DRONE-ASSISTED THERMAL MAPPING OF FUMAROLES FOR SUSTAINABLE FARMING ON ACTIVE VOLCANOES

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Abstract - The impact of fumaroles on the sustainability of agricultural activities is investigated on Nisyros Island, an active volcano in the South Aegean Sea. Utilizing drone thermal scanning and advanced GIS techniques, we aim to locate fumaroles as their connection to heavy metal contamination in soil, water, and crops. High-resolution thermal images are captured using a thermal drone (MAVIC 3T), and analyzed using R programming, generating contamination source maps. The findings inform agricultural management strategies to mitigate possible heavy metal risks, contributing to sustainable practices in volcanic regions. Two thermal scans derived during the summers of 2019 and 2022 show consistent heat emissions, supporting continuous soil fertility and nutrient availability for sustainable agricultural practices. The cost-effectiveness of drone thermal scanning, which includes the initial purchase of drones, personnel salaries, and fieldwork days, makes it a viable method for ongoing environmental monitoring compared to other standard methods of aerial thermal scanning, such as using airplanes or helicopters.

Keywords - Fumaroles, Heavy Metals, Sustainable Agriculture, Thermal Scaning.

I. INTRODUCTION

Agriculture on Nisyros Island, an active volcanic region in the South Aegean Sea in Greece, faces unique sustainability challenges due to the presence of fumaroles (figure 1), which are openings in the Earth's crust emitting steam and gas. These geological features can both enhance soil fertility by depositing essential nutrients and pose risks through heavy metal contamination. This paper explores the impact of fumaroles on agricultural sustainability by employing innovative technologies such as drone thermal scanning and advanced Geographic Information Systems (GIS) techniques. The goal is to identify fumaroles and evaluate their dual role in heavy metal contamination of soil, water, and crops, which can pose significant risks to human health and the environment, while also considering their contribution to soil fertility through the deposition of essential nutrients [1]-[4].

Heavy metals, such as arsenic, cadmium, iron, lead, chromium, copper, zinc, nickel, and mercury, are naturally occurring elements with a high specific gravity. These metals can become concentrated in soils due to various natural and anthropogenic activities, including volcanic emissions. The ingestion of heavy metals is the most common route of exposure, with lead being a leading cause of poisoning from soils. Plants generally do not absorb significant amounts of lead, especially in the fruiting parts, and maintaining a neutral soil pH can reduce lead uptake [5].

The integration of drone technology with thermal imaging represents a cutting-edge approach in sustainable agriculture, offering precision, efficiency, and cost-effectiveness. Drones can swiftly cover large fields, delivering high-resolution images that pinpoint areas of concern, such as those affected by heavy metal contamination. This precision enables targeted interventions, conserving resources and enhancing crop health and yield. The use of drone-assisted thermal imaging is particularly relevant for irrigation management, where traditional methods are often unsustainable due to their indiscriminate water distribution [6]. By minimizing waste and conserving water, drone technology supports more sustainable irrigation practices for crops, especially on volcanic islands where water resources are limited, especially in Nisyros. This approach ensures that water is utilized efficiently, promoting the health and productivity of crops while preserving vital resources. Fluctuations in fumarole behavior and volcanic thermal signatures may indicate constant or variable changes in element deposition, requiring adjustments in agricultural practices. Annual thermal scanning and continuous ground temperature logging [7]-[8] have proven to be effective methods for monitoring heat emissions from fumaroles. This data can be leveraged to support sustainable agricultural practices by informing management strategies that mitigate heavy metal risks and optimize soil nutrient levels.

Studies have demonstrated the importance of monitoring volcanic activity to mitigate risks associated with gas emissions and thermal anomalies [9]-[10]. Remote sensing technologies offer cost-effective solutions for continuous monitoring, especially in remote areas where traditional methods are challenging [11]. Remote sensing using satellites, high-resolution mapping and analysis of thermal anomalies have been widely used to monitor

agricultural threats and support sustainable development near active volcanic regions. Satellite-based systems, such as Sentinel-2 and Landsat-8, provide valuable data for mapping volcanic thermal activity. The Multispectral Instrument (MSI) and the Operational Land Imager (OLI) are particularly effective for this purpose due to their spatial and spectral resolution [11]-[12].

The quality of food produced on volcanic soil has also been a subject of interest. Volcanic soils are often rich in minerals, which can enhance the nutritional value and taste of agricultural produce. This phenomenon has been observed in various volcanic regions around the world, where local food is renowned for its exceptional quality, especially in Niryros [14]-[15].



Figure 1: (A) Pointing with a green glove to an active sulfuric fumarole at Stefanos Crater (Nisyros) emitting gasses at 99 oC. (B) sulfuric fumarole; (C) Faith Renner next to a fumarole inside Stefanos Crater.

II. METHODOLOGY

Nisyros Island, part of the Hellenic Volcanic Arc, is characterized by active fumaroles emitting volcanic gas and steam. The island's agricultural activities are at risk of heavy metal contamination from these emissions. Aerial scanning was implemented using a DJI Matrice drone equipped with a FLIR XT thermal camera (13 mm) to capture high-resolution thermal images of the study area. The drone conducted survey flights at a predetermined altitude to ensure optimal image resolution and coverage. Thermal images were collected at night to avoid sun radiation artifacts, with a resolution of 5 cm/pixel. Thermal images were processed and analyzed using Geographic Information Systems (GIS) software and the R programming language to enhance the image. GIS software such as the combination of Global Mapper v.23.1 and PiX4D was used to georeference the images and align them with spatial data of the study area. Further GIS processing took place using R by applying the Kolmogorov-Zurbenko (KZ) filter, implemented using the "kza" package in R [16], was applied to enhance image contrast and accurately identify thermal anomalies indicating potential fumaroles and contamination sources. This filter has shown to be very efficient to reveal signals from noise [17]-[18]. The cost-effectiveness of using GIS and R programming provides an efficient detailed analysis with minimal additional cost.

III. RESULTS

The high-resolution thermal maps revealed consistent heat emissions from the fumaroles on Nisyros Island. The thermal maps show a maximum temperature of approximately 76 degrees of Celsius, which is a spatial average of the pixel resolution (5 pixels/cm), while in situ temperature scanning has shown 99oC with a thermoprobe reaching approximately 20 cm inside the fumarole. Thermal scanning in 2019 and 2022 from the thermal drone images showed no significant

changes in the surface temperature, with only a slight increase of 2°C in maximum temperatures, likely due to atmospheric influences.

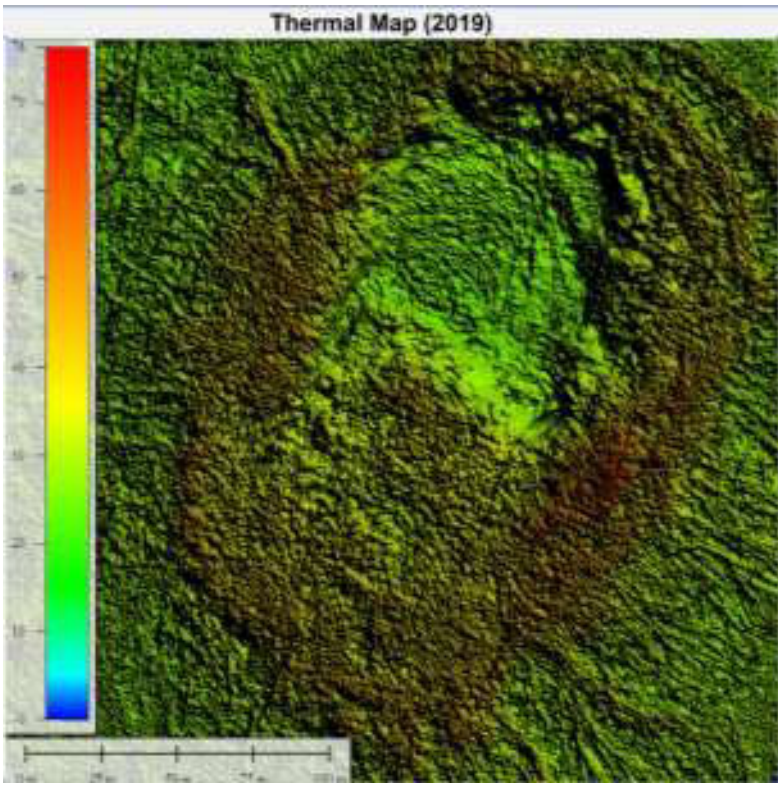

Figure 2: Thermal map made in Pix4D and reclassified in Global Mapper v.23.1 with a vertical scale showing the maximum (red) and minimum temperatures (green) scanned on Stefanos crater at Nisyros in 2019.

In figure 2 and 3 green regions are cooler surface temperatures while red regions are hotter temperatures representing most of the time fumaroles. These findings suggest that the heat emissions from the fumaroles remain relatively stable over time, supporting the sustainability of agricultural practices on the island.

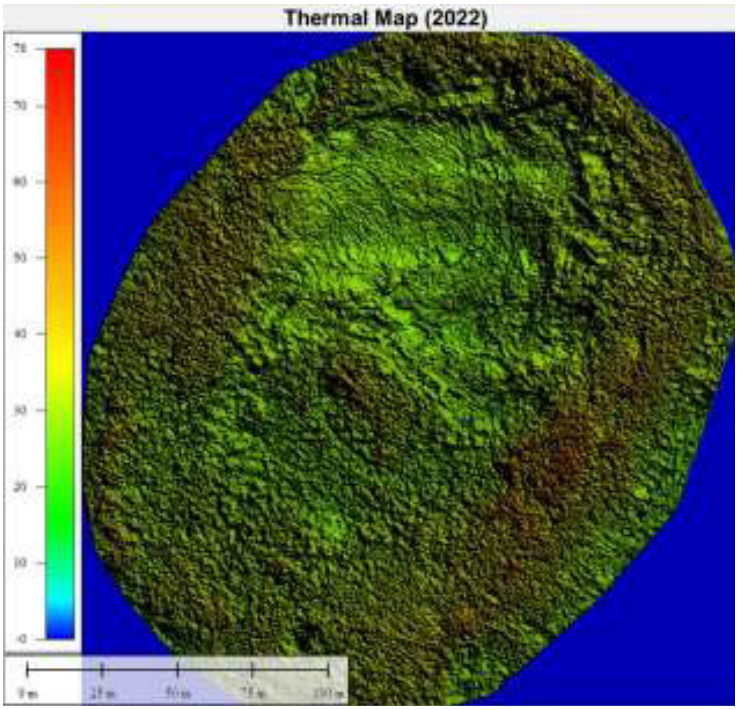

Figure 3: Thermal map made in Pix4D and reclassified in Global Mapper v.23.1 with a vertical scale showing the maximum (red) and minimum temperatures (green) scanned on Stefanos crater at Nisyros in 2019. Thermal map made in 2022 utilized the same parameters, equipment and methodology as in thermal images in 2019.

The consistent thermal signature observed indicates that fumaroles continue to operate as sources of important elements. These elements may include heavy metals, which may pose risks to human health, as well as beneficial nutrients that enhance soil fertility and support agricultural productivity. The results are consistent with previous research indicating the stability of volcanic emissions in the region. The absence of significant temperature changes aligns with other studies [19], which reported similar thermal stability in the Nisyros volcanic system.

IV. DISCUSSION

A. Implications for Agricultural Sustainability

The stable heat emissions from the fumaroles suggest that the risk of heavy metal contamination is manageable, allowing for the continuation of agricultural activities on Nisyros Island. However, ongoing monitoring is essential to detect any potential changes in emission patterns that could impact soil and water quality. Of course there are challenges and limitations, including but not limited to funding and flight conditions upon arrival to ensure a successful scan. While drone thermal scanning provides valuable insights, it is limited by factors such as atmospheric conditions and the resolution of thermal cameras. Complementary methods, such as geochemical XRF analysis, are needed to verify and quantify heavy metal contamination. The cost of additional geochemical analyses should be considered in future budget planning to ensure a sustainable annual monitoring practice.

B. Recommendations for Agricultural Management

Based on the findings, it is recommended that agricultural practices on Nisyros Island continue with regular monitoring of thermal emissions and soil quality. The integration of drone thermal scanning with geochemical analysis will enhance the accuracy of contamination assessments and support the development of effective mitigation strategies. The cost-effectiveness of drone-based monitoring allows for frequent assessments, ensuring timely detection of potential risks.

V. CONCLUSION

This study demonstrates the utility of drone thermal scanning for assessing the impact of fumaroles on agricultural sustainability in volcanic regions. The consistent heat emissions observed on Nisyros Island support the continuation of agricultural activities with appropriate monitoring and management practices. Integrating thermal scanning with geochemical analysis should provide a comprehensive assessment of heavy metal risks. The cost-effective nature of drone thermal scanning makes it a viable option for ongoing environmental monitoring and management.

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