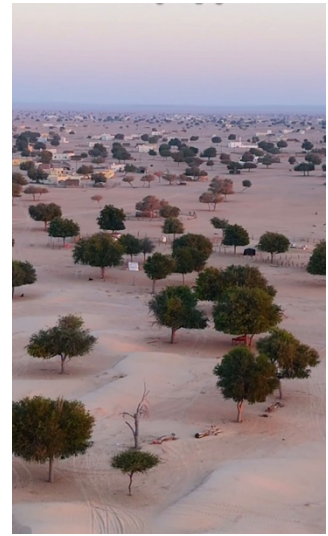




Sultanate of Oman
The General Directorate of Education in Al Wusta Governorate
Haj Basic Education School (Grades 5–12)

The Impact of Climate Change
(Humidity and Rainfall) and Sulfuric Soil Properties
on the Growth of the Ghaf Tree Over the Past Twenty Years



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1. Abstract

The findings indicate that climate change may exert **positive effects on the growth of the Ghaf tree** under specific environmental conditions. Increased relative humidity in Wilayat Mahout contributes to improving the efficiency of the photosynthetic process by reducing transpiration rates, thereby allowing stomata to remain open for longer periods and enhancing carbon dioxide uptake. This, in turn, positively affects nutrient absorption efficiency and prolongs the vegetative growth season.

Furthermore, higher rainfall rates during certain seasons promote deeper and denser root system development and contribute to increased plant biomass by supporting rapid vegetative growth. In addition, adequate moisture availability enhances the efficiency of biological nitrogen fixation through the stimulation of symbiotic *Rhizobium* bacteria associated with the roots, while also increasing germination rates and improving seedling survival during the early stages of growth.

With regard to sulfur-rich soils, the presence of sulfur as an essential nutrient involved in protein and enzyme synthesis can support the growth of the Ghaf tree, provided that soil acidity is properly managed and beneficial microbial activity is stimulated. Certain microorganisms play a role in decomposing heavy metals and converting them into more plant-available forms, while chemical reactions within these soils contribute to the release of bound phosphorus, thereby increasing its availability to plants.

Moreover, exposure of the Ghaf tree to harsh environmental conditions stimulates the development of more efficient physiological and adaptive mechanisms. This is supported by field observations of the spatial distribution of Ghaf trees at distances ranging from **100 to 150 meters** from water sources. In this context, a synergistic interaction emerges between increased rainfall and humidity on the one hand, and the characteristics of sulfur-rich soils on the other, leading to enhanced beneficial microbial activity that facilitates the transformation of sulfur compounds into less harmful forms and improves the overall root environment.

Based on these findings, it can be concluded that **positive climate changes**, particularly increased humidity and rainfall, have the potential to significantly enhance the growth of the Ghaf tree, especially when combined with proper management of sulfur-rich soils through pH adjustment and the reduction of harmful salt accumulation, particularly sodium chloride. This positions the Ghaf tree as a highly adaptable plant species capable of utilizing climate variability to achieve higher productivity and support environmental sustainability in arid and semi-arid regions.

2. Introduction and Literature Review

In recent decades, arid and semi-arid regions have experienced accelerated climatic transformations manifested in changes in humidity patterns, rainfall regimes, and rising temperatures. These transformations are often perceived as a direct threat to environmental balance. However, they may also present unexpected opportunities for certain plant species capable of adapting to harsh environmental conditions and capitalizing on climatic shifts to their advantage.

The Ghaf tree (*Prosopis cineraria*) is among the most prominent plant species adapted to dry environments, as it possesses exceptional physiological and adaptive capacities that enable it to survive and grow under conditions of water scarcity, high salinity, and low soil fertility. The Ghaf tree plays a pivotal role in combating desertification, stabilizing sand dunes, and improving soil properties, in addition to providing shade and food resources for wildlife and livestock. Accordingly, it is regarded as a key component of environmental sustainability strategies and natural resource management in arid and semi-arid regions.

Recent climate models indicate that some of these regions may experience noticeable changes in humidity patterns and rainfall amounts, although such changes are often characterized by temporal and spatial variability and irregularity. Despite this variability, seasonal increases in humidity and rainfall may create windows of opportunity to enhance the growth of plant species capable of benefiting from these conditions, particularly the Ghaf tree and other drought-resistant native trees, through improved vegetative growth efficiency and enhanced root system development.

Conversely, sulfur-rich soils, which are widespread in coastal areas and some reclaimed lands, represent a well-recognized environmental challenge due to their chemical properties, which may increase soil acidity and limit the availability of certain essential nutrients for plants. Nevertheless, several studies suggest that when these soils are managed using sound scientific practices, they can be transformed from an environmental constraint into a supportive resource for plant growth, especially for well-adapted species such as the Ghaf tree.

The challenges associated with utilizing these environments are not limited to natural factors alone but also extend to deeply rooted social and cultural dimensions, particularly with respect to natural water springs distributed across the region. In some local communities, popular beliefs prevail that regard these springs as sacred sites with spiritual and healing properties, where the water is believed to possess special blessings and curative powers. As a result, such sites are viewed primarily as places for visitation and spiritual practices rather than as natural resources suitable for sustainable agricultural investment.

This issue is further compounded by beliefs associated with the vegetation growing around these springs, as some local residents believe that these plants are inhabited by spirits or protected by unseen forces. Such perceptions generate fear and strong resistance to any form of human intervention or agricultural activity in the surrounding areas. Consequently, local populations tend to avoid approaching or utilizing these plants and often reject agricultural or developmental projects, even when such initiatives aim to improve living conditions or enhance food security.

This cultural perception constitutes a major barrier to the implementation of modern agricultural practices and the sustainable utilization of water-rich and fertile sites for cultivating environmentally and economically valuable plant species such as the Ghaf tree and other drought-resistant trees. Moreover, these beliefs contribute to the neglect of proper environmental management of these sites, as cleaning or maintenance activities are avoided out of concern for disturbing what is perceived as the sanctity of the المكان, which may ultimately lead to gradual environmental degradation or contamination of water sources.

The significance of this study lies in its attempt to reframe the prevailing traditional perception of sulfur springs and climate change from a purely negative perspective to a more balanced and comprehensive one that explores the potential positive aspects inherent in these environments. While most previous studies have focused on the adverse impacts of climate change, there is a pressing need for a deeper understanding of how the Ghaf tree, owing to its unique adaptive characteristics, can benefit from potential increases in humidity and rainfall, and how the properties of sulfur-rich soils can be transformed from limiting factors into growth-supporting opportunities through proper environmental management. Such understanding is essential for the development of sustainable agricultural strategies that contribute to enhancing food and environmental security in arid and semi-arid regions.

3. Research Questions

1. To what extent have changes in relative humidity levels affected photosynthetic efficiency and transpiration rates in the Ghaf tree over the past twenty years?
 2. How do different rainfall patterns—in terms of amount, temporal distribution, and intensity—influence growth indicators of the Ghaf tree, such as vegetative growth, root system development, biomass accumulation, and seedling survival rates?
 3. What are the direct and indirect effects of sulfur-rich soil properties—including soil pH, salinity, and nutrient availability—on nutrient uptake and the growth performance of the Ghaf tree?
 4. Is there a synergistic or antagonistic interaction between climatic factors (relative humidity and rainfall) and sulfur-rich soil characteristics in shaping the physiological and developmental responses of the Ghaf tree?
-
1. **What are the prevailing social beliefs and perceptions** among residents of **Wilayat Mahout (Al Wusta Governorate)** regarding **sulfur springs**, and how might these beliefs influence the **acceptance or resistance** to environmental and agricultural initiatives aimed at sustainably utilizing these sites?

4. Research Objectives

This study aims to analyze the available scientific evidence regarding the potential positive impacts of climate change in the Haj area of Wilayat Mahout, with particular emphasis on changes associated with increased relative humidity and continued rainfall during the autumn season, and to clarify their effects on the growth rates and physiological and developmental indicators of the Ghaf tree. In addition, the study seeks to explore the beneficial aspects of sulfur-rich soil properties when managed using sound scientific practices, as well as to examine the potential integrative interactions between climatic factors (humidity and rainfall) and these soil characteristics in supporting the growth and sustainability of the Ghaf tree.

The study further aims to develop a comprehensive knowledge framework that integrates physiological, environmental, and agricultural data, thereby providing an integrated scientific perspective capable of supporting decision-makers, researchers, and farmers in formulating practical policies and practices that promote the utilization of vast underutilized lands, enhance native vegetation cover, and strengthen environmental sustainability in arid and semi-arid regions.

Moreover, the study seeks to address the prevailing social and cultural challenges related to sulfur springs, particularly the inherited perceptions and beliefs among older generations that have contributed to the neglect of these sites and the underutilization of their natural resources. In this context, the study emphasizes the importance of adopting a balanced approach that combines respect for cultural beliefs and traditional heritage on the one hand, and the enhancement of scientific and environmental awareness on the other. This includes advocating for the engagement of community and religious leaders in an informed dialogue on the importance of sustainable investment in sulfur springs, in a manner that does not conflict with prevailing spiritual values, while clearly communicating the potential environmental and economic benefits that may accrue to the local community in the long term.

5. Research Methodology (Methods)

This study adopted a descriptive–analytical approach supported by fieldwork in order to achieve the research objectives and address the research questions. The methodology was implemented through the following steps:

1. Collection of Theoretical Data (Secondary Sources):

Relevant scientific information related to the research topic was collected from books available in learning resource centers, as well as from scientific studies and research articles published online. This process aimed to establish a comprehensive theoretical framework addressing climate change, sulfur-rich soil characteristics, and the growth of the Ghaf tree.

2. Research Plan Development:

A structured research plan was developed outlining the research problem, objectives, research questions, spatial and temporal boundaries, and the methodological approach adopted for implementation.

3. Preparation of the Timeline:

A detailed timeline was prepared to guide the implementation of the various research phases, beginning with theoretical data collection, followed by fieldwork and data analysis, and concluding with the derivation of results and formulation of recommendations.

4. Fieldwork and Sample Collection:

Fieldwork included the collection of soil samples from selected sites within the study area, along with monitoring plant growth rates at these locations. Soil samples were sent to Duqm Laboratories for the necessary physical and chemical analyses, including soil pH, salinity, and nutrient availability.

5. Field Interviews:

Semi-structured interviews were conducted with relevant stakeholders, including agricultural and environmental specialists and members of the local community. These interviews aimed to collect qualitative data related to environmental conditions, prevailing practices, and social beliefs associated with sulfur springs.

6. Identification of Research Protocols:

Standard scientific protocols were established for conducting field measurements, laboratory analyses, and interviews to ensure data accuracy and reliability.

7. Identification of Research Tools:

The tools required for conducting the research were identified, including sampling equipment, environmental measurement instruments, interview questionnaires, and statistical software used for data analysis.

8. Data Analysis and Graphical Representation:

Quantitative and qualitative data were analyzed using appropriate statistical and descriptive methods. The results were presented graphically in the form of tables and figures to facilitate interpretation and comparison.

9. Derivation of Results and Recommendations:

Based on the analysis outcomes, a set of scientific findings aligned with the research objectives was derived, and practical recommendations were formulated to support the development of sustainable environmental and agricultural practices within the study area.

6. Research Implementation Timeline

The following table outlines the stages of the research implementation, specifying the main tasks, the time frame for each stage, and the individuals or entities responsible:

No.	Task	Time Frame	Student / Supervising Authority
1	Collection of preliminary information related to the research topic from available scientific sources	20–30 September 2024	Habiba Ashraf
2	Measurement of water properties according to the water analysis protocol, and assessment of climatic characteristics	20 October 2024	Tasneem Abdulaziz
3	Identification of the field study site	25 November 2025	Shahama Al-Hakamani
4	Preparation of soil samples and conducting investigations according to the soil analysis protocol	23–26 December 2025	Habiba Ashraf Shahama Al-Hakamani
5	Submission of soil samples to the research center for laboratory analysis	26–29 December 2025	Mr. Saeed Al-Hashmi Director of Mahout Municipality
6	Observation of final results, data analysis, and writing of the research report	3 January 2026	Habiba Ashraf Tasneem Abdulaziz

7. Study Area

This study was conducted in the **Sultanate of Oman**, specifically in **Al Wusta Governorate – Wilayat Mahout – Haj area**, during the period extending from **September 2024 to March 2025**.



The study area is characterized by a relatively moderate climate during the research period, with temperatures ranging between **30 and 36°C**. The region also records notably high levels of relative humidity, reaching **85% to 95%** during the early morning and nighttime hours, accompanied by a clear prevalence of fog, particularly during the autumn season. In contrast, relative humidity levels decline during midday and afternoon periods, ranging between **28% and 34%**.

These climatic characteristics provide suitable conditions for examining the effects of elevated humidity and its daily variability, in addition to the role of seasonal rainfall, on the growth of the Ghaf tree and its interaction with sulfur-rich soil properties. Consequently, the Haj area represents an appropriate model for achieving the study objectives and analyzing the environmental changes under investigation.

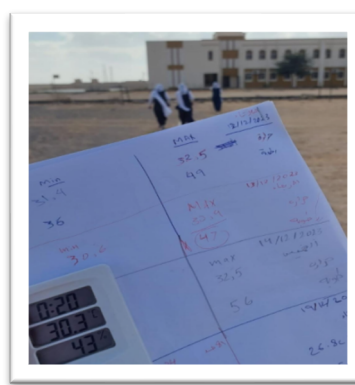
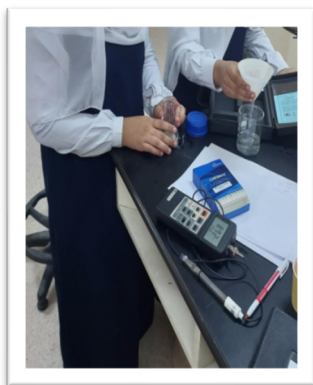
8. Data Collection and Analysis

To address the research questions and achieve the study objectives, soil and water analysis protocols were adopted as the primary methodological framework for collecting field and laboratory data. The processes of data collection and analysis comprised the following steps:

The properties of irrigation water were measured through laboratory analyses, including the determination of pH, electrical conductivity (EC), dissolved oxygen concentration, and water transparency, in accordance with standardized scientific protocols. These measurements were conducted to evaluate the suitability of the water for Ghaf tree growth and its potential influence on nutrient uptake.

In addition, local climatic variables in Wilayat Mahout – Haj area were monitored, specifically air temperature and relative humidity, in order to document daily and seasonal variations throughout the field study period.

With regard to long-term climatic data, coordination was carried out with the relevant meteorological authorities to obtain historical records covering the past twenty years, particularly data related to relative humidity levels and the amount and temporal distribution of rainfall within the study area. These datasets were used to analyze climatic trends and to examine their relationship with growth indicators of the Ghaf tree.



With regard to soil characteristics, coordination was carried out with the relevant authorities, including Mahout Municipality, the Department of Agricultural and Animal Wealth in Mahout, and the Duqm Laboratories Center, to conduct the necessary physical and chemical analyses of soil samples. These analyses included measurements of soil pH, salinity, and nutrient availability, thereby ensuring the accuracy of the measurements and the reliability of the results.



The study also included field visits to Mahout Municipality Center – Haj area, during which an interview was conducted with Mr. Saeed Al-Hashmi, Director of Mahout Municipality. The purpose of this interview was to strengthen institutional cooperation and to discuss the current status of vegetation cover and the impacts of desertification in the region, in addition to exploring sustainable approaches for utilizing sulfur springs. This interview also provided an opportunity to examine soil samples in greater detail and to benefit from practical expertise and relevant previous research.

Following the completion of data collection, quantitative and qualitative data were analyzed using appropriate statistical and descriptive methods. The results were presented graphically to facilitate interpretation, link findings to the research questions, and derive accurate scientific conclusions.

9. Data Collection and Analysis

Climatic and field data were collected and analyzed based on direct measurements and authorized meteorological sources, following an integrated scientific methodology aimed at linking climatic factors and soil characteristics to the growth of the Ghaf tree.

9.1 Climatic Data

Air temperature and relative humidity levels were measured **in situ** in the **Haj area of Wilayat Mahout**, and these measurements were entered into the **GLOBE Program platform** for use in comparison with official meteorological data issued during **2025**. This comparison was conducted to verify the accuracy and reliability of the field measurements.

The image displays two screenshots of the GLOBE Program platform. The left screenshot shows data for a measurement taken on 2025-12-17 at Hig School, Alhij school in Mahout, Oman. The right screenshot shows data for a measurement taken on 2026-01-28 at the same location. Both screenshots include a 'Show on Map' button and a 'Relative Humidities' section.

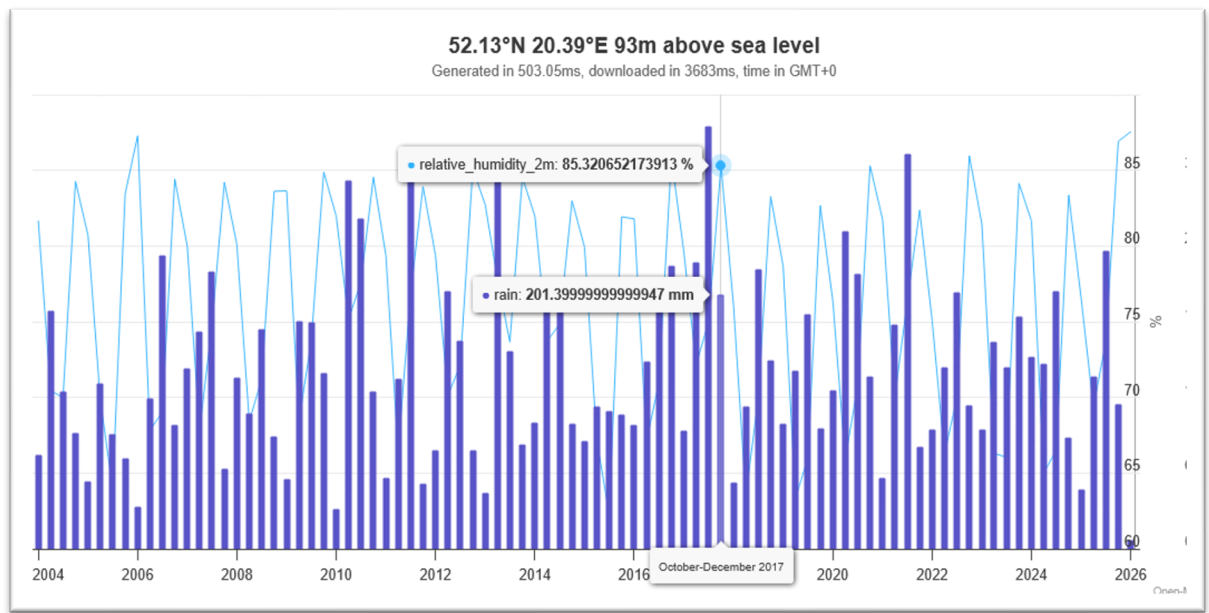
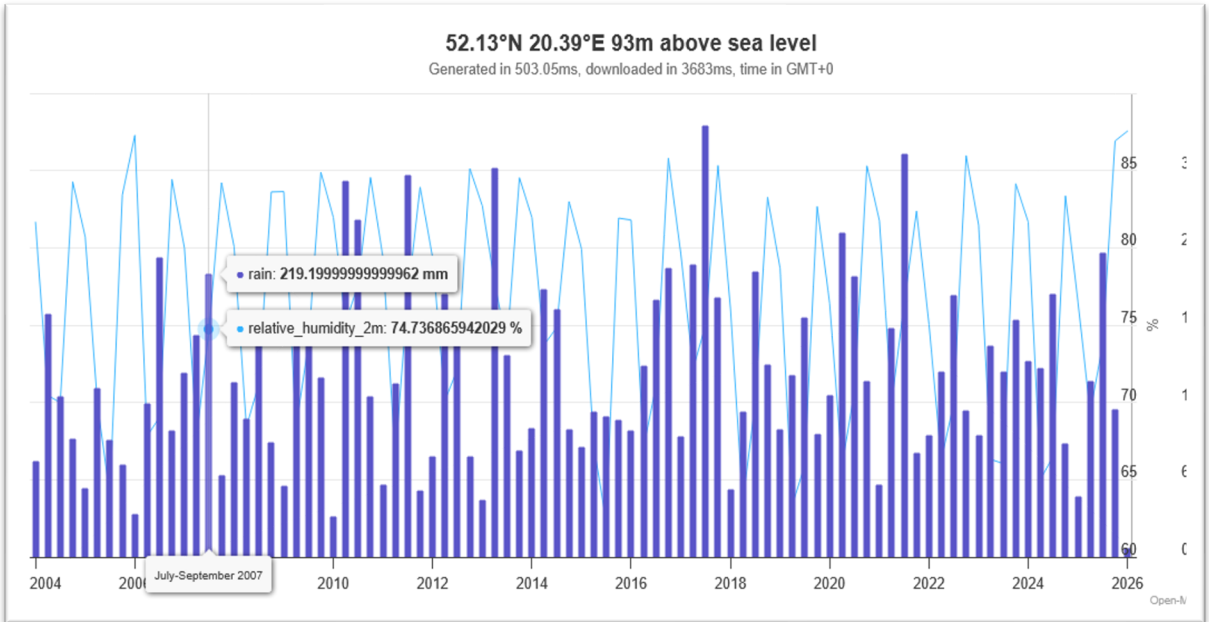
Field	Value
Measured Date:	2025-12-17
Organization Name:	Hig School
Site ID:	330732
Site Name:	Alhij school in Mahout
Country Name:	Oman
Country Code:	OMN
Latitude:	20.62665
Longitude:	58.1951
Elevation:	8.1m
Measured At:	2025-12-17T03:53:00
Solar Measured At:	2025-12-17T07:49:00
Solar Noon At:	2025-12-17T08:03:00
Relative Humidity:	71 %
Dewpoint:	17.6 °C

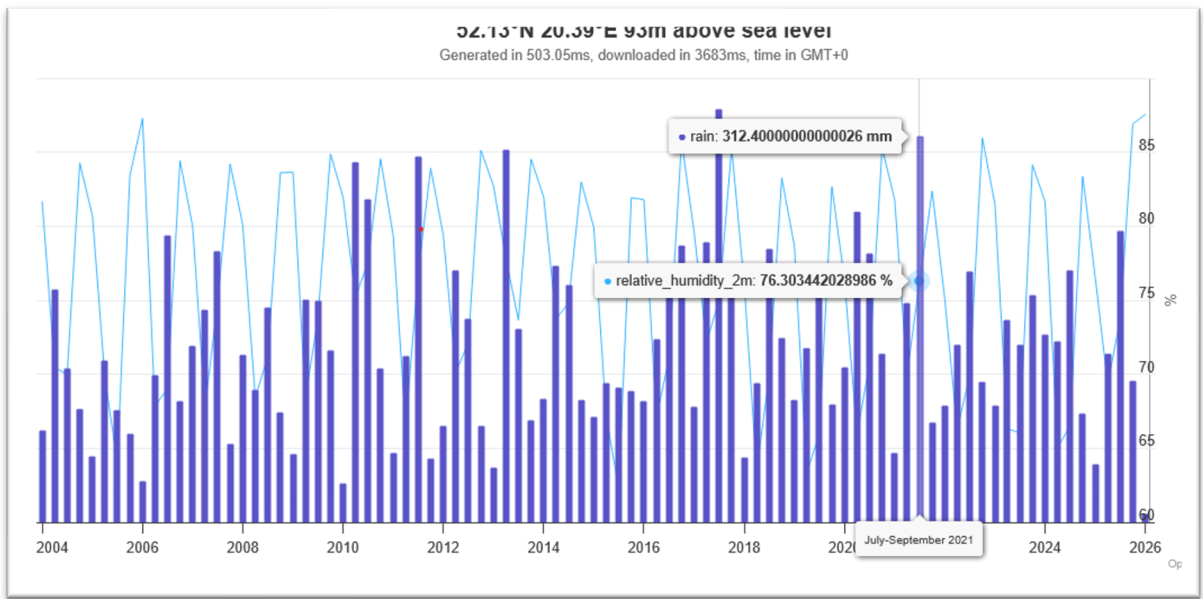
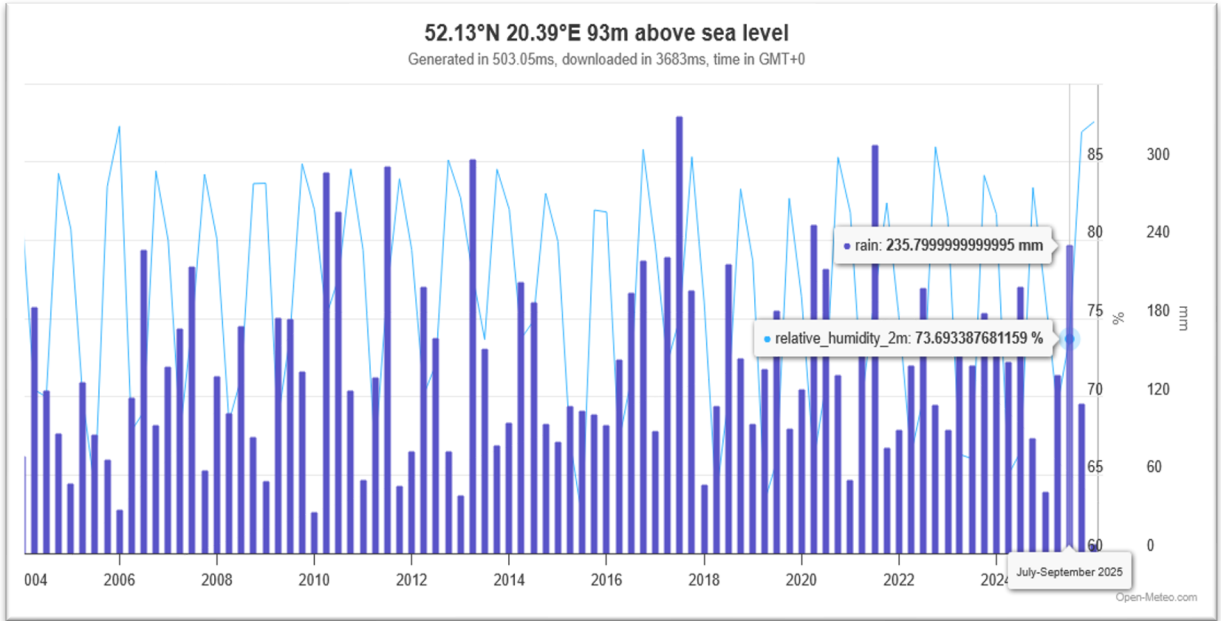
Field	Value
Country Code:	OMN
Latitude:	20.62665
Longitude:	58.1951
Elevation:	8.1m
Measured At:	2026-01-29T01:32:00
Solar Measured At:	2026-01-29T05:10:00
Solar Noon At:	2026-01-29T08:20:00
Relative Humidity:	86 %
Dewpoint:	14.7 °C

Show on Map

Field	Value
Measured Date:	2026-01-28
Organization Name:	Hig School
Site ID:	330732
Site Name:	Alhij school in Mahout
Country Name:	Oman
Country Code:	OMN
Latitude:	20.62665
Longitude:	58.1951
Elevation:	8.1m
Measured At:	2026-01-28T01:44:00
Solar Measured At:	2026-01-28T05:22:00
Solar Noon At:	2026-01-28T08:20:00
Relative Humidity:	79 %
Dewpoint:	14.4 °C

Historical climatic data were also obtained from the Open-Meteo platform through its Historical Weather API (<https://open-meteo.com/en/docs/historical-weather-api>). Data on relative humidity and rainfall amounts were extracted for the period extending from 2004 to 2026, with the aim of analyzing long-term climatic trends in Wilayat Mahout – Haj area and utilizing these records to assess the impacts of climate change over the past twenty years.





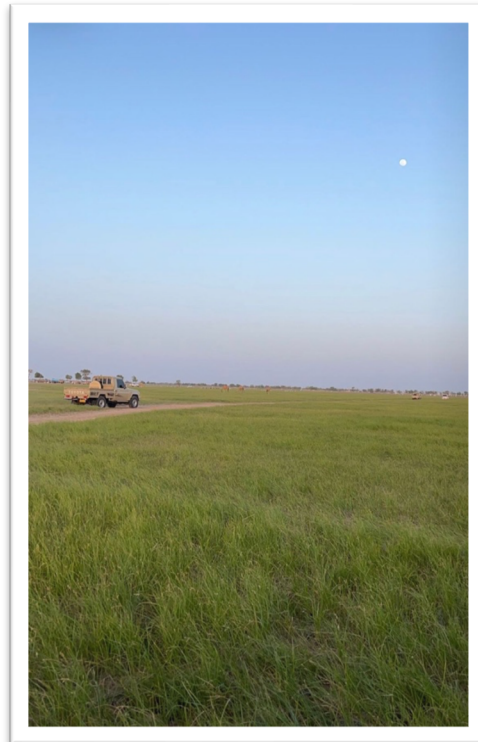
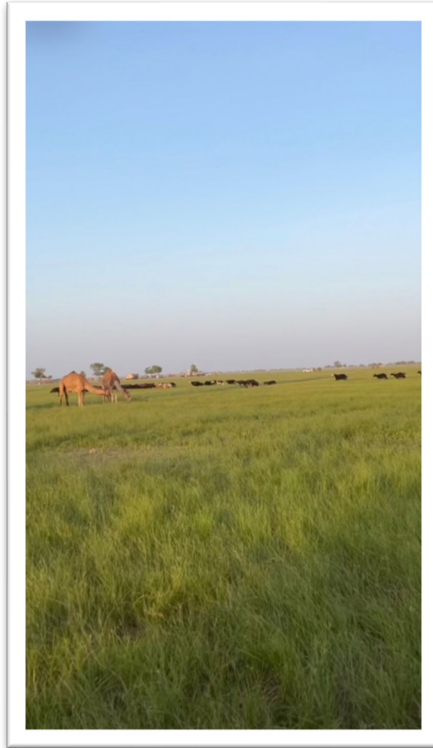
Selected examples of relative humidity and rainfall data across different years:

2004-08-30T13:00	47	0
2004-08-30T14:00	46	0.1
2004-08-30T15:00	47	0.3
2004-08-30T16:00	52	0.2
2004-08-30T17:00	58	0.1
2004-08-30T18:00	67	0.3

2017-07-21T07:00	88	0
2017-07-21T08:00	79	0
2017-07-21T09:00	69	0
2017-07-21T10:00	80	2.9
2017-07-21T11:00	93	5.9
2017-07-21T12:00	94	1.7
2017-07-21T13:00	94	2.8
2017-07-21T14:00	93	2.9
2017-07-21T15:00	93	1.7
2017-07-21T16:00	91	0.2

2025-05-28T21:00	91	0.4
2025-05-28T22:00	94	1.4
2025-05-28T23:00	95	1.3
2025-05-29T00:00	96	1.9
2025-05-29T01:00	97	0.4
2025-05-29T02:00	97	0.3
2025-05-29T03:00	97	0.1
2025-05-29T04:00	97	0.1
2025-05-29T05:00	97	0.3
2025-05-29T06:00	94	0.6
2025-05-29T07:00	90	0.3
2025-05-29T08:00	88	0.1
2025-05-29T09:00	89	0.4
2025-05-29T10:00	87	0.2
2025-05-29T11:00	75	0.1

2017-04-12T00:00	70	0.1
2017-04-12T07:00	77	0.4
2017-04-12T08:00	82	0.3
2017-04-12T09:00	80	0.3
2017-04-12T10:00	82	0.3
2017-04-12T11:00	80	0.3
2017-04-12T12:00	84	0.5
2017-04-12T13:00	85	0.2
2017-04-12T14:00	87	0.3
2017-04-12T15:00	88	0.4
2017-04-12T16:00	89	0.6
2017-04-12T17:00	90	0.4
2017-04-12T18:00	90	0.9
2017-04-12T19:00	91	0.9
2017-04-12T20:00	91	0.5
2017-04-12T21:00	94	0.6
2017-04-12T22:00	91	0.4

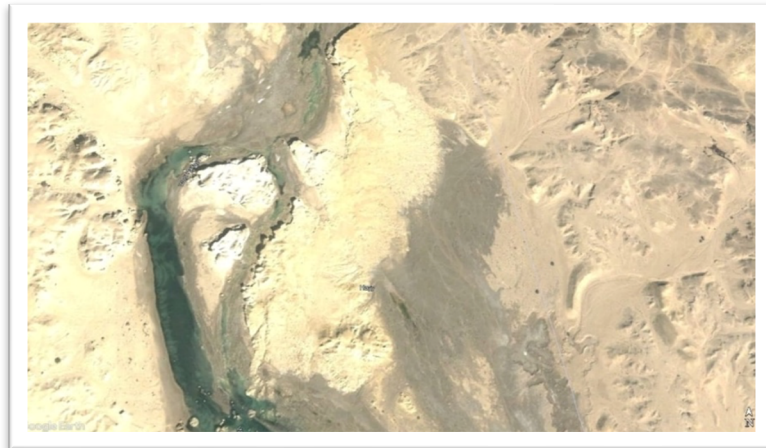


The images clearly demonstrate the impact of rainfall during 2023 on the activation of wadi systems within the study area, where precipitation contributed to water flow along wadi channels and enhanced soil moisture availability. This, in turn, had a positive effect on increasing natural vegetation cover along wadi banks and in surrounding low-lying areas, thereby creating favorable conditions for seed germination and the growth of native trees, including the Ghaf tree. These observations highlight the vital role of seasonal rainfall in supporting ecological balance and promoting the regeneration of natural ecosystems in arid and semi-arid regions.

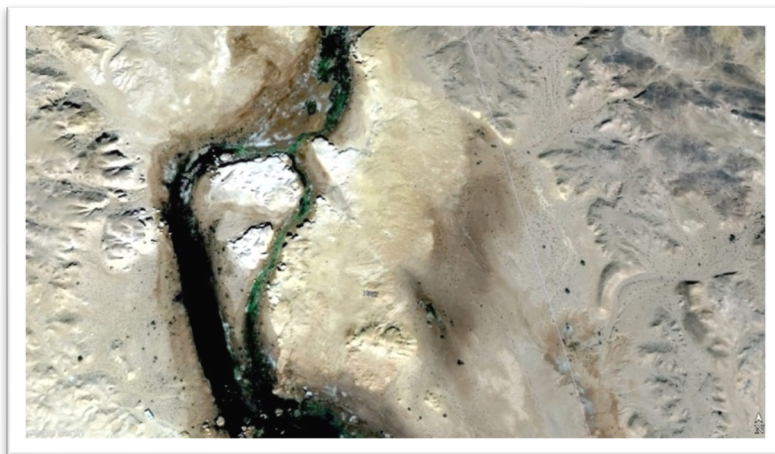
9.2 Analysis of Climatic Trends

The extracted climatic data revealed a continuous increase in relative humidity levels in the study area across different months throughout the past twenty years, with values ranging between 60% and 80%. With respect to rainfall, the highest precipitation rates were recorded during the autumn season, as a result of the region's exposure to monsoonal climatic influences. This finding highlights the critical importance of utilizing this period for the cultivation of native trees and the dispersal of their seeds.

In addition, visual comparisons based on satellite imagery and Google Maps analysis indicated a noticeable increase in vegetation cover in Wadi Haj over the past two decades. This observation supports the hypothesis that native vegetation has benefited from the relative improvement in climatic conditions during this period.

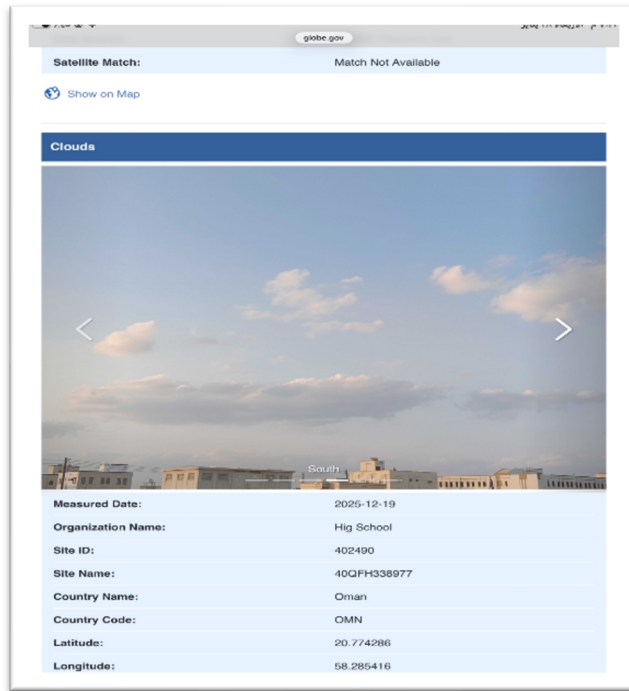


2004



2017

Considering that native trees, including the Ghaf tree, require continuous rainfall for a period of no less than two months during the germination and acclimatization stages, the results indicate the necessity of focusing environmental and agricultural efforts on the autumn season. This period is characterized by elevated humidity levels and the frequent presence of clouds and fog, which contribute to reducing water loss from plants, even if only to a limited extent.



Choose a Start Date:

2025-09-02

Choose an End Date:

2026-01-28

Choose an Observation:

Atmosphere

Air Temperature Dailies
 Air Temperature Noons
 Air Temperature
 Clouds Noons
 Relative Humidities Noons
 Clouds
 Relative Humidities
 Relative Humidities Monthlies
 Surface Temperature

189 Observation(s) found.

9.3 Water and Soil Data

Analysis of Water Properties

A total of 50 samples of irrigation water were collected and analyzed in accordance with the water analysis protocol. The average values were as follows:

Parameter	Mean Value
pH	7.3
Salinity (ppm)	140
Transparency	110
Dissolved oxygen	5
Temperature (°C)	25

The results of the water quality analysis indicate that the water is relatively suitable for irrigating *Ghaf* trees, as the recorded values of pH, salinity, dissolved oxygen, and temperature fall within ranges that do not hinder plant growth or nutrient uptake. These findings support the potential use of this water in educational and environmental afforestation projects, both within and beyond the school environment.

In this context, cultivating *Ghaf* trees within the school environment can contribute significantly to enhancing students' environmental awareness and reinforcing concepts of sustainability and eco-friendly living. Soil fertility can also be improved through treatment with green mussel shells, which play an effective role in reducing salinity, improving soil permeability, and increasing overall agricultural efficiency. This approach represents a practical model that can be implemented both on school premises and in surrounding areas.

In natural environments, particularly wadis and sulfur springs, field visits have confirmed the widespread presence of *Ghaf* trees in the vicinity of these sites, reflecting the species' high adaptability to harsh environmental conditions. This observation highlights the importance of encouraging students and the local community to participate in studying sulfur springs, including their water and soil characteristics and their influence on surrounding vegetation. Such engagement contributes to expanding the scientific knowledge base on these natural resources and transforming them from neglected or culturally constrained sites into open natural laboratories for environmental education and sustainable research.

These results indicate that the water used for irrigation is relatively suitable for the cultivation of the Ghaf tree and does not pose a constraint to its growth.

Analysis of Sulfur-Rich Soil

A total of 30 sulfur-rich soil samples were collected from different locations surrounding the sulfur springs. The results showed that the soil texture ranged between clayey and fertile, with moderate permeability, near-neutral pH values (7.3–8.1), and moderate electrical conductivity. These characteristics suggest that, despite certain limitations, the soil has the potential to support plant growth when managed appropriately.



Average Results of Selected Soil Samples:

Sample No.	Soil Type	Color	Permeability	Electrical Conductivity (ppm)	pH
Mean	Clayey to fertile	Light brown	Moderate	1280	7.4
1	Clayey to fertile	Light brown	Moderate	1150	7.3
2	Clayey to fertile	Light brown	Moderate	1310	7.9
3	Clayey to fertile	Light brown	Moderate	1250	8.1
4	Clayey to fertile	Light brown	Moderate	1450	7.5
5	Clayey to fertile	Light brown	Moderate	1215	7.56
6	Clayey to fertile	Light brown	Moderate	985	7.78

Treatment of Sulfur-Rich Soil

The students conducted a treatment experiment on a sulfur-rich soil sample based on a previous study carried out under the **GLOBE Program** at **Haj Basic Education School** during the **2024–2025 academic year**, entitled:

“A Study on the Effect of Biogenic Grinding of Green Mussel Shells on Plant Growth and Soil Treatment through Reducing Salinity and Increasing Permeability in the Haj Area of Wilayat Mahout.”

This approach was adopted to improve soil properties and assess its potential for supporting sustainable plant growth.



These results confirm the potential of sulfur-rich soils to support the growth of native vegetation when properly managed, particularly through the reduction of harmful salinity—especially sodium chloride—and the improvement of soil permeability.

Mineral-rich soils, particularly those containing sulfur, are of high agricultural and environmental importance due to their role in enhancing soil fertility, strengthening root systems, and promoting leaf and fruit development, which positively affects both productivity and crop quality. Sulfur also contributes to reducing soil acidity and improving overall chemical balance.

Nevertheless, elevated levels of sodium chloride in certain sulfur-rich soils constitute a limiting factor for plant growth, thereby necessitating targeted intervention using scientifically sound and sustainable treatment methods.

Accordingly, the research team sought to capitalize on the beneficial properties of sulfur-rich soils by treating them and replacing harmful salts, drawing on a previous study conducted by

team members under the GLOBE Program. This study examined the use of green mussel shells as a soil amendment to reduce salinity and enhance soil permeability.



Results of the Analysis of a Sulfur-Rich Soil Sample after Treatment with Green Mussel Shells

Property	Value
pH	7.2
Salinity (ppm)	750
Soil type	Moderately permeable, clayey to fertile
Porosity	Moderate
Carbonate content	High
Structure	Semi-compacted
Texture	Granular
Rock fragments	Very fine

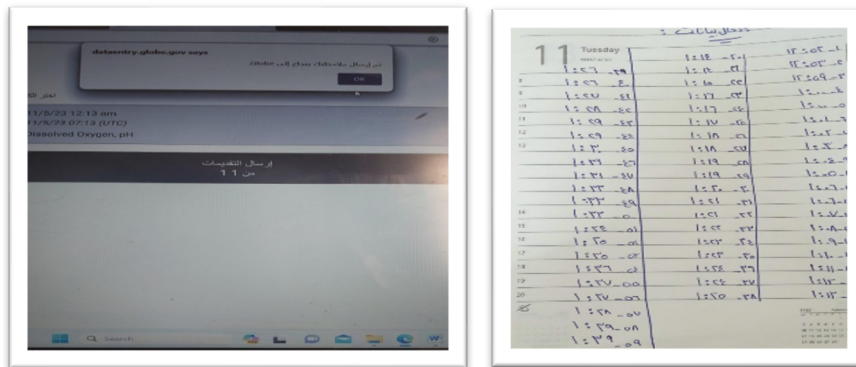
These findings demonstrate that treated sulfur-rich soils exhibit improved physicochemical properties, making them more suitable for supporting sustainable plant growth and enhancing native vegetation restoration efforts.

These results confirm the **effectiveness of bioremediation using green mussel shells** in improving the properties of sulfur-rich soils, particularly through reducing harmful salinity and enhancing soil permeability, thereby making such soils more suitable for the growth of native vegetation.



Field visits also revealed the presence of **agricultural oases in proximity to sulfur springs**, where dense, broad-canopied Ghaf trees were observed at distances of up to **200 meters**. This distribution reflects the strong adaptive capacity of native trees to harsh environmental conditions. Field observations, supported by previous studies, indicate that trees growing near sulfur springs exhibit **higher chlorophyll content** compared to those in sulfur-deficient environments, which enhances photosynthetic efficiency and vegetative growth.

Accordingly, these findings underscore the importance of proper management of sulfur-rich soils and their utilization in expanding native vegetation cover and promoting the growth of indigenous trees. Such practices contribute significantly to environmental sustainability and the mitigation of desertification in arid and semi-arid regions.



All field data and measurements related to soil and climatic variables were entered into the GLOBE Program platform via its official website

www.globe.gov, with the aim of documenting the results and making them available for scientific use and comparison in future studies.

10. Discussion of Results

The study findings indicate that increased relative humidity plays a clearly positive role in improving the physiological performance of the Ghaf tree by reducing transpiration rates, thereby allowing stomata to remain open for longer periods. This physiological response enhances carbon dioxide uptake, leading to higher photosynthetic efficiency and improved vegetative growth. These findings are consistent with the well-documented adaptive characteristics of the Ghaf tree as a species capable of benefiting from humid conditions even within arid environments.

Field studies conducted by the GLOBE Program team at Haj School also demonstrated a strong positive relationship between rainfall amount and growth rates of the Ghaf tree. Seasons characterized by higher rainfall were associated with noticeable increases in vegetative growth and plant density. Light to moderate rainfall during the monsoonal climate period—particularly in the autumn season—represents a suitable opportunity for planting Ghaf trees and expanding vegetation cover, as it enhances the plant’s capacity to absorb water and nutrients from the soil.

In addition, soil moisture resulting from rainfall contributes to enhancing biological nitrogen fixation by stimulating the activity of Rhizobium bacteria within the root nodules of the Ghaf tree. Studies indicate that optimal nitrogen fixation rates occur when soil moisture ranges between 60% and 80%, underscoring the importance of utilizing the autumn season to expand Ghaf tree cultivation. Adequate rainfall also improves seed germination rates and seedling establishment, thereby promoting the regeneration and sustainability of native plant communities.

Sulfur is considered an essential nutrient for plants, as it is involved in the synthesis of amino acids, proteins, and enzymes. For the Ghaf tree, as a leguminous species, sulfur is particularly important for the formation of the nitrogenase enzyme responsible for nitrogen fixation. Research has shown that adequate sulfur availability can enhance biological nitrogen fixation efficiency by up to 40%, positively influencing plant growth and biomass production.

The results further indicate that sulfur-rich soils treated with shells and mollusks can be effectively utilized for cultivating fruit trees and native species characterized by strong root systems. The availability of sulfur provides a clear nutritional advantage, and studies have shown that Ghaf trees grown in improved sulfur-rich soils exhibit higher growth rates than those grown in sulfur-deficient soils. This improvement is partly attributed to chemical reactions within these soils that facilitate the release of essential nutrients such as phosphorus and certain micronutrients, thereby increasing their availability to plants.

Adequate soil moisture is also a fundamental requirement for the activity of beneficial microbial communities, including Rhizobium bacteria and symbiotic mycorrhizal fungi. When

sulfur-rich soils are improved through appropriate treatment and regulated irrigation, symbiotic activity is restored and enhanced, leading to improved nitrogen fixation and the uptake of phosphorus and other micronutrients. These findings highlight the importance of integrating favorable climatic conditions with proper management of sulfur-rich soils to support the growth of the Ghaf tree and expand vegetation cover in arid and semi-arid regions.

11. Conclusion

The scientific evidence derived from this study indicates that climate changes, particularly the increase in relative humidity levels and rainfall, can contribute positively to enhancing the growth and productivity of the Ghaf tree in arid and semi-arid environments. The results demonstrate that these climatic conditions improve the plant's physiological performance, reduce water stress, and increase the efficiency of biological processes associated with growth.

The study also shows that sulfur-rich soils, despite the environmental challenges they may present, can be transformed from a growth-limiting factor into a promising agricultural opportunity when managed using sound scientific practices, such as pH adjustment, improved drainage, and regulated irrigation. These soils provide essential nutrients—most notably sulfur—which plays a key role in enhancing plant adaptive mechanisms, particularly in the Ghaf tree as a leguminous species capable of nitrogen fixation.

Furthermore, the findings highlight that the synergistic interaction between favorable climatic conditions and properly managed sulfur-rich soils represents a promising framework for the development of sustainable agricultural strategies that maximize the potential of the Ghaf tree in coastal and arid environments affected by climate change.

12. Closing Remarks

The results of this research reveal promising opportunities for the Ghaf tree to benefit from positive climate changes, especially when rainfall seasons—particularly the autumn season—are optimally utilized. Scientific evidence confirms that elevated relative humidity enhances photosynthetic efficiency and reduces water stress, while additional rainfall stimulates root system development, increases biomass, and enhances biological nitrogen fixation, thereby contributing positively to the sustainability of vegetation cover.

The study also demonstrates that sulfur-rich soils, despite their associated environmental challenges, can represent a valuable agricultural resource when properly managed. The available sulfur in these soils serves as an essential nutrient for the Ghaf tree, and the integrative interaction

between increased rainfall and improved soil properties creates a favorable environment for the growth of this highly adaptable species.

However, the optimal utilization of these environmental opportunities faces social and cultural challenges, particularly those related to popular beliefs surrounding water springs and the surrounding vegetation. Addressing these challenges requires the adoption of an integrated approach that combines modern scientific knowledge with respect for local cultural heritage, through environmental awareness programs and the engagement of community and religious leaders in constructive dialogue on the importance of sustainable resource utilization.

Overall, the findings of this research confirm that climate change is not necessarily a catastrophic scenario for all species and regions, but may instead offer windows of opportunity for well-adapted plant species such as the Ghaf tree, provided that natural resources are managed wisely and efficiently. Investing in a deeper understanding of these environmental dynamics and in the development of appropriate agricultural techniques represents a critical step toward building resilient agricultural systems capable of supporting food and environmental security and addressing future challenges in arid and semi-arid regions.

13. Recommendations

To achieve the maximum possible benefit from positive climate changes and the characteristics of sulfur-rich soils in supporting the cultivation of the Ghaf tree and expanding vegetation cover, this study recommends the following:

1. Agricultural and Environmental Recommendations

- The necessity of **treating sulfur-rich soils** and making them suitable for cultivation through pH adjustment, reduction of harmful salt accumulation, and improvement of their physical properties.
- Improving **agricultural drainage systems** to prevent salt accumulation and ensure adequate soil aeration.
- Adopting **modern irrigation systems**, particularly drip irrigation, to optimize the use of rainfall, reduce water loss, and maintain soil moisture.
- Enhancing the activity of **beneficial microorganisms**, especially *Rhizobium* bacteria, which contribute to nitrogen fixation and improve the nutritional status of the Ghaf tree.
- Selecting **Ghaf genotypes** that are best adapted to local climatic and soil conditions to ensure higher survival and growth rates.

2. Community-Based Recommendations

- Organizing **awareness and extension programs** targeting local communities to highlight the environmental and economic importance of the Ghaf tree and its role in combating desertification and improving livelihoods.
- Respecting beliefs and traditions associated with water springs, while clarifying that **sustainable agriculture does not conflict with spiritual values**, but rather contributes to the preservation of natural resources as blessings that should be safeguarded.
- Strengthening cooperation with **tribal leaders, religious figures, and community leaders** to communicate awareness messages in a culturally appropriate manner.
- Initiating **small-scale pilot projects** around water springs to demonstrate feasibility in practice and gradually build community trust before scaling up implementation.

3. Research and Governmental Recommendations

- Supporting **scientific and applied research** related to the cultivation of Ghaf and native trees in challenging soils and arid environments.
- Providing **financial and technical support** to farmers and community initiatives seeking to adopt sustainable agricultural practices.
- Establishing **clear regulatory and legislative frameworks** for water resource management to ensure the rational use of water springs and protect them from degradation or pollution.

14. Future Vision

This study envisions a future in which desert and coastal regions are transformed into thriving green landscapes dominated by Ghaf trees. In the initial phase, small-scale pilot projects will be implemented around water springs to demonstrate environmental and economic viability. Upon achieving positive outcomes, gradual expansion of Ghaf cultivation will follow, along with the establishment of specialized nurseries for seedling production and distribution to farmers and local communities.

In the long term, this vision aims to convert these areas into productive forests that contribute to livestock fodder supply, honey and timber production, air quality improvement, soil stabilization, and the mitigation of desertification. It also seeks to foster a gradual positive shift in community perceptions toward water springs by highlighting their genuine environmental and economic benefits, so that sustainable investment in natural resources becomes an integral part of community culture, while fully respecting local traditions and values.

Within this framework, the Ghaf tree is regarded as a symbol of humanity's ability to transform environmental challenges into tangible opportunities that serve society and achieve a balance between development and environmental conservation.

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