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Intelligent System for Forecasting Climate Deterioration and Assessing the Potential Impact of Pollutants

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Abstract

The potential impact of climate change on olive cultivation in Mediterranean regions, with a specific focus on Djibouti, is studied, and a smart agriculture approach, based on climate change adaptation, is proposed. This study, conducted in Djibouti, examines the utilization of advanced technologies such as data mining, artificial intelligence, the Internet of Things, drones, and cloud computing to anticipate the damage caused by climate change on agricultural yields. The overall objective of this study is to create sustainable and intelligent agriculture, often referred to as Agriculture 4.0, by controlling soil, water, and weather conditions to optimize plant growth in the unique context of Djibouti. By integrating these technologies, the project aims to increase yields and profits for farmers in Djibouti, thereby promoting more resilient agriculture in the face of climate change. Expected outcomes include pilot projects, policy models, blueprints, and the development of human resources specialized in the field of smart agriculture tailored to the conditions of Djibouti. In summary, the article presents an innovative approach to address climate challenges in olive cultivation in Djibouti and other Mediterranean regions, utilizing advanced technologies.

Keywords: Climate change; Smart agriculture; Artificial intelligence; Agriculture 4.0; Sustainable agriculture and Djiboutian agricultural human resources

Introduction

Djibouti is going through a crucial moment concerning environmental pollution, climate change, and crop quality [1]. Ongoing research emphasizes agricultural pollution, necessary changes in farming practices, and the vulnerability of agriculture to changing climatic conditions [2]. To address these issues, it is important to identify and implement viable solutions for more sustainable agriculture [2]. This study aims to analyze the complex interactions between agriculture, climate change, and environmental pollution and find context-appropriate solutions for Djibouti. In this context, chemicals could be used to counteract the effects of climate change, although this also raises concerns about environmental pollution and crop quality. This study seeks to address these issues and find balanced solutions to promote more sustainable agriculture in a changing environment. Djibouti, a small East African nation, faces a critical juncture as it grapples with the interlinked challenges of environmental pollution, climate change, and agricultural sustainability [3, 4].

The current research underscores the urgency of addressing agricultural pollution and the need for adaptive changes in farming practices, considering the susceptibility of the agricultural sector to the evolving climate conditions [5-7]. In response to these challenges, it becomes imperative to not only recognize but also implement practical and sustainable solutions for agriculture. This comprehensive study delves into the intricate relationships between agriculture, climate change, and environmental pollution, aiming to devise tailored solutions that align with Djibouti's specific circumstances. Within this framework, the use of chemicals emerges as a potential strategy to mitigate the impacts of climate change.

However, this approach raises valid concerns regarding its implications for environmental pollution and the overall quality of crops. The study is dedicated to addressing these concerns and seeks to formulate well-balanced solutions that foster sustainable agricultural practices within Djibouti's evolving landscape. In essence, the primary goal of this study is to gain a deep understanding of and effectively respond to the multifaceted challenges posed by environmental pollution, climate change, and crop quality in the developing context of Djibouti.

The identified solutions hold the promise of not only enhancing the resilience of Djibouti's agricultural sector but also contributing to the promotion of sustainable development in a world undergoing constant transformation In summary, the main objective of this study is to understand and respond to the complex challenges posed by environmental pollution, climate change, and crop quality in developing Djibouti. The identified solutions could contribute to improving the sustainability of Djibouti's agriculture and promoting sustainable development in an ever-changing world.

Environmental issues pose a significant obstacle to sustainable development in Djibouti [8]. The country is endowed with abundant natural resources, thanks to its marine and terrestrial biodiversity [8]. However, some of its plant and animal species are on the verge of extinction, including corals, mangroves, and breeding whale sharks. While Djibouti has renewable energy sources such as solar, wind, and marine energies, it faces numerous environmental challenges of both natural and anthropogenic origins, with economic, social, and environmental repercussions. Approximately 35% of the country's economy is estimated to be exposed to natural disasters. Djibouti has grappled with annual and seasonal droughts, desertification, severe water shortages, frequent and intense flash floods, active volcanism, and recurring high-magnitude earthquakes [8]. The majority of its population resides in urban areas characterized by high environmental risks.

Materials and Methods

Study area

The Intergovernmental Authority on Development (IGAD) is a trade bloc comprising eight African nations (refer to the Figure 1) [9]. It encompasses the governments of the Horn of Africa, the Nile Valley, and the Great Lakes region, namely Djibouti, Ethiopia, Kenya, Sudan, South Sudan, Somalia, Uganda, and Eritrea. The headquarters of IGAD is located in Djibouti [9].

Source: IGAD.

Figure 1: Pays de l'IGAD.

The Republic of Djibouti is a country in the Horn of Africa. It borders Eritrea to the north, Ethiopia to the west and south, and Somalia to the southeast (Figure 2). The remaining borders are formed by the Red Sea and the Gulf of Aden to the east. Djibouti occupies a total surface area of just 23,200 km^2.

Source: CIA [10].

Figure 2: Djibouti.

Environmental pollution has been identified as one of the most serious environmental problems [11]. Djibouti has had to cope with severe environmental degradation, desertification, drought and water shortages [11, 12]. As the climate is extremely hot, environmental problems are taking a heavy toll on Djibouti's population. Djibouti is a country on the Horn of Africa, on the shores of the Red Sea [12]. Its seaway and transshipment port make it a strategic point in the region. Marine pollution presents a real environmental challenge. The cities lack treatment plants for solid and liquid waste. As a result, it's not uncommon to see piles of garbage along the roadsides, as well as accumulations of rainwater due to blocked drains. However, it is the pollution caused by accidents involving large trucks on the border between Eritrea and Djibouti that is most often cited. As a result of these accidents, hazardous petroleum products and chemicals are spilled on the road, often leading to both point-source and non-point-source environmental pollution [8].

What's more, following the intrusion of seawater into the water table, the water has been extensively polluted by contamination and salinization. The country also faces serious endemic problems of air pollution, both internal and external [7]. In Djibouti, man-made pollution can be observed in the coastal zone around the capital [8]. Outside the city, pollution is not very significant. Increased maritime traffic, the storage and transit of petroleum products to Ethiopia, and the shipment of livestock to Saudi Arabia and certain Middle Eastern countries are the main sources of pollution in the port of Djibouti and coastal areas [8]. Due to the large number of ships and boats, the high concentration of industrial activities and urbanization, marine and coastal areas are the most affected by pollution.

These impacts are due to the urban and industrial activities of Djibouti's international port. The "degassing" of tanks transporting oil and the channeling of the port's underground increase liquid effluents and become the main source of pollution contributing to environmental degradation in the country. The main problems observed in coastal and marine areas concern the degradation of the national fisheries potential and of certain habitats, notably mangroves and coral reefs. Waste oils, hydrocarbons and heavy metals are also major sources of pollution. Djibouti is a trade route between the West and the Far East, through which huge quantities of hydrocarbons, gas and agro-industrial products transit.

Pollution has serious repercussions on economic growth and well-being in Djibouti. Its impact on health, resource depletion and natural disasters linked to climate change is very real. There are two main categories of policy instruments for reducing pollution: regulatory instruments and market-based economic instruments. Regulatory instruments impose emission standards or effluent limits. They require a great deal of information, and their implementation and monitoring involve considerable administrative costs. Market-based instruments include eco-taxes and carbon taxes, subsidies and trading instruments.

Unlike regulatory policies, market-based instruments use incentives to reduce the costs of achieving a given level of environmental protection. With regard to regulatory instruments, the country has taken steps to manage environmental pollution, keep pollution levels under control and create more sustainable economic growth while controlling its high urbanization rates. However, the country lacks the financial and technological resources, as well as the human and institutional capacity, to develop, implement and enforce environmental codes and legislation.

Sample collection
Meteorological data

Meteorological data, essential for understanding climatic and environmental conditions, are collected through several stations scattered across Djibouti, each covering a specific region of the country. Station Day, located in the Day region, is a major observation point for gathering local meteorological parameters. Similarly, the Wea Station, located in the Wea region, provides precise data for this specific area of the country. The Ali-Sabieh Station, established in the region of the same name, collects crucial meteorological data for this semi-arid region. The Dikhil region is covered by the Dikhil Station, which records and reports environmental variables for this locality. The Obock Station, located in the Obock region, provides information on weather conditions in this coastal area. Finally, the Institut d'Observatoire Régional de Recherche pour l'Environnement et le Climat, in Djibouti-city, is a focal point for the collection and analysis of varied meteorological and environmental data in this dynamic urban area. Each station plays a crucial role in gathering precise information, enabling an in-depth understanding of the climatic and environmental conditions specific to their respective regions.

Meteorological variables

Meteorological variables are attributes or measurements describing different aspects of weather and climate. They include parameters such as temperature, humidity, atmospheric pressure, precipitation, wind speed and direction, air quality, among others. These dimensions provide essential details for understanding and analyzing a region's weather conditions at a given time, and are crucial for studying climate variations over a defined period. By grouping these dimensions into a data structure, we can better understand weather trends, cycles and phenomena on different time and space scales, which is crucial for fields such as meteorology, climatology and environmental studies.

Meteorological data variables	***Explanation of variables***
Date_time	The date and time at which measurements were recorded.
Temperature [°C]	A measure of air temperature in degrees Celsius. It is often used to determine climate and weather conditions.
Dew point [°C]	Temperature at which air must be cooled to reach water vapor saturation. It indicates the humidity of the air and is crucial for assessing the potential formation of fog, dew or precipitation.
Solar radiation [W/m2]	Amount of solar radiation received per unit area. This provides information on the solar energy received at a specific location.

Vapor pressure deficit [kPa]	The difference between the actual vapor pressure in the air and the saturation vapor pressure at the same temperature. It is often used to determine air dryness.
Relative humidity [%]	Percentage of humidity in the air in relation to the maximum amount it could contain at a given temperature. This indicates thermal comfort and can influence how hot or cold it feels.
Precipitation [mm]	Total amount of precipitation over a given period, usually measured in millimeters. It is vital for understanding precipitation patterns and water availability.
Wind speed [m/s]	Speed of air movement, measured in meters per second. Wind speed can influence perceived temperature and affect various aspects such as marine navigation, wind power, etc.
Wind gusts [m/s]	Wind speed peaks that occur over short periods.
Wind direction [deg]	The direction in which the wind blows. It is usually measured in degrees, often in relation to north.
Solar panel [mV]	Electrical voltage generated by a solar panel, measured in millivolts. It provides information on solar energy production.
DeltaT [°C]	Temperature difference between two given points or times, measured in degrees Celsius. It can be used to analyze temperature changes over a specific period.
Daily ETP [mm]	The theoretical amount of water evaporated and transpired from soils and plants in one day, measured in millimeters. This measurement is crucial for assessing crop water requirements and irrigation management.

Table 1: Meteorological data variables.

Environmental variables

Environmental tables represent parameters related to the natural and human environment. They include measures such as air quality, pollution levels, gas emissions, biodiversity, soil characteristics, water quality, health impacts and so on. These dimensions describe the state of the environment in a given area and make it possible to assess changes in that environment over time. By bringing these measurements together in a data structure, we can better understand the interactions between man and his environment, assess the impact of human activities on the ecosystem and make informed decisions for the sustainable management of natural resources and environmental protection.

Environmental data variables	***Variable explanation***
Timezone	The time zone with which the data is associated, indicating the time offset from Coordinated Universal Time (UTC).
Datetime	The date and time at which measurements were recorded.
AQI US and AQI CN	The air quality index for the United States and China, respectively. It assesses air quality in relation to various atmospheric pollutants.
PM2.5, PM10, PM1 (ug/m3)	Concentrations of fine particles of various sizes, measured in micrograms per cubic meter (ug/m3).
CO2 (ppm)	The concentration of carbon dioxide in the air, measured in parts per million (ppm).
Temperature (Celsius) and Temperature (Fahrenheit)	The temperature in degrees Celsius and Fahrenheit, respectively.

Humidity (%)	The relative humidity of air, indicating the percentage of water vapor present in the air in relation to the maximum amount the air can contain at a given temperature.
Pressure (pascal)	Atmospheric pressure expressed in pascals, measuring the force exerted by air on a given surface.

Table 2: Environmental data variables.

Results and discussions

Data Description

Dataset 1

The dataset under analysis is an informative collection of air quality and meteorological data, providing a detailed insight into various environmental parameters. The dataset is structured into several columns, each representing a specific measure of air quality or weather-related data, recorded over a specific period.

- *Timezone*: This column indicates the timezone for each data entry, providing context for the timing of the measurements.
- ***Datetime***: The date and time of each measurement, crucial for understanding the temporal context of the data.
- ***AQI US***: The Air Quality Index according to United States standards, a key indicator of air quality.
- ***AQI CN***: The Air Quality Index according to Chinese standards, offering an alternative air quality measurement.
- ***PM2.5 (ug/m3)***: Concentration of particulate matter less than 2.5 micrometers in size, in micrograms per cubic meter. PM2.5 is a significant measure due to its health impacts.
- ***PM10 (ug/m3)***: Concentration of particulate matter less than 10 micrometers in size, also in micrograms per cubic meter.
- ***PM1 (ug/m3)***: Concentration of particulate matter less than 1 micrometer in size, highlighting finer particulate pollution.
- ***CO2 (ppm)***: Carbon dioxide concentration in parts per million, a measure relevant to both air quality and climate change.
- ***Temperature (Celsius)***: The ambient temperature at the time of measurement in degrees Celsius.
- ***Humidity (%)***: The relative humidity, in percentage, providing insights into the moisture content of the air.
- ***Pressure (pascal)***: The atmospheric pressure in pascals, relevant for weather analysis.

Dataset 2

The dataset encompasses a range of critical atmospheric parameters, such as average temperature, dew point, and solar radiation, offering insights into thermal and solar dynamics.

It also includes vapor pressure deficit, a vital metric in understanding atmospheric moisture and its implications for weather patterns and plant-water relations.

- ***Date and Time***: The dataset is time-stamped with separate columns for date and time, indicating the precise moment each set of data was recorded.
- ***Average Temperature [°C]:*** This column records the average temperature at each time point, providing a snapshot of the thermal conditions.
- ***Average Dew Point [°C]:*** The average dew point is noted, which is a measure of atmospheric moisture, indicative of the level of humidity.
- ***Average Solar Radiation [W/m2]:*** This measures the intensity of solar radiation, an important factor for understanding solar energy potential and weather patterns.
- ***Average Vapor Pressure Deficit [kPa]:*** This column indicates the vapor pressure deficit, a key variable in understanding evapotranspiration and plantwater relationships.

- ***Average Relative Humidity [%]:*** The dataset includes measurements of relative humidity, crucial for understanding moisture levels in the air.
- ***Precipitation [mm]:*** It records rainfall or precipitation levels, essential for hydrological and agricultural studies.
- ***Average Wind Speed [m/s] and Maximum Wind Gust [m/s]:*** These columns provide insights into wind conditions, important for weather forecasting and studying atmospheric dynamics.
- ***Last Wind Direction [deg]:*** Indicates the direction of the wind, offering additional insights into weather patterns.
- ***Last Solar Panel [mV] and Last Battery [mV]:*** These columns reflect the operational status of the meteorological station, showing the solar panel output and battery levels.
- ***Average DeltaT [°C]:*** Represents temperature differential.

Data analysis
Correlation Matrix

A correlation matrix is a powerful statistical tool used to measure and display the degree of relationship between multiple variables in a dataset. Each element in the matrix represents the correlation coefficient between two variables, providing insights into how they move in relation to each other. The values range from -1 to 1, where 1 indicates a perfect positive correlation, -1 signifies a perfect negative correlation, and 0 implies no correlation at all.

Dataset 1

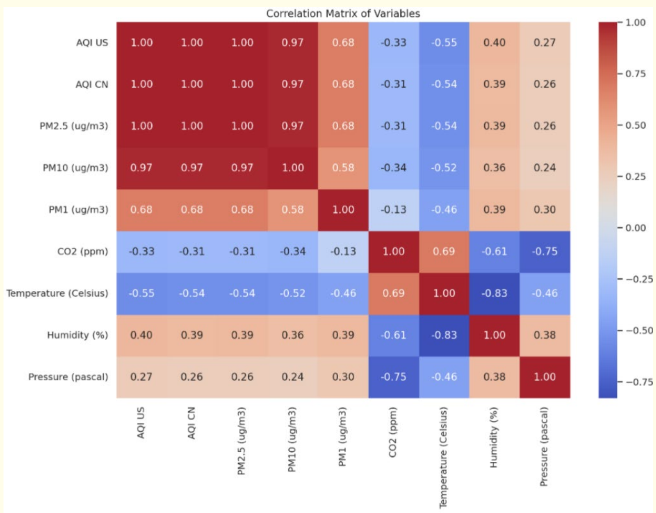


Figure 3: correlation matrix for dataset 1.

The correlation matrix generated from the dataset reveals several interesting relationships between the environmental and meteorological variables:

- ***Air Quality Indices Correlations:*** There might be notable correlations between the different Air Quality Indices (AQI US and AQI CN) and particulate matter concentrations (like PM2.5 and PM10). A strong positive correlation here would indicate that as the concentration of particulate matter increases, the AQI also increases.
- ***Temperature and Pollution Correlation:*** The matrix shows how temperature correlates with air pollution levels. A positive

correlation would suggest that higher temperatures are associated with higher pollution levels, or vice versa.

- ***Humidity and Pollution:*** The relationship between humidity and pollution levels is important . A positive or negative correlation can provide insights into how moisture in the air interacts with pollutant particles.
- ***Pressure and Environmental Variables:*** The atmospheric pressure might have varying degrees of correlation with pollution and other meteorological variables, which can be crucial for understanding weather-related patterns in pollution levels.

Dataset 2

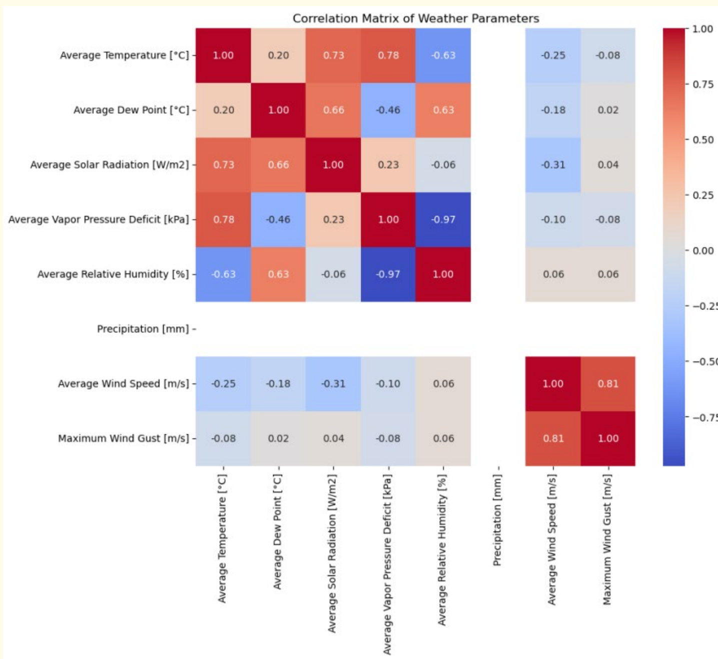


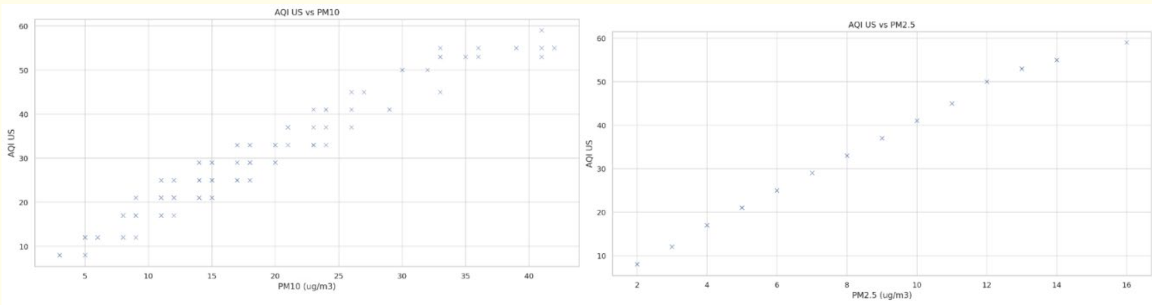
Figure 4: correlation matrix for dataset 2.

From this matrix, we can get some insights such as:

- ***Temperature and Dew Point Correlations:*** Correlations between temperature and dew point can reveal how these two factors are related in terms of atmospheric moisture and thermal conditions.
- ***Solar Radiation and Other Environmental Variables:*** The relationship between solar radiation and other variables like temperature or humidity can provide insights into how solar energy interacts with different weather conditions.
- ***Wind Speed, Direction, and Atmospheric Conditions:*** Correlations involving wind speed and direction with other meteorological factors can be important for understanding the dynamics of air movement and its impact on weather patterns.
- ***Relationships with Solar Panel and Battery Data:*** Correlations involving the solar panel and battery readings might indicate how these parameters are influenced by environmental conditions or vice versa.

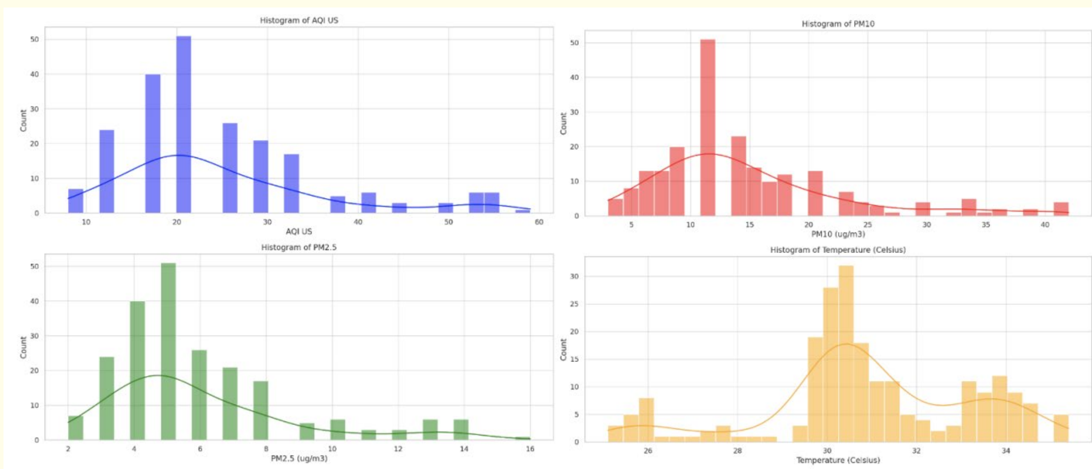
Data visualizations

Dataset 1



AQI US vs PM2.5: This plot explores the relationship between the Air Quality Index according to US standards and the levels of PM2.5. A pattern or correlation can be observed here, providing insights into how PM2.5 levels might affect the AQI.

AQI US vs PM10: Similar to the first plot, this one examines the relationship between AQI US and PM10 levels.



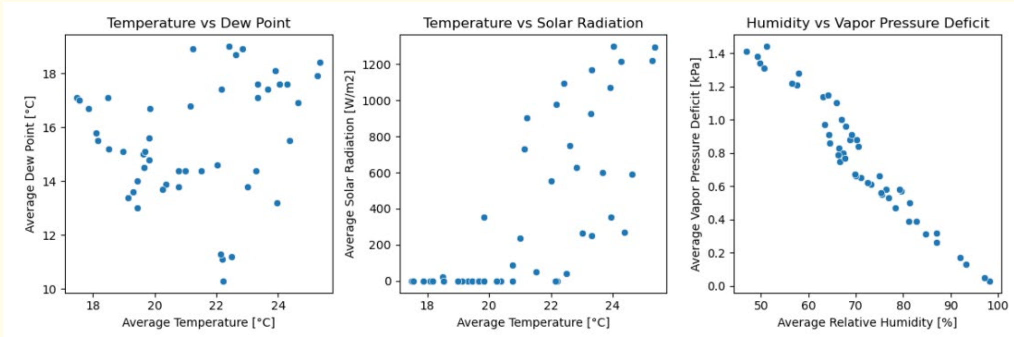
Histogram of AQI US: This histogram shows the distribution of the Air Quality Index according to US standards, providing insights into its spread and central tendencies.

Histogram of PM2.5: Illustrates the distribution of PM2.5 levels in the data, showing how these particulate matter concentrations vary.

Histogram of PM10: Similar to the PM2.5 histogram, it shows the distribution of PM10 levels.

Histogram of Temperature (Celsius): Displays the distribution of temperature values in degrees Celsius, highlighting the range and common temperatures in the dataset.

Dataset 2



Humidity vs Vapor Pressure Deficit: The plot exhibits an inverse correlation, where higher humidity levels correlate with lower vapor pressure deficits, an important factor in meteorology and agriculture for understanding atmospheric moisture and its effects on plant life.

Discussion

Based on the data collected and their interpretation, it can be concluded that Djibouti is a country with a dry, hot climate, the result of progressive environmental degradation leading to desertification, drought and water scarcity. These factors have a direct impact on various sectors of the country, such as the economy, agriculture, health and infrastructure. Based on these elements and scientific interpretations, we can identify various causes of pollution in Djibouti, whether indirect, such as the lack of purification plants and solid and liquid waste treatment, or direct, notably water pollution introducing marine intrusions into groundwater polluted by contamination and salinization, thus leading to the progressive degradation of fisheries, mangroves and coralline reefs.

Conclusion

This comprehensive study underscores the pressing challenges faced by Djibouti, a nation at a critical juncture in its struggle with environmental pollution, climate change, and the sustainability of its agriculture. The analysis reveals the intricate interplay between agriculture, climate change, and environmental pollution, highlighting the urgent need for context-specific solutions. The alarming rate of environmental degradation, including desertification, drought, water scarcity, and pollution, poses severe threats to various sectors including the economy, agriculture, health, and infrastructure in Djibouti.

The research underscores the significant impact of these environmental challenges on the country's natural resources, including its unique marine and terrestrial biodiversity. It also points to the pivotal role of advanced technologies such as data mining, artificial intelligence, the Internet of Things, drones, and cloud computing in mitigating the effects of climate change on agriculture. By integrating these technologies, the study aims to pioneer a sustainable and intelligent agricultural framework, Agriculture 4.0, tailored specifically to Djibouti's unique conditions.

The findings of this study can help in the adoption of smart agriculture approaches that leverage cutting-edge technologies to optimize agricultural practices, enhance crop yields, and ensure environmental sustainability. The study also calls for increased investment in human resources and infrastructure to support the implementation of these innovative solutions.

Author contributions

The authors of this article made the following contributions:

Author 1: Conceptualizing, acquiring funding, developing methodology, collecting data, analyzing data and writing the manuscript.

Author 2: Conceptualization, methodological approach, data analysis and visualizations, writing and reviewing the manuscript.

Author 3: Collecting data, analyzing data, and reviewing the manuscript. Author 4: Analyzing data and reviewing the manuscript.

All authors: Reviewed and endorsed the final manuscript.

Conflict of interest

The authors declare that there are no conflicts of interest related to the publication of this article. No financial assistance or funding was obtained from any individual or organization that could potentially conflict with their research. Additionally, the authors have not been involved in any other activities that could undermine the research's integrity or impact the objectivity of the results presentation.

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