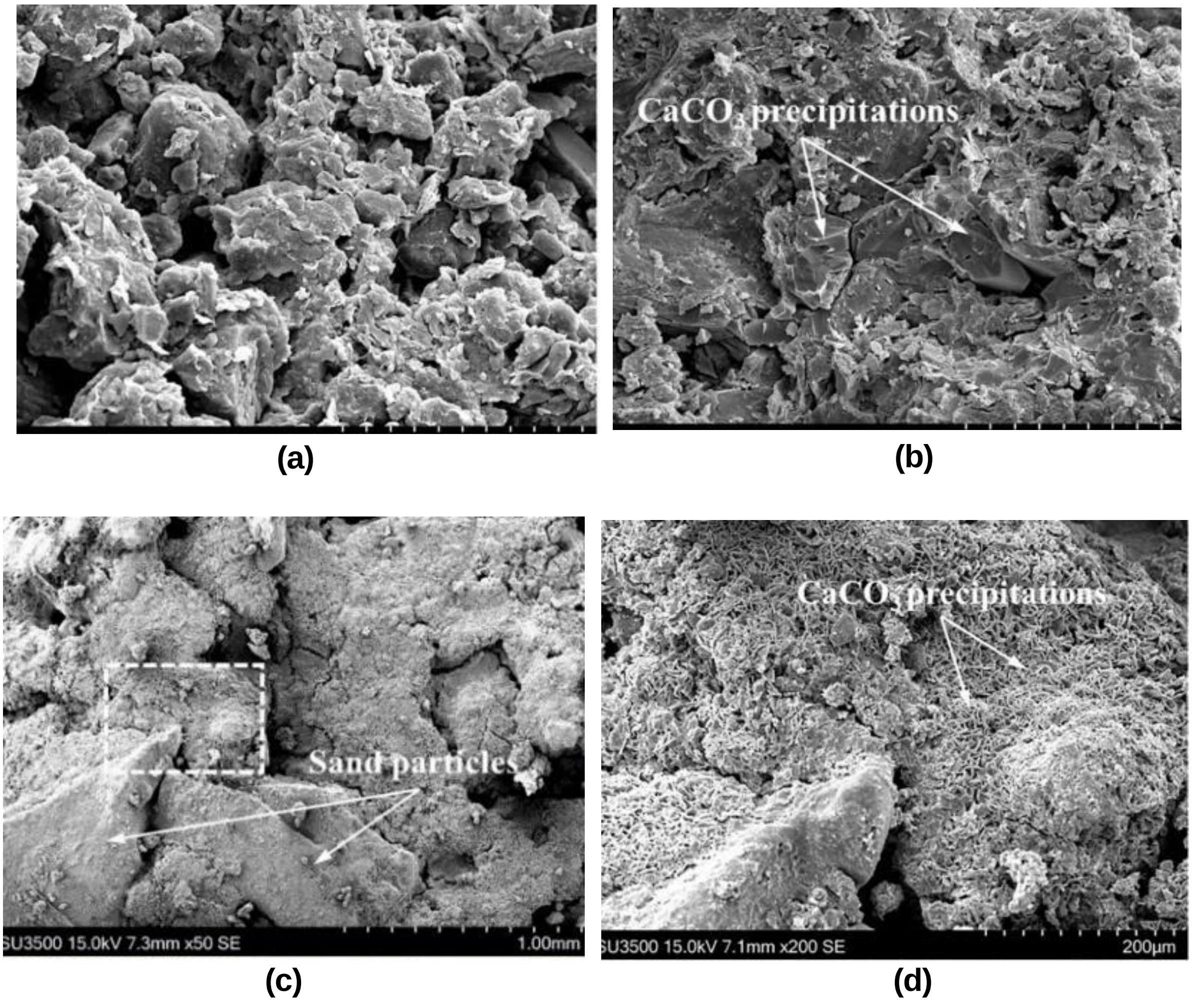



**Fig. 5.2 SEM images of samples treated with S.pasteuri (a) B0 (b) S0 (c) S2 (d) Enlarged image of (c)**

The study introduced a new strategy to mitigate erosion-induced landslides of clayey soil through the MICP technique. The performance of different bacterial strains in mitigating the landslide was examined. Model test results showed that the efficiency of MICP treatment is affected by the influence of sand particles.

The following conclusions are drawn based on the results obtained:

1. The bonding effect of calcium carbonate precipitation between soil particles and the filling effect in pores are responsible for the mitigation mechanism. As a result, a double-layer structure made up of an upper hard crust layer on the soil surface and a lower weak cemented layer is formed.
2. The efficacy of MICP in controlling shallow landslides is due to the surface crust and cemented - CaCO3 precipitate at the top layers. With the exceptional water stability of the CaCO3 precipitation, the crust exhibited a hydrophobic nature, increasing shear strength and reducing the rainwater from penetrating into deeper soil layers, which decreased the chance of sliding of soil mass.
3. The effectiveness of MICP treatment for controlling erosion-induced slope failure in clayey soil is generally improved by an increase in sand content. Sand played a major role in the formation of a stable soil structure, and with more sand contents, the treatment depth of MICP improved due to the increased soil permeability.
4. The performance of S.pasteuri treated soil was much better than soil treated with B.subtillis. The urease activity of S.pasteurii was much higher than B.subtillis. The amount of CaCO3 precipitated in the soil matrix is more in the case of S.pasteurii.

The ecotechnological and sustainable approach utilizing bacterial strains presents a promising solution to mitigate erosion-induced shallow landslides. The application of these strains, harness the natural processes of soil stabilization and reinforcement, offering a cost- effective and environmentally friendly alternative to traditional methods. This approach addresses the immediate threat of erosion-induced landslides, but it also promotes ecosystem health and resilience in the long term. By integrating scientific advancements with ecological principles, fosters a deeper appreciation and stewardship of the natural environment.

## Innovation in the project

**Biogrout Technology** and **Sustainable Practices** utilize specific strains of bacteria to enhance soil slope stability thereby minimizing the risks of landslides. Further, this bio- stabilization technique enhances soil cohesion, reducing erosion susceptibility on slopes and effectively cements soil particles together, stabilizing the slope.

**Future scope**

- Long-term performance of specific bacterial type in enhancing slope stability.
- Large-scale study on the application of bacterial strain to mitigate erosion-induced landslide.
- Microbial Consortia and Synergistic Interactions which produce extracellular polymeric substances or carbonate precipitation that bind soil particles together, secrete biopolymers that enhance soil aggregation or facilitate the formation of protective biofilms on soil surfaces.
- Development of genetically modified bacteria tailored to specific soil types, climatic conditions, and erosion control objectives.