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Floating Microbial Mass for Reservoir Evaporation Control and its Effect on Soil Mineralogy

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ABSTRACT

Background: The combined application of microbiology, biotechnology and hydrology has the potential to address a multitude of issues related to water contamination, water conservation and waste management. This research aims to contribute to water conservation efforts through ecological and environmental preservation. In Gujarat, India, there are numerous large reservoirs (water bodies) where millions of liters of water are lost due to higher temperature and evaporation. To mitigate this loss, it is crucial to identify, process and apply natural microbes found in these water bodies in a way that maximizes reduction in evaporation.

Methods: To achieve our objective, we developed a laboratory-scale experimental setup (Class A pan evaporimeter) to measure evaporation rates under varying humidity and temperature conditions. We used the serial dilution and spread plate methods to isolate microorganisms from water and soil samples and then grew selected microorganisms (*Bacillus megaterium*, *Bacillus subtilis*) in slants to minimize water loss. These isolated floating microbes were then placed in the Class A pan evaporimeter and the evaporation loss was periodically measured under different temperature and humidity levels. We also evaluated the sustainability of these floating microbes and their ability to improve water retention capacity before and after treatment. Additionally, we used X-ray diffraction to assess the effect of these microbes on the mineral composition of the reservoir bed.

Result: A recent study revealed that the use of floating microbes can effectively reduce evaporation loss by up to 30-40% overall. Additionally, this method can help maintain the quality of water, sediment composition and the overall ecological balance for aquatic animals.

Key words: Class a pan evaporimeter, Determination mineralogical properties of soil, Evaporation rate, Formation of floating microbial biofilm, Hydrological cycle, Mineralogy of soil.

INTRODUCTION

The need for efficient water storage solutions, particularly during rainy seasons, highlights the urgency to address evaporative losses from reservoirs. Research has explored various methods, including self-assembling floating elements (Assouline *et al*., 2010, 2011; Cooley, 1983), plastic covers (Gallego-Elvira *et al*., 2011), windbreaks (Hipsey and Sivapalan, 2003) and surfactant monolayers (Barnes, 2008), especially in arid regions facing persistent water scarcity. Several meteorological variables influence the rate of evaporation, including the heat of both the water and air, the difference in vapor pressure between the water and air, the velocity of the wind and the intensity of solar radiation. Few researches focuses on reducing water availability especially for crops yielding by use of certain organic and inorganic manures (Venkatakrishnan *et al*., 2021), while Rajanna *et al*. (2018) found that bed planting (FIRBS) improved soil moisture use efficiency and reduced consumptive water use by 9-12%. Similarly, Singhal *et al*. (2022) showed how controlled soil moisture levels positively affected pea yield and enhanced soil microbial counts. Kumar Ramesh *et al*. (2025) discussed on scarcity of fresh water resources and doing optimization of crop-water productivity. Different researchers have alternate perspectives on either economizing water mobility or using microbes in reducing moisture mobility, but no one focuses on reducing water evaporation even from plants/crops/roots using soil microbes.

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Accurate measurements of evaporation are crucial for water and energy balance studies, climate change impact assessments (Tarawneh *et al*., 2018) and effective management decisions, particularly in arid regions. However, the rate of evaporation tends to be faster during drought years according to drought years (Wurbs and Ayala, 2014).

There are various mechanical, chemical, biological and physical methods available to reduce water loss from reservoirs due to evaporation. These strategies can be combined to effectively manage evaporation, especially in conditions with warmer air, strong winds and low humidity (Oribi *et al*. 2020).

Millions of reservoirs larger than 100 m^2 are used globally for urban and agricultural purposes, but evaporation loss significantly impacts their effectiveness. In two regions with seven key dams, the average daily evaporation rate is around 10% of the total water stored. South Gujarat has the highest water level in 13 reservoirs at 82.60%, while Central Gujarat has the highest water level in 17 reservoirs at 82.14%. Approximately 573 cusecs of water evaporate daily from the reservoir managed by SSNNL. The Sardar Sarovar, seen as vital to the state, currently holds water at 78.45% of its capacity and 30% of the water in the Ukai Dam evaporates. Evaporation occurswhen water at the surface changes from a liquid to a gas below its boiling point, driven by heat and wind energy.

Mineralization process through microorganisms

This process is influenced by factors such as temperature, humidity, wind speed and the surface area of the water body. In addition to its role in the water cycle, evaporation also plays a crucial role in mineralization processes. For example, comparing three bacteria taken from a Narmada sand sample,Sporosarcina pasteurii, Bacillus subtilis and Bacillus sphaericus, can be used for bioaugmentation and calcite formation. *Sporosarcina pasteurii* (ATCC 11859) produces the urease enzyme needed for calcite precipitation, *Bacillus subtilis* (ATCC NCIB 8533) is a gram-positive, catalase-positive, rod-shaped, spore-forming bacterium and *Bacillus sphaericus* (ATCC 14577) is a non-pathogenic, mesophilic, gram-positive, rod-shaped bacterium typically found in soil. Bacillus sphaericus is commonly found in soil, as stated by Berry (2012). The study aims to evaluate the potential applications of theses bacteria in environmental remediation and bio minerali zation processes. Microorganisms play a crucial role in mineralization processes by consuming water ingredients, converting them and excreting waste. For example, Bacillus megaterium, a mineralization-friendly bacterium, forms a biofilm on reservoir beds, metabolizing organic substances and releasing by-products such as carbon dioxide and organic acids, promoting mineralization.

MATERIALS AND METHODS

Develop a scale model of class A pan evaporimeter

The method used was the Class A pan evaporimeter, following the standards set by IS 5973:1998. The apparatus was a cylindrical container made of non-magnetic stainless steel, with dimensions of 305 mm in diameter and 63.8 mm in depth. It was placed in the ground with the rim positioned 20 mm above ground level. To ensure proper air circulation, the pan was placed on a wooden platform elevated 15 cm above ground level. Please refer to Fig 1 for a visual representation of the Class A pan evaporimeter model.

Biofilm formation from water and soil samples

*Bacillus megaterium*is capable of forming a biofilm on the surface of water, acting as a physical barrier and reducing evaporation rates. This biofilm is beneficial in retaining moisture and reducing evaporation, particularly in high temperatures and low humidity. Additionally, the biofilm aids in retaining nutrients and resources in the water. Fig 2 displays the biofilm formed from a Narmada water sample.

To create the nutrient broth, 5 grams of peptone, 2.5 grams of beef extract and 2.5 grams of sodium chloride, were dissolved in 500 ml of distilled water in a suitable container. The mixture was thoroughly stirred until all ingredients were completely dissolved. The pH of the solution was then adjusted to approximately 7.0 using a pH meter or pH indicator strips. Next, the nutrient broth was sterilized by autoclaving at 121°C (250°F) for 15 minutes, effectively eliminating any existing microorganisms and making the broth suitable for bacterial growth. Bacillus megaterium was then inoculated into the broth for culture. The culture was incubated at 30°C for 72 hours, allowing for significant growth and proliferation of Bacillus megateriu-mcells in the nutrient broth. After the incubation period, the bacterial culture was mixed with water and carefully transferred to the pan evaporimeter.

Experimental setup

In this research study, two pan evaporimeters were used to compare and observe the evaporation rate of samples in the same category. The first pan was filled with tap water, while the second pan contained tap water mixed with a 500 ml bacterial solution. During the observation period, a floating microbial mass developed on the surface of the

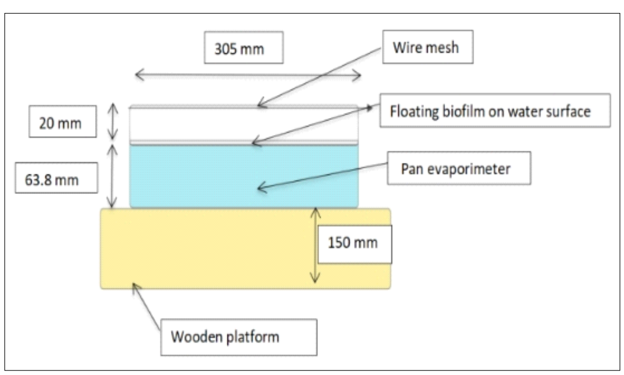

Fig 1: Scale model of class A pan evaporimeter (IS code 5973:1998).

water in the second pan. This phenomenon was monitored alongside the evaporation rates, which were measured by tracking the water level drop over time. Temperature was measured using a thermometer, humidity was measured with a digital hygrometer (HTC-2) and wind speed was measured with a digital anemometer (GM-816). Fig 3 shows the experimental setup for measuring evaporation rate in a class A pan evaporimeter and the required apparatus. Fig 4 depicts the preparation of PVC moulds of diameter 100 mm and length 100 mm for preparation of Narmada soil sample using bacterial solution. The developed microorganisms were to float on the water's surface and the evaporation was measured over 5 and 10 days. The pan coefficient, based on IS Code 6939:1992, was found to be 0.70.

$$V_E = A . E_{pm} . C_p$$

Where,

V_E= Volume of water loss in reservoir.

A = Average reservoir area.

E_{pm} = Pan evaporation.

C_p = Pan coefficient.

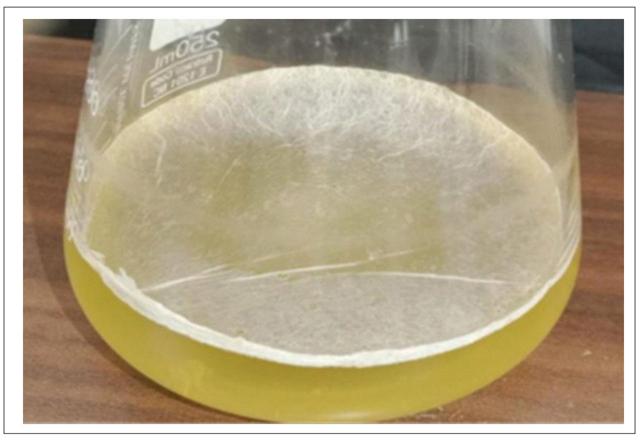

Fig 2: Biofilm Formed through Narmada water sample.

Dehydration method

To study soil mineralogy, dehydration method was used to identify specific mineral present in the soil mass so as to get the effect of infused microbes on reservoir bed soil curve can provide valuable insights into the behavior of minerals present in the soil. In this process, a soil sample is heated in the muffle furnace to a high temperature (around 550°C) to burn off organic matter. A dehydration curve typically represents the relationship between the moisture content of a soil sample and the temperature at which dehydration occurs. X-ray diffraction method is used to identify mineral composition and substitute changes through post treatment.

RESULTS AND DISCUSSION

The study investigates the impact of floating microbial mass on soil mineralogical properties and water evaporation rates. It isolates specific microorganisms from water and soil samples, cultured to reduce water loss and alter soil mineralogy. Results show that increasing microbial mass, particularly Bacillus species, can reduce water evaporation loss. The study explores microbial impacts on water quality and sediment composition in reservoirs. Different tests are done to check water quality, *viz*. temperature, pH level and the amount of suspended, dissolved and total solids in it.

Table 1 shows the recorded water temperature during sample collection to be 30°C. The temperature of Tapi water, Dosvada water and Sant Sarovar water were also measured at 30°C between 11 am and 2 pm, while the temperature of Narmada water was slightly lower at 28!. All water samples tested using pH paper had a pH of 7, indicating neutrality. This is important for maintaining a healthy aquatic ecosystem in freshwater reservoirs. The TDS value of Sant Sarovar water was found to be 317 mg/L, which is considered high. Generally, TDS levels should be below 500 mg/L for good drinking water quality. In comparison, Tapi water had a lower TDS value, making it suitable for

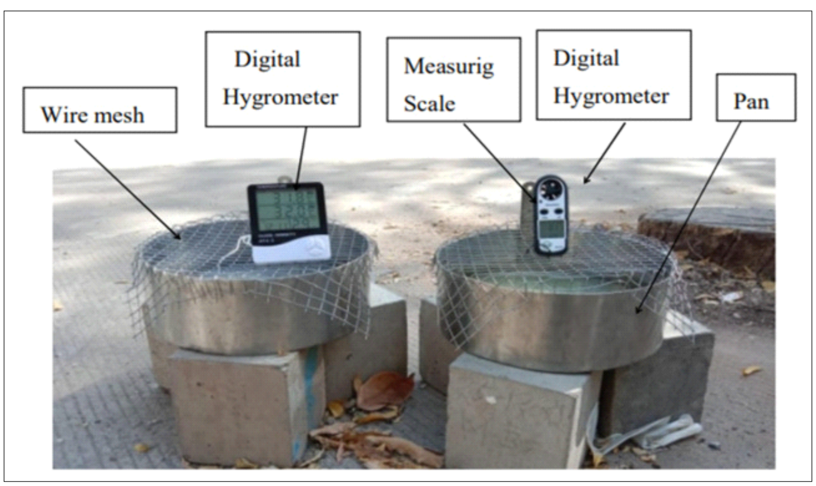

Fig 3: Evaporation rate measured in class A pan evaporimeter.

drinking. Lower concentration of dissolved substances, leading to a better taste and clearer appearance compared to water with higher TDS levels.

Table 2 represents the 10 days Evaporation data of Class A pan evaporimeter with *Bacillus megaterium*. Measurements were conducted daily within the time slot from 1 pm to 2 pm. Water temperature (Tw) ranges from 27.7°C to 32°C, with an average of 29.95°C cover the 10 days period. Air temperature (Ta) ranges from 31.0°C to 35.8°C, with an average of 33.9°C. Wind speed (W) fluctuates between 0.7 m/s and 4.17 m/s, averaging at 1.93 m/s. Wind speed influences the rate of evaporation, with higher wind speeds enhancing evaporation by removing saturated air above the water surface. Humidity (H) ranges from 27% to 31%, with an average of 29.3%. Humidity plays a role in evaporation, with lower humidity levels facilitating higher evaporation rates due to the reduced concentration of water vapor in the air. Evaporation loss with biofilm pan evaporimeter (EB) ranges from 2 mm to 5 mm, with a total of 32.7 mm over the 10 days. Evaporation loss without biofilm evaporimeter (EWB) ranges from 4 mm to 7 mm, totaling 55.6 mm over the same period. The maximum evaporation loss with the biofilm pan evaporimeter (EB) over the 10-day period is 5 mm,while without the biofilm pan evaporimeter (EB), the maximum evaporation loss reached 7 mm.

Table 3 represents the 10 days Evaporation data of Class A pan evaporimeter with *Bacillus subtilis*. Measurements were conducted daily within the time slot from 1 pm to 2 pm. Water temperature (Tw) ranges from 31.1°C to 32.7°C, with an average of 32.05°C cover the 10 day period. Air temperature (Ta) ranges from 37.6°C to 41.7°C, with an average of 40.4°C. Wind speed (W) fluctuates between 0.1 m/s and 0.6 m/s, averaging at 0.29 m/s. Wind speed influences the rate of evaporation, with higher wind speeds enhancing evaporation by removing saturated air above the water surface. Humidity (H) ranges from 28% to 29%, with an average of 28.5%. Humidity plays a role in

Table 1: Water quality tests.

Water sample	Temperature of water	PH	TSS (mg/l)	TDS (mg/l)	TS (mg/l)
Tapi water sample	30	7	80	160	240
Narmada water sample	28	7	23.8	209.3	233.1
Sant sarovar	30	7	26.78	317	343.78
Dosvada dam	30	7	40	273.4	313.4

Table 2: Evaporation data of class a pan evaporimeter with *Bacillus megaterium*.

Time (days)	T_w(°C)	T_a(°C)	W (m/s)	H (%)	E_B(mm)	E_{WB}(mm)
06/03/2024	27.7	31	4.17	31	3	7
07/03/2024	28.3	31.8	3.61	31	2	4
08/03/2024	28.5	32.4	2.53	30	2.5	4.5
09/03/2024	29	33.4	2.22	29	3	5
10/03/2024	29.7	34.3	1.61	30	4	6
11/03/2024	30.5	35	1.11	30	5	7
12/03/2024	30.8	35.1	1.42	29	3	5
13/03/2024	31.2	35.4	1.1	28	2.7	4
14/03/2024	31.8	35.7	0.7	28	3	6
15/03/2024	32	35.8	0.8	27	4.5	6.9
Total= 10 days	29.95	33.9	1.93	29.3	32.7	55.6

Table 3: Evaporation data of class a pan evaporimeter with *Bacillus subtilis*.

Time (days)	T_w(°C)	T_a(°C)	W(m/s)	H(%)	E_B(mm)	E_{WB}(mm)
16/03/2024	32.7	37.6	0.3	28	5	7
17/03/2024	31.8	39.6	0.2	29	3.5	5
18/03/2024	31.1	40.5	0.1	29	2	4
19/03/2024	31.9	40.5	0.2	29	3	4.5
20/03/2024	32.0	41.1	0.1	29	5	6
21/03/2024	31.4	39.2	0.4	28	3	5
22/03/2024	32.1	41.0	0.3	28	4	6.5
23/03/2024	32.5	41.7	0.6	29	3	5
24/03/2024	32.3	41.2	0.5	28	4	6
25/03/2024	32.7	41.6	0.2	28	6	7
Total=10 days	32.05	40.4	0.29	28.5	38.5	56

evaporation, with lower humidity levels facilitating higher evaporation rates due to the reduced concentration of water vapor in the air. Evaporation loss with biofilm pan evaporimeter (EB) ranges from 2 mm to 6 mm, with a total of 38.5 mm over the 10 days. Evaporation loss without biofilm evaporimeter (EWB) ranges from 4 mm to 7 mm, totaling 56.0 mm over the same period. The maximum evaporation loss with the biofilm pan evaporimeter (EB) is 6 mm, whereas without the biofilm pan evaporimeter (EB), it reaches 7 mm.

Comparison of 10 days results pre and post treatment of reservoir water for per square km area

Table 4 represents the reservoir area of Narmada river, Tapi river, Doswada dam and Sant sarovar dam are 88000 km^2, 62255 km^2, 1.33 km^2 and 4.4 km^2, respectively. But in our study we have assumed the reservoir area to be 100 km^2 for which we got the volume of evaporation loss; with and without biofilm for the four reservoirs based on the pan evaporation of each reservoir. With biofilm out of all the four reservoirs' water sample, onlyin Narmada and Tapi reservoirs water, significant amount of reduction in evaporation loss has been observed whereas in Doswada dam and Sant Sarovar dam water, less reduction in evaporation was noted.

Table 5 represents the Comparison of Evaporation loss rate with floating biofilm of *Bacillus megaterium* and floating biofilm of *Bacillus subtilis.* Evaporation of biofilm water reduces with respect to microbially untreated reservoirs. The Evaporation rate of floating biofilm of *Bacillus megaterium* on the water surface of NR, TR, SR and DR is 2371.6*l*, 1677.77*l*, 0.1 *l* and 0.0304 *l* respectively for the period of 10 days. Evaporation loss with floating biofilm of *Bacillus subtilis*on the water surface of NR, TR, SR and DR is 2014.32*l*, 1425.01*l*, 0.118*l* and 0.035*l* respectively for the period of 10 days.

Table 4: Comparison of evaporation data without biofilm and with biofilm for 10 days.

Name of River/ Reservoir	Reservoir area (km^2)	Volume of water (L)	Average pan evaporation without biofilm	Average pan evaporation with biofilm	Assume area as 100 km^2 for all	Evaporation rate for 100 km^2 area with-out biofilm (L)	Evaporation rate with biofilm (L)
Narmada river	88000	9500000 million	55.6 mm	32.7 mm (with biofilm of BM)	100	3892	2289
Tapi river	62255	6730000 million	56 mm	38.5 mm (with biofilm of BS)	100	3920	2695
Doswada dam	1.33	6083560 million	55.6 mm	50 mm(negligible change)	100	3.85	2.24
Sant sarovar	4.4	10060 million	55.6 mm	52 mm(negligible change)	100	3892	2283.3

Table 5: Comparison of Evaporation loss rate with floating biofilm of *Bacillus megaterium* and floating biofilm of *Bacillus subtilis.*

Name of river/ reservoir	Duration	Evaporation loss rate with floating biofilm of BM (L)	Evaporation loss rate with floating biofilm of BS (L)
Narmada river	10 days	2371.6	2014.32
Tapi river	10 days	1677.77	1425.01
Daswada dam	10 days	0.1	0.118
Sant sarovar	10 days	0.0304	0.035

Fig 4: Preparation of mould: (1) Narmada soil sample with bacterial solution.

Dehydration method

Fig 5 and Fig 6 illustrates the variability in water loss among different types of soils when subjected to a maximum temperature of 800°C. Some soils may exhibit higher rates of water loss compared to others, indicating differences in their heat resistance and water retention capacities. Comparison with standard dehydration graphs (Clay mineralogy) reveals the presence of the minerals Hallosite (Leige, Belgium) and Hallosite (Adam Conty, Ohio), respectively.

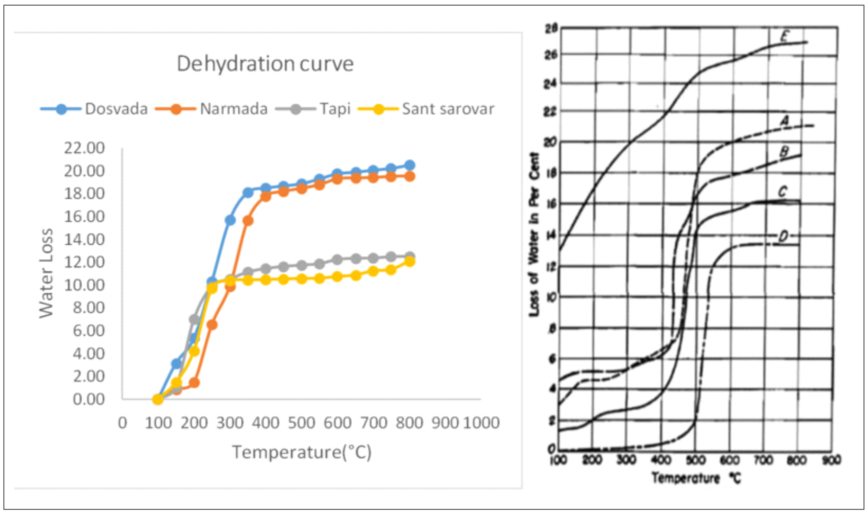

Fig 5: Comparison of dehydration curve of different types of soil w.r.t standard dehydration curve (Clay mineralogy pg no.193).

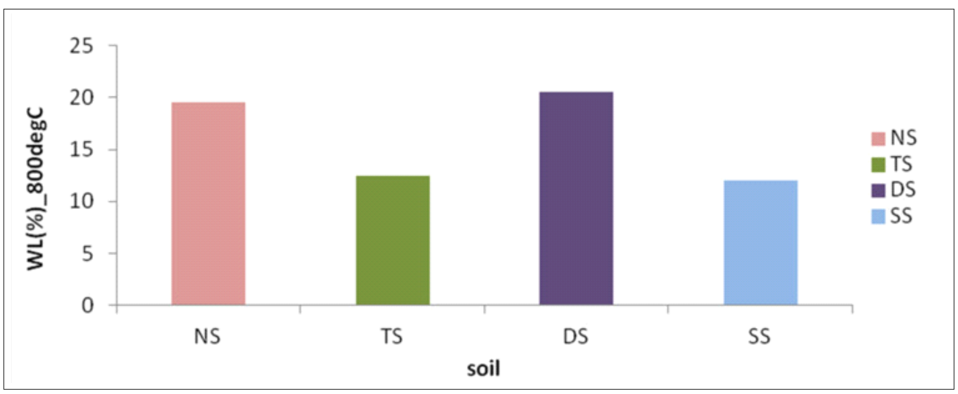

Fig 6: Comparison of water loss at a max temperature 800°C at different type of soil.

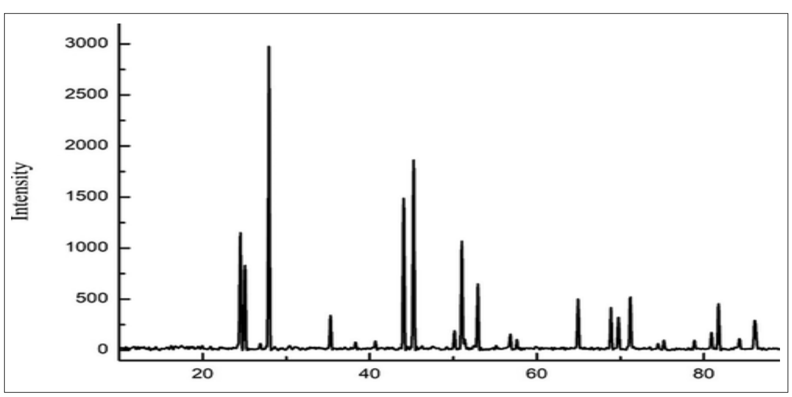

Fig 7: XRD on natural Narmada soil.

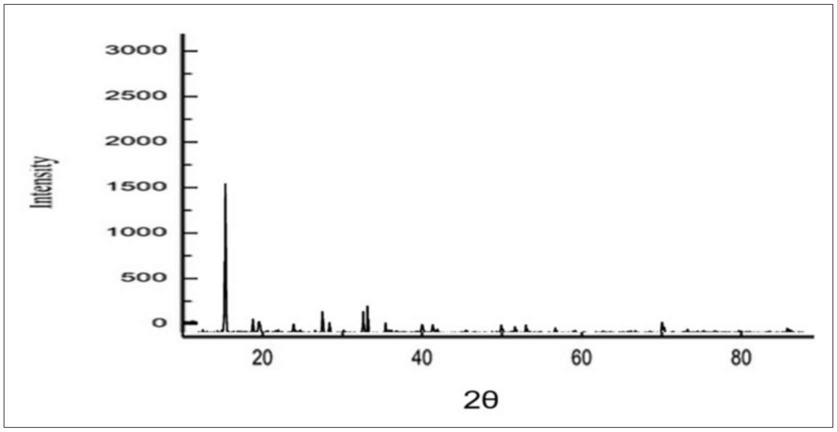

Fig 8: XRD on biological treated soil after 14 days curing period.

X-ray diffraction method

Fig 7 illustrates the X-ray diffraction (XRD) analysis conducted on untreated Narmada soil samples, revealing the presence of quartz crystals. Figure 8 displays the XRD results from Narmada soil samples treated with isolated bacteria for 15 days, showing an increase in quartz content. This increase indicates that treatment with Narmada-isolated bacteria led to a notable enhancement in quartz crystals within the soil; the soil fraction shows a particular increase.

CONCLUSION

This study assessed water and soil samples from Gujarat reservoirs, examining biological and mineralogical parameters for evaporation control. Two non-pathogenic, gram-positive bacteria-Bacillus megaterium and Bacillus subtilis-were analyzed for biofilm-mediated evaporation suppression. Bacillus megaterium, forming longer chains and denser biofilms, achieved a 40.18% evaporation reduction over 10 days, outperforming Bacillus subtilis (30.70%) due to its lower biofilm density. Water quality analysis confirmed Total Dissolved Solids (TDS) levels within acceptable (500 mg/L) and permissible (2000 mg/L) standards. Mineralogical evaluation through dehydration curves identified halloysite in Tapi, Narmada, and Dosvada soils (20-22% water loss) and kaolinite in Sant Sarovar soil (12-14% water loss). XRD analysis indicated increased quartz content in bacteria-treated Narmada soil, confirming microbial-induced mineralogical modification. Overall, Bacillus megaterium demonstrated higher evaporation control potential through superior biofilm formation. The results highlight the feasibility of using microbial floating biofilms for reservoir evaporation reduction and soil mineral modification as sustainable water conservation strategies in arid regions.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions.

Informed consent

Not applicable.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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