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ARTICLE

Utilizing Remote Sensing and GIS to Study Natural Disasters "Volcanoes" and Their Impact on Climate Change

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ABSTRACT

Multifarious regions around the world are exposed to natural hazards and disasters, each with unique characteristics. A higher frequency of extreme hydro-meteorological events, most probably related to climate change, and an increase in vulnerable population have been addressed as potential causes of such disasters. To mitigate the consequences of these disasters, Disaster Risk Management, including hazard assessment, elements-at-risk mapping, vulnerability and risk assessment of spatial components as well as Earth Observation (EO) products and Geographic Information Systems (GIS), should be considered. Multihazard assessment entails the evaluation of relationships between various hazards, including interconnected or cascading events, as well as focusing on various levels from global to local community levels, as each level manifests particular objectives and spatial data. This paper presents an overview of the diverse types of spatial data and explores the methods applied in hazard and risk assessments, with volcanic eruptions serving as a specific example. The rapid development of scientific research and the advancement of Earth Observation satellites in recent years have revolutionized the concepts of geologists and researchers. These satellites now play an indispensable role in supporting first responders during major disasters. The coordination of satellite deployment ensures a swift response along with allowing for the timely delivery of critical images. In tandem, remote sensing technologies and geographic information systems (GIS) have emerged as essential tools for geospatial analysis. The application of remote sensing and GIS for the detection of natural disasters was examined through a review of academic papers, offering an analysis of how remote sensing is utilized to assess natural hazards and their link to climate change.

Keywords: Remote Sensing; Volcano; Climate Change; GIS

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1. Introduction

Earth and planetary system science has experienced remarkable progress that is mainly due to advancements in observational technologies for both Earth and celestial bodies. At the same time, research has delved into the complex interactions between natural phenomena and human activities by addressing environmental concerns along with resource management and disaster mitigation as key issues [1]. This field has transitioned from its origins in resource-heavy governmental and military projects to a broader landscape that includes commercial ventures. It has also focused on missions along with using small satellites and cost-effective solutions for better improvements onwards. As of three years ago, seven nations have successfully established their operations regarding independent *"Earth observation satellite systems"* along with forecasting the number properly. This number has the potential to double within the next three years. In addition, several commercial satellite systems are capable of high-resolution imagery, marking a significant development in space technology [2].

The rapid development of scientific research and the advancement of Earth Observation satellites in recent years have revolutionized the concepts of geologists and researchers. These satellites now play an indispensable role in supporting first responders during major disasters. The coordination of satellite deployment ensures a swift response along with allowing for the timely delivery of critical images. In tandem, remote sensing technologies and geographic information systems (GIS) have emerged as essential tools for geospatial analysis. They also enable researchers to monitor Earth's natural resources along with assessing the impact of human activities on the environment. These tools have benefited from advancements in sensor technology along with data processing capabilities and algorithms, which have significantly expanded their applications. Remote sensing and GIS now enable continuous monitoring of the Earth's resources, making sustainable resource management more achievable [3]. Numerous research projects have leveraged cutting-edge technologies to investigate the causes and impacts of natural disasters. This also reflects the increasing importance of this field in light of the rising threat of climate change.

Many urban areas are particularly vulnerable to natural disasters where researchers are growing concerned over their effects [4]. The threat is amplified by their ability to bring about rapid and significant environmental changes posed by disasters. These events often result in injuries or fatalities along with the destruction of vital infrastructure and natural resources, as well as arable land and forests [5]. The socio-economic effects of natural disasters are profound, depending on the frequency and magnitude of these events. Furthermore, natural disasters have denoted geographical specificity, with different regions facing different types of threats. Nations are also developing through suffering disproportionately, accounting for over 95 percent of all fatalities linked to natural disasters. High population density and poor infrastructure have also contributed to chronic exposure to extreme weather conditions, making these regions especially vulnerable [6].

Over the past four decades, the world has witnessed numerous catastrophic events, including floods, earthquakes, volcanic eruptions, and storms. These factors have caused extensive economic damage along with environmental damage. The livelihoods of millions have been disrupted by destruction, as these disasters have often undone years of progress in urban development. Buildings, infrastructure, and the essential elements of modern cities are destroyed in the blink of an eye, and lives are tragically lost. Another level of devastation occurred during the 2011 tsunami in Japan, which resulted in enormous loss of life along with widespread destruction of property [7]. Their effects can range from the immediate loss of life and property to long-term disruptions in a nation's development. The majority of countries with limited resources are recovering from such disasters, which is often an uphill battle. The costs of rebuilding infrastructure and providing healthcare for managing displaced populations can overwhelm governments in developing nations. The environmental damage caused by these disasters can further hamper efforts to rebuild when agricultural land and forests are destroyed. These challenges underscore the importance of continued research and development in Earth and planetary system science for improving disaster prediction and proper strategies.

Volcanic risks represent a significant category of natural hazards that impact both developed and developing nations equally [8]. Volcanoes can offer numerous benefits, where fertile soils and clean water supplies are developed for accessible construction materials. The dangers are often underestimated when their eruptions occur infrequently [9]. Volcanic eruptions create hazardous conditions that can extend far beyond the immediate area surrounding the volcano. It also impacts people and infrastructure in valleys downstream where regions are located far away[10]. Throughout the 20th century, volcanic eruptions have caused considerable disruptions to both economies and societies, making them a crucial natural force with the potential to drive significant changes. Volcanic eruptions play a vital role in climate change over various timescales, as they can inject massive amounts of gases and solid aerosol particles into the stratosphere. They can influence the Earth's radiative balance and disturb the chemical equilibrium of the stratosphere.

These emissions include tens of teragrams of sulphur dioxide (SO_2), which are converted into sulphate aerosols over a period of weeks[11, 12]. The resulting sulphate aerosol cloud remains in the atmosphere for about a year, impacting both shortwave and longwave radiation[13]. This imbalance affects surface temperatures, causing direct radiative effects and indirect impacts on atmospheric circulation (Robock). The challenge is further compounded by increasing populations along with developmental pressures and the expansion of air travel over volcanic regions which are posed by volcanic eruptions. The increasing exposure of populations and infrastructure to volcanic hazards, exacerbated by urban expansion near volcanic areas and the growth of global air travel, is a serious concern. Fortunately, satellite data has become an invaluable resource for monitoring volcanic activity, which has been since around 50% of potentially active volcanoes (approximately 1,400), along with a lack of traditional ground-penetrating monitoring instruments[12, 14]. Satellite data provides additional spatial and temporal perspectives, where complementing on-the-ground data collection along with proper monitoring instruments. The use of satellite imagery and data for studying volcanic activity is increasing which is offering researchers vital information to better understand and mitigate the effects of volcanic eruptions[15].

To achieve sustainable development, it is essential to incorporate volcanic hazard assessments into various domains, along with developing land-use planning, infrastructure development, and disaster management policies. By adopting these strategies, communities can improve their preparedness for volcanic events, reducing the potential harm and building long-term resilience[16]. Satellite remote sensing has become an essential tool for disaster management because it can provide broad geographical coverage and frequent data updates. These tools must be capable of handling large datasets for integrating them with other sources of information, along with maps and measurements from ground stations[17]. Geographic Information Systems (GIS) have gained increasing importance in the field of disaster management for enabling better planning and response to natural hazards. First, the subject and relevant sub themes are identified by using specific keywords. A database has been conducted in reputable indexing systems through SCI, Scopus, and Google Scholar. After reviewing the abstracts, articles are prepared based on predetermined criteria and more than 44 papers are sorted into three distinct groups for further analysis. By improving our ability to assess volcanic hazards, we can not only protect lives and property but also enhance the sustainability of communities living near volcanic regions.

Remote sensing on volcano monitoring:

Persistently active volcanoes pose a constant threat to both populations and infrastructure, which are exposed to the risks of primary and secondary volcanic hazards. In these areas, continuous ground-based monitoring is conducted by local or regional volcano observatories, and it is crucial for mitigating potential hazards. Over the past few decades, advancements in satellite technology have led to a growing role for satellite remote sensing, also known as *"Earth observation (EO),"* within the volcano monitoring. EO data has proven useful in various applications within volcanology, including the tracking of volcanic gases and ash. It also monitors heat emissions and conducts optical measurements for mapping ground deformation to assess geological hazards. However, half of potentially active volcanoes are monitored by ground-based sensors due to the high cost and difficulties of maintaining equipment in volcanic regions. The absence of comprehensive monitoring systems can have serious consequences, as demonstrated during the 2018 eruptions at "Fuego (Guatemala)" and "Anak Krakatau (Indonesia)". This incident resulted in over 430 fatalities. In the context of Chaitén in Chile, volcanoes are considered dormant, having erupted in 2008 after 8,000 years of inactivity. These are often not monitored but still pose significant risks.

1.1. Types of Volcanic Monitoring and Related Methods to Detect Volcanic Risks

1.1.1. Surface Deformation

Volcanic activity is characterised by alternating periods of eruptions and quiescence, where volcanic systems can remain active beneath the surface. During the quieter phases, it is also exhibiting signs of seismic activity, which is associated with the hydrothermal processes, degassing, and deformation [18]. These ongoing processes are critical in understanding the dynamics of magma movement within the Earth's crust. The ascent and emplacement of magma play a significant role in crustal differentiation where magma introduces new material to alter the composition of the crust. James Hutton's concept of plutonism is one of the remarkable theories where magma transport has dated back to the 18th century for understanding geological processes [19]. A significant portion of the oceanic crust at divergent plate boundaries is formed by the intrusion of magma into dykes and it is divided into *"vertical fractures"* full of magma. The study of dyke mechanics is crucial for understanding the process of crustal formation. In many cases, magma-filled fractures are arrested before they can result in an eruption. Theoretical explanations have indicated that dykes may contribute to the formation of grabens along with large rift valleys which are in rift zones and volcanic regions [4].

In these areas, the minimum principal compressive stress (σ3) is typically horizontal, where it aligns with the direction of rifting. Vertical dykes are the most common pathway for magma in rift zones where magma-filled fractures tend to form perpendicular to σ3. This tracking of the magma-filled fractures where the Earth's surface is critical for both forecasting eruptions and assessing volcanic hazards. Magma accumulates at shallow depths to move upward, where it generates surface deformation along with seismic activity and gas emissions. These signals allow scientists to infer the path of magma for observing and interpreting the characteristics of the underlying magma plumbing system. Ground displacement is caused by the movement of magma, where it can be measured using various techniques. *"Monitoring Volcanic Deformation"* has included the location, depth, and volume of the magma, which can be deducted as well. Surface deformation is observed in volcanic rift zones, where volcanic edifices provide valuable insights into the geometry to develop sheets and dykes during periods of unrest.

The models and methods used to interpret these deformations are vital for assessing volcanic hazards and predicting the behaviour of magma and its potential impact. They have included analytical tools for understanding the surface, which affects vertical extension fractures developed over many years [20–22]. According to this model by [23], surface tensile stress concentrations develop on either side of the dyke where no concentration occurs directly above the fracture tip [4]. As per the concepts of the Harrat Lunayyir episode (2009) (**Figure 1**), both dyke emplacement and normal faulting are triggered by regional extensional forces. The surface deformation has been caused by the 2009 dyke emplacement, where it has resulted in the formation and reactivation of tension fractures and normal faults. Tension fractures can only extend to a limited depth before transitioning into normal faults, as explained by Griffith's crack theory [24]. As per the clarification of this theory, the entire clarification is supported by field observations in both active and fossil rift zones. Numerical models suggest the 2009 episode, where the dyke tip was arrested at a shallow depth, which was only a few hundred metres below the surface [25]. This arrest has significantly heightened the volcanic hazard, where the magma intrusion came dangerously close to reaching the surface, posing a considerable threat (**Figure 2**). This event illustrates the importance of continuous monitoring along with accurate modelling in understanding volcanic systems to reduce the risks to human populations and infrastructure.

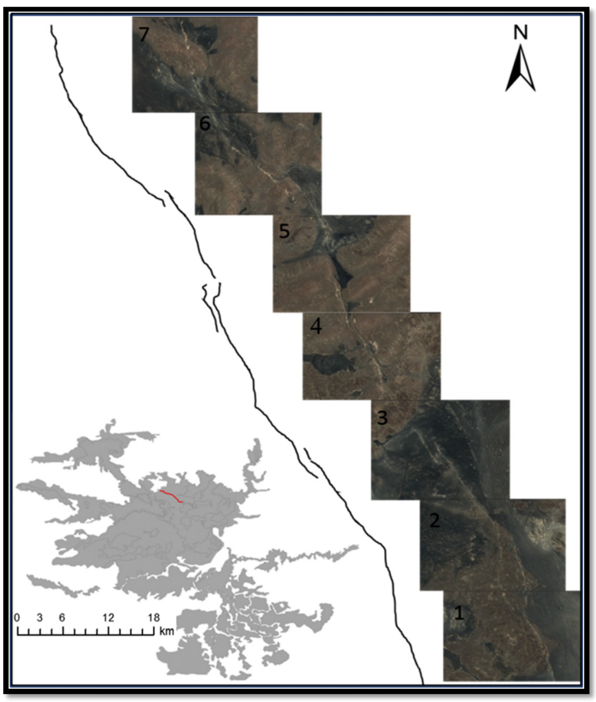

Figure 1. Harrat Lunayyir.

Figure 2 illustrates a numerical model of a dyke that is arrested with its tip located 300 metres below the Earth's surface. The magmatic overpressure exerted within the dyke is 6 MPa, where the Poisson's ratio for all rock layers is set at 0.25. The uppermost four layers of the model are each 100 metres thick and the surface layer has a Young's modulus of 3 GPa, which is followed by a more compliant layer with a Young's modulus of 1 GPa. Two additional layers have a Young's modulus of 27 GPa. The layer containing the dyke itself has the highest Young's modulus of 40 GPa. Part (a) presents a schematic overview of the model, though the thicknesses of the layers and the dyke height are not to scale. Part (b) shows the maximum principal tensile stress distribution where σ3 shows values ranging from 0 to 10 MPa. Part (c) highlights the von Mises shear stress at the Earth's surface, which is a measure of the stress combination for values ranging from 0 to 10 MPa. Part (c) highlights the von Mises shear stress at the Earth's surface, which is a measure of the stress combination. Finally, part (d) depicts the distribution of the maximum principal tensile stress at the Earth's surface.

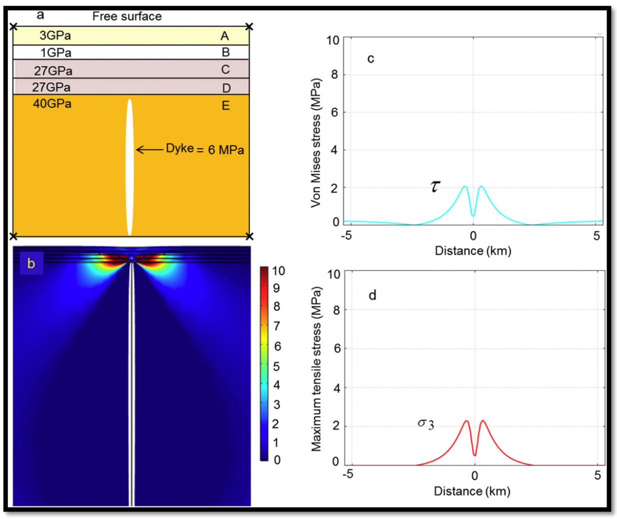

Figure 2. Arrested Dike.

Volcanic geodesy is one of the parts of the study of ground deformation at volcanoes, which began in the early 20th century in the U.S. and Japan by using traditional topography techniques. The first electronic distance measurements (EDM) for monitoring volcanic activity were conducted at *"Kilauea volcano (Hawai'i)"* between October 1964 and March 1965.. Similar measurements were carried out in 1965 at Mauna Loa's caldera. This approach has been widely adopted for tracking surface changes at active volcanoes.

Recent advances in satellite technology have significantly improved the ability to monitor volcanoes, particularly in remote areas[26]. Space-based techniques allow for detailed observation of surface deformations along with modelling of subsurface processes, including magma intrusion[19]. *"Synthetic Aperture Radar (InSAR)"* has been in use since 1995 to detect volcanic ground displacement. InSAR allows for continuous year-round monitoring of deformation with high spatial resolution, making it ideal for studying volcanic processes and surface changes (Measuring Ground Deformation, **Figure 3**).

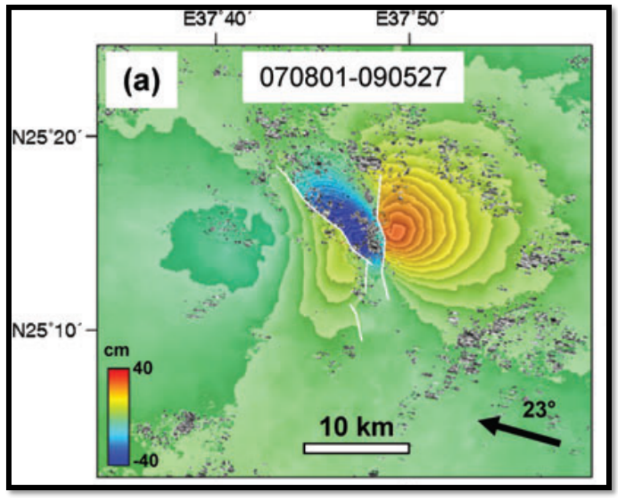

Figure 3. For the major deformation periods, the unwrapped phase is draped upon the corresponding wrapped fringes. Each fringe cycle corresponds to 28 mm displacement in the satellite-to-ground direction. White lines in (**a**) mark the faults. Arrows show satellite view directions and incidence angles.

"Interferometric Synthetic Aperture Radar (InSAR) data" is from *"Sentinel-1 and COSMO-SkyMed",* which helps to measure surface displacements in volcanic regions worldwide. InSAR provides highly precise measurements that detect ground deformation with centimetre to sub-centimeter accuracy over large areas. This technology is essential for monitoring magmatic processes in active volcanic zones, where it has the ability to capture data in all weather conditions within *"the Aleutian Islands"*. The region makes it invaluable for volcano monitoring where optical imagery is often unreliable due to poor weather. The surface deformation data is collected from InSAR images which allow scientists to create detailed models to better understand volcanic processes. SAR amplitude imagery is useful for tracking changes in volcanic structures over time so that SAR data can measure the growth rate of the lava dome[27].

1.1.2. Thermal Signals on the Surface

Volcanic eruptions pose unpredictable hazards to both populations living near active volcanoes and air travelers where flight paths may intersect with ash-laden eruption clouds. One key method involves detecting variations in thermal signals from fumaroles along with lava domes, which can indicate volcanic activity [28]. Volcanic regions often feature geothermal systems that are characterised by elevating the crustal heat flow. This heat is typically related to young igneous bodies along with deeper hot rocks where heat is transferred to the Earth's surface through the convection of groundwater by forming *hydrothermal systems* [29].

Volcanic eruptions generate significant heat from a geophysical perspective, where magma ascends toward the surface. It fractures the surrounding rock during intrusion and eruption, where it loses heat to the crust and atmosphere [16]. This heat exchange is a critical signal that helps scientists monitor volcanic activity. During the 21st century, infrared remote sensors have been increasingly utilised to observe volcanoes, making it easier to detect thermal signals and monitor changes in these signals. Wright et al. [30] used satellite sensors to track the eruption of Anatahan Volcano in the Northern Mariana Islands, capturing radiant emissions as well as ash and sulfur dioxide (SO_2) ejections. Similar studies were conducted by Webley et al. [31] for eruptions at the Alaskan volcanoes Augustine and Redoubt. Volcanic activity manifests in various forms across wide temporal and spatial scales making it challenging to monitor every active volcano from the ground. Geographical and topological challenges often prevent ground-based observation of volcanoes where volcanic activity results in increased surface temperatures [7]. This has led to the development of remote-sensing approaches that use satellite data to investigate volcanic hotspots. These methods are primarily divided into two categories: one explains the *"Landsat Thermal Mapper (TM)"* and other explains the *"Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)"*.

The ASTER sensor is particularly useful for monitoring volcanic activity because it collects image data across different wavelength channels. It captures the stages of emitting energy in the visible and "near-infrared (VNIR)" region in three "wavelength channels (0.56–0.81 μm)" at 15 metres per pixel spatial resolution. In the "shortwave infrared (SWIR) region", it captures "six channels (1.65–2.40 μm) at 30 metres per pixel". In the "thermal infrared (TIR) region", it captures five channels "(8.29–11.32 μm) at 90 metres per pixel spatial resolution" [32]. Moreover, the ASTER sensor maintains a regular observation schedule for the world's active volcanoes to focus on the circumstantial situations. As of June 2009, over 96,000 distinct ASTER scenes have been collected for 964 of the most active volcanoes globally. Pieri and Abrams (2004) [33] included that it counted to an average of five daytime and six nighttime observations per volcano per year. These regular acquisitions provide critical data for understanding volcanic activity. It is also assessing potential risks by making remote sensing a valuable tool in volcanic hazard monitoring. Through these efforts, the study aims to contribute to the understanding of remote sensing and GIS technologies which can be leveraged to better monitor volcanic activity.

Researchers can obtain comprehensive satellite photos of volcanic ash flows and lava flows by using above-ground satellite sensors that have extremely high resolution in space [33]. However, they lack high temporal resolution and are not designed for ongoing volcanic surveillance [34]. The second type has low spatial resolution but high temporal resolution. It uses sensors from "the Geostationary Operational Environmental Satellite series (GOES)", "the Advanced Very High-Resolution Radiometer (AVHRR) on board NOAA", and "the MODerate Resolution Imaging Spectroradiometer (MODIS)" in terms of further continuously monitoring some volcanic activities [35, 36].

Small lava flows are not visible in these satellite photos; however, MODIS allows for four daily monitoring of the target volcano. Every 15 minutes, GOES sensors may produce an image of the surface temperature. But only the MODIS sensor can provide a detailed view. While GOES has a maximum spatial resolution of 4 km, MODIS has a maximum of 1 km. According to Wright et al. [37], MODIS can monitor a wide range of objects, including atmospheric temperature, cirrus clouds, water vapour, cloud characteristics, plumes, and ozone. It can view 36 distinct wavelengths in the mid-infrared spectrum. Although there is less atmospheric effect in the mid-infrared range, such as "Band 20 of MODIS" and "Channel 3 of AVHRR", there is a trend for cloud surfaces to be colder. Compared to "Channels 4 and 5 of the AVHRR (thermal infrared range)", "Bands 31 and 32 of MODIS" are more sensitive. For this reason, MODIS is regarded as one of the most effective instruments for tracking volcanic activity [38]. However, concentrating on volcanic surfaces specifically, highlight the value of infrared observations from the Hyperion sensor aboard the NASA Earth Observation System (EOS) satellite, illustrating how an algorithm might offer automated volcanic observations [39].

With a range of view that encompasses multiple active volcanoes, the "SEVIRI imager" is now the most sophisticated "geostationary multispectral imager" available. This multispectral imager is part of "the EUMETSAT-operated Meteosat 2nd generation geostationary meteorological satellite fleet". The sensors cover "12 channels" in the visible, shortwave, and thermal infrared spectrum, with coverage of Africa, Europe, and the Middle East every 15 minutes or less. With an overlap factor (detector size to sampling distance) of 1.6, the panchromatic band's sample interval at nadir is 1 kilometre, whereas the other bands' is 3 km [40].

1.1.3. Emissions of Gas and Ash

The main gaseous emissions of volcanoes are hydrogen sulfide, water vapour, carbon dioxide, carbon monoxide, hydrogen, sulfur dioxide, and hydrogen chloride in the form of H_2O, CO_2, SO_2, HCl, NH_3, H_2S, and HF. Some other highly reactive metal components are also emitted [41]. Several gases, compounds and aerosols are released directly into the tropical troposphere through volcanic activities. At times large events can soar to the stratosphere level. Explosive volcanic eruptions discharge large quantities of gases into the atmosphere and since the upper winds are likely to move them in any direction when a number of eruptions occur at some distance, the combined effects of those eruptions are felt. They can be moved rapidly zonally; for example, the eruption of Puyehue Córdon Caulle, southern Chile erupted in June 2011 when ash and SO_2 moved in circles around the Southern Hemisphere in latitudes 30° S and below. It can be ejected vertically through air circulation, as happened with Nabro, Eritrea, also in June 2011, where the monitoring circulation may have contributed to the lifting of SO_2 gas to the stratosphere [42]. These gases react swiftly with the ash of a working plume and especially atmospheric water to yield acidic aerosols [43]. The identity and concentration of F-bearing compounds developed in aerosols that coat the tephra particles are generally studied by leaching approaches.

Technological development of volcanology instrumentation and monitoring techniques in the last decade gives higher spatial and temporal scaling of temperature, composition, and flux of volcanic emissions of gaseous and tephra materials than earlier observations. Volcanic activity is inherently irregular and random and occurs all over the world. Satellite remote sensing is used to monitor and quantify emissions around the globe. This is because these emissions can be injected at any point of the troposphere or in the stratosphere; they are rapidly dispersed by the 3-D winds. Satellite measurements through passive infrared (IR) have limited vertical height information. This, nevertheless, can be derived from a combination of satellite data and transport simulation [44].

SO_2 emissions from volcanic sources sensed from the ground and from the air have often been seen to increase before eruptions, and have been suggested as resulting from changes in three instances. Firstly, because of relative magma degassing in response to low volatile solubility in pressure-releasing magma [45]. Secondly, due to conduit permeability [46], or thirdly, by scrubbing of strong acid gases. Predicting the movement of fine ash in the 3-D is carried out through volcanic ash transport and dispersion models. The mass eruption rate (MER) is not normally accessible even after analysis, for the required initialization and thus either an arbitrary value is chosen. For this purpose, Stohl et al. [47] developed an inversion scheme using satellite observations with the flexpart Lagrangian transport model for better calibration of the MER of fine ash and SO_2.

Only major eruptive plumes [i.e., rising higher into the upper troposphere and to the stratosphere] SO_2 and ash concentrations have been routinely sampled until now. However, more recent attempts have been made to measure other gases. For example, a minor volcanic plume constituent such as BrO was detected from the eruptive sites of Kasatochi and Eyjafjallajökull [48, 49]. Satellite-based estimates of volcanic CO_2 carry a lot of potential even at an earlier stage. The first experimental Greenhouse Gas (GHG) sensor, Greenhouse gases Observing SATellite (GOSAT) was carried into orbit by the Japanese Space Agency in 2009 [50]. GOSAT is in a sun-synchronous orbit, and it takes three days to repeat a cycle over the same area. In a way to enhance the fraction of solar radiation, CO_2 and CH_4 columns can be retrieved from Short-Wave Infrared Spectra (SWIR) spectra with high accuracy and very high sensitivity to the lower atmosphere where the volcanic enhancements will take place [51]. GOSAT has a target-pointing ('stare') mode with high utility in observing enhancements in volcanic regions. NASA plans to launch its

OCO-2, an instrument that will measure the concentration of CO_2, in 2014.

1.1.4. Lava Flows

Lava flow eruptions have multifarious consequences on groups and structures in volcanic areas around the globe. Pāhoehoe lava flows affect habitats and are potentially dangerous to societies living close to modern basaltic volcanic centres globally. Quantifying lava flow hazards is useful for preliminary planning at intervals between eruptions. Critical assessments are crucial where there are outbreaks of eruptions. In general, Pāhoehoe spreads slower than ʻaʻā. However, it moves further and occupies a larger area which is threatening in the long run [52].

Consequently, the mapping of active lava flows is a source of information useful for documenting the current eruptions. It is also beneficial for understanding the process of lava flow fields' formation which is important for future behaviour prediction. Lava flow mapping from volcanic eruptions has several applications including vent positioning, areal extents (widths and lengths), and volumes of the flows. Lava fields are mapped mostly based on ground observations, as stated by Ganci et al. [53]. It is also done through Unmanned Aerial Vehicles (UAVs) in the air. Satellite remote sensing provides the big picture for active lava zones without the complications of dealing with dangerous areas. Mapping the aerial extent of active lava flows is a difficult process when using conventional field techniques. This is because of the enormous area that the flow fields occupy, and several flow field areas are often inaccessible. Lava volumes can be obtained by either folding or compounding the lava flow area with real field lava flow thickness or by using the method of deducting pre-eruption and post-eruption digital elevation models (DEMs). These volumes can be applied in magma supply models and time-series analyses to further the understanding of volcanic eruption mechanisms [54].

As noted by Aufaristama et al. [55], in the high eruption frequency areas, the lava flows are mainly overlapping, and they may have similar spectral responses that make it challenging to distinguish them. Other factors that may slim down or limit the extent to which it separates one spectral signature from another are the spectral variety and the resolution, the variety of spectral bands, and the decision of the satellite imagery. Hyperspectral satellite statistics, nonetheless, lack spatial resolution (Earth gazing-1 or EO-1 Hyperion having a floor resolution of 30 m). Therefore, airborne sensors may assist, but acquisition surveys are required on precedence. Such abilities are discussed by the authors regarding the evaluation of hyperspectral statistics. The information is recorded in the 622 channels with a spectral range of about 400 to 2500 nm, making use of the Aisa Fenix sensor onboard the Natural Environment Research Council (NERC) Airborne Research Facility five months after the Holuhraun 2014–2015 lava flow, NE Iceland. This event lasted for nearly six months, from 31 August 2014 to 27 February 2015, and generated a voluminous batch of basaltic lava of approximately 1.44 km^3. For instance, a heterogeneous landscape to explore and map lava accumulation. The aim is to extract the dominant lava surface type meditated inside the airborne hyperspectral information at the uppermost surface of Holuhraun over the period, around the eruptive fissures vent. This availed excessive-decision aerial photographs of the lava area at 0.5 spatial decisions for validation of the unmixing results. In a way to address the problem of atmospheric interference, the Quick Atmospheric Correction (QUAC) algorithm was applied to the data and for the hyperspectral image classification for spectral endmembers and fraction analysis, the Sequential Maximum Angle Convex Cone (SMACC) method was used. In total, 15 members (i.e., portraying pure surface components in a hyperspectral image) were estimated and categorised into six groups based on the shape of the end members. The six groups are Basalt, hot material, oxidised surface, sulfate mineral, water, and VI is noise. This was necessary because the amplitude was not uniform due to illumination conditions, spectrum and terrain data. For the respective abundances from each endmember group, fully constrained Linear Spectral Mixture Analysis (LSMA) was performed. The authors further find that the application of SMACC and LSMA methods provides an optimum and fast selection of volcanic product segregation. Nevertheless, original spectra are suggested to undergo further analysis with the ground-truthing spectra.

However, Dávila et al. [56] used satellite imagery to adjust and enhance the assessment of the temporal situation of the various eruptive phases recorded at Volcán de Colima in Mexico from September 2014 to September 2016, with the July 10–11, 2015 eruption. This eruption was the most violent since the 1913 Plinian phase. To a large extent, their analysis focused on satellite products. The topographic models of the SPOT-6 twin-stereoscopic and tri-stereo pair pixels were used to create the virtual surface fashions or DSMs. It then estimates the volumes of the lava flows and the main pyroclastic flow deposits. In parallel, satellite Pour l'Observation de la Terre 6 and 7 (SPOT-6/7) and Earth Observing-1 Advanced Land Imager (EO-1 ALI) statistics have been recombined to specify the spatial distribution of the lava flows before and after the eruption of July 2015. Those two units of Digital Surface Models (DSMs) were then used to carry out course-making plans to simulate the manner lava may flow once released from a volcanic vent with the use of a lava simulation software known as the Flow Model of Etna Lava (ELFM). In this manner, the authors used this method to estimate the overall extent of the magma discharged throughout the event of 2014–2016 as forty 10^7 m^3. This is one order of magnitude lower than that of the 1913 Plinian eruption. A larger magma volume resident in a magma chamber could be required. As seen within the supplementary section of the 1913 eruptions, dome destruction might have been determined by way of explosive processes for the 2015 eruption considered just like the 1913 event.

The Fuego volcano was looked upon by Cando Jácome and Martínez-Graña et al.[57]. Here, the presented civil work uses satellites to supplement the hazard maps as a result of an eruption. For instance, the authors were concerned with the strong eruption that happened on 3rd June 2018. Here, a dark cloud of volcanic ash 10 kilometres high and destructive pyroclastic flows jointly led to about two hundred lives lost and enormous economic losses in the surrounding area. Two lahars for medium and heavy rains in the post-eruption scenario were created from the numerical models using the LAHARZ software organised at the United States Geological Survey. In an attempt to enhance lahar location mapping, Sentinel-1 SAR (Synthetic Aperture Radar) data were subjected to Differential Interferometric SAR (DInSAR) analysis. This was relevant to identify regions of the volcano flanks where lahar emplacement and triggering may have taken place. Thus, in an effort to model the pathways of the lahars, several parameters and morphology are considered. They check the accumulation of flow, a topographic wetness index, and an identification of the length-magnitude factor of the slope, which has been analysed within the framework of the System for Automated Geoscientific Analysis or SAGA software application. A separate procedure for the stability analysis of the slope was done with Shallow Landslide Stability software (SHALSTAB). This and its parameters are dependent on the Mohr-Coulomb theory. This helped in the accurate management of areas destroyed due to primary and secondary lahars of volcanoes.

2. The Role of GIS in Volcano Disasters

Volcanic hazard and risk have gained increased attention in recent years, particularly in light of some catastrophic eruptions and the resulting social and physical effects, as demonstrated by the eruptions of Mount Sinabung, Indonesia (2014), Taal, Philippines (2020), and Chaitén, Eyjafjallajökull, Iceland (2010). The first idea is hazard, which is the likelihood that a potentially harmful natural phenomenon would manifest itself at a certain location during a given time frame. According to Gehl et al.[58], this phenomenon may result in property damage, loss of livelihoods and services, injury or other health effects, loss of life, disturbance of the social and economic order, or environmental harm. Hazard assessment, on the other hand, is the process of mapping and characterising the location, size, shape, probability of occurrence, and other features of a specific threat, event, phenomenon, process, circumstance, or activity that could potentially harm the impacted population as well as harm the public and the natural world[59].

The evaluation of volcanic hazards in the past has mostly relied on heuristic methods supported by thorough ground-based geological and geomorphological surveys[60]. With the help of geographic information systems (GIS) and computer codes, recent developments in information technology have made it possible to simulate natural disasters like flooding, storms, tsunamis, and damage scenarios in a realistic manner[61]. To help with risk analysis, GIS offers a tool for expanding hazard and vulnerability mapping. Developing a process using GIS assistance facilitates the automation of the laborious and intricate steps involved in creating a risk assessment. Knowing how communities may be impacted can help respond to volcanic occurrences more effectively (Sheridan and Patra, 2005). Computer-based tools called GIS are used to store and manage geographic data. According to Aranoff (1989), their purpose is to "assist in the capture, management, manipulation, analysis, modelling, and display of spatially referenced data towards the resolution of complex organisational and planning problems." Data manipulation can take many forms: from the straightforward overlay of several theme maps to identify regions meeting particular requirements, to the more complex applications of mathematical operators or integrated numerical models to forecast the dynamics of natural occurrences. GIS technology enhances scientific research as well as decision making when used in land use planning, natural resource protection and management. It can also act as a "stand-in laboratory for researching environmental processes"[62].

Thanks to recent technology advancements, web-based mapping is now mature enough to distribute spatial information about heterogeneous hazards and risks[63]. Nevertheless, creating web-based geographic information systems (WebGIS) goes beyond simply showcasing pre-existing maps. Rather, it necessitates considering the workflows of the intended users (such as decision-making authorities and civil security), i.e., how they use geographic data in their daily jobs[64]. When a disaster strikes, GIS can help with the response phase by locating the emergency vehicles nearest to the scene and allocating them to the area by the best or shortest route. As rescue vehicles are equipped with GPS equipment that allows them to be precisely located, this is becoming more and more feasible. GIS can assist in managing the entire situation and delivering timely information updates during a complicated disaster. For this reason, GIS databases must be created and kept up to date before the calamity. The best site for fire stations in the event that a 10-minute response period is needed, as well as the safest area for new healthcare facilities, emergency facilities, and headquarters, can all be determined using GIS. Which escape routes, depending on whether the volcanic plumes are real or predicted, should be chosen? Can the expected traffic be handled by the road networks? Early warning system real-time monitoring can also be shown using GIS.

3. Volcanoes and Climate Change

Gases and ash are released into the atmosphere during explosive volcanic eruptions, changing the Earth's overall radiative energy balance. The injection of sulfur gases, which produces sulfur aerosols, has the greatest effect on Earth's radiative balance at annual to centenary time scales through the scattering of solar radiation and the absorption of solar and Earth radiation (aerosol-radiation interactions)[61, 65]. Within a few weeks, "tropospheric volcanic aerosols" are removed. Because of this, it is generally believed that the global effects of individual eruptions' tropospheric aerosol-radiation interactions are insignificant, even though aerosol particles strengthen cloud condensation nuclei and thereby indirectly affect Earth's radiative balance through aerosol-cloud interactions[66]. In contrast, "stratospheric volcanic aerosols" typically have an e-folding time of one year and have a major impact on climate during these time spans. The troposphere cools while the stratosphere warms as a result of the comparatively long lifetime of these particles, which scatter shortwave radiation as well as absorb longwave radiation[61, 65]. Apart from the aforementioned worldwide impacts on air temperature, interactions between stratospheric volcanic aerosol and radiation have the potential to induce noteworthy alterations in "atmospheric and oceanic circulation", "sea ice dynamics", and precipitation patterns[67, 68]. Although this forcing is small in comparison to aerosol-radiation interactions and primarily depends on halogen scavenging in the plume, whether an eruptive plume reaches the stratosphere also controls ozone depletion by halogen species injected by a volcano[69].

Volcanic aerosols are particularly significant in the context of current global warming, which is primarily caused by anthropogenic greenhouse gas emissions, because their fingerprint of atmospheric temperature differs from that of CO_2, resulting in a net cooling of the stratosphere alongside a net warming of the troposphere[70].

"The eruption of Mount Pinatubo in the Philippines" is a recent example of a massive volcanic eruption that has a detectable climate influence, making it the greatest example to understand how a large eruption could affect the climate. June 15, 1991, saw this eruption in the Philippines at 15.1 °N, resulting in the injection of 20 Tg of SO_2 into the stratosphere[65, 71]. Because of this, the Northern Hemisphere's continents experienced a 2 °C cooler summer than usual during the boreal season in 1992. The area of Arctic sea ice increased as a result of this cooling. The warmer surface air temperatures throughout the continents of "the Northern Hemisphere" during the boreal winters of 1991–1992 and 1992–1993 separated this colder summer. According to, the winter warming is a dynamic reaction to temperature gradients created in the lower stratosphere as a result of aerosol heating, ozone depletion, and decreased tropical storminess. For the two winters after the eruption, additional dynamical impacts resulted in a positive mode of the Arctic Oscillation [72]. However, the high latitude eruptions examined here would not be predicted to cause this winter warming response; rather, it is exclusive to tropical eruptions [63].

Depending on their size and season, volcanic eruptions can have extra effects on the climate, which are amplified when they happen at high latitudes. When they happen at the right time of year, massive volcanic eruptions can impair the monsoon systems in Asia and Africa. A tropical eruption reduces solar radiation at all latitudes as the aerosol cloud covers the entire planet, extending to both the Northern and Southern Hemispheres [71]. The temperature fall over land is significantly more than the reduction in temperature over the ocean because of the land's comparatively lower heat capacity compared with that of the ocean. As a result, the temperature gradient that causes monsoonal precipitation between the land and the ocean is lessened. This was demonstrated for the Pinatubo eruption by Trenberth et al. [73]. Because of the large-scale circulation, the aerosol cloud in a high latitude Arctic eruption seldom moves south of 30° N [74]. As a result, solar flux decreases over huge landmasses, particularly in Asia, but is generally unaffected in the Indian Ocean, which amplifies the reduction in the land-ocean temperature differential. The impact of the eruptions of Laki in 1783–1784 at 68° N) and Katmai on June 6, 1912 at 58° N has been observed in historical proxy records and climatic simulations.

Based on the understanding of volcanism and its impacts on the surroundings, remote sensing techniques have been considered significant for their extensive application in mapping and monitoring eruptions. Regarding this, there has been emphasis on the timely collection of satellite images for better and detailed understanding of volcanism and its behavior. Understanding volcanism is crucial to enhancing a risk-free environment for the regions prone to volcanic eruptions severely affected by large-scale emissions and drastic rises in surrounding temperatures [60]. Hence, remote sensing methods of collecting volcanic updates have been considered appropriate for identifying and analysing the precursor signals.

In addition to mapping and deriving the precursor signals related to volcanism, remote sensing enables better understanding and reading of the land surface temperature in the surrounding regions where the volcanism occurs. Hence, it becomes an effective method for understanding the intensity of volcanism and the areas most affected by its eruptions. Thus, it facilitates risk aversion and mitigation for the surrounding regions. The remote sensing method for tracking volcanic activity is associated with the collection of Thermal Infrared (TIR) data that illustrates a synchronous aspect of dynamism in the temperature of a place [15]. Therefore, such information enables bridging the gap faced in meteorology or land surface data. Therefore, in the long term, such data ensures better mapping and monitoring to address and minimise the risks resulting from volcanic activity.

TIR data specifically becomes significant as it enables both the detection and measurement of varied mechanisms to understand and evaluate the seismic signals. In addition, the information allows a simultaneous and sequential record of changes in temperature after the volcanic activity. However, despite the benefits and necessity of TIR-based generated data, studies in this field highlight the limited application of TIR data in predicting the seismic signals of volcanism. The prime reason behind this is the existing use of conventional satellite images .Conventional satellite images are often characterised by low resolution that further limits the elaborate study of volcanism and its precursor signals. Hence, risk address and mitigation still need to be completed in the regions affected by such activities.

In this regard, satellite imagery for studying volcanism encompasses using and applying images through Landsat 7 through an advanced sequence of temperatures recorded from the surrounding surface of land and its threshold limits for measuring the heat emissions over time. However, even Landsat 7 has several disadvantages that include the use of a single thermal band that limits the scope of emission measurement and its alignment to the project goals of identifying and detecting the land surface anomalies An associated concept with this is thermal mapping techniques that rely on data generated from satellite images. Compared to the satellite imagery technique, thermal mapping is considered relatively common in studying varied thermal patterns that enable the proper prediction of volcanic eruptions.

Conventional techniques, such as meteorological monitoring and detection, are limited due to their analysis's need for appropriate spatial dimension. Hence, regarding the specific focus on spatial aspects, remote sensing projects are essential for addressing the adverse impacts of volcanic and tectonic activities. Therefore, collective analysis through the thermal technique of mapping becomes significant for a comprehensive understanding of the volcanic observations derived through remote sensing. Hence, it is concluded that despite several conventional methods to study tectonic and volcanic activities, remote sensing is significant for carefully analysing and predicting volcanic and tectonic activities in specific regions.

4. Conclusions

This research paper gives important insights into the application of remote sensing and GIS in terms of detecting natural disasters based on the information from a collection of papers. In this context, the scientific quality of these papers has also been evaluated by a diverse network of knowledgeable and reputable scientists in a variety of disciplines, such as remote sensing used to assess volcanic risk and hazard, geophysics, and volcanology. While the range of approaches and case studies covered in the papers cannot be comprehensive and representative of the entire field of scientific research on this subject, this paper offers a selection of the most recent developments in scientific knowledge and monitoring methods for volcanoes that, for various reasons, are not only fascinating to study from a scientific standpoint but, more importantly, may pose a threat to the safety of the nearby communities.

New insights into the intricate processes of the Earth that frequently result in disasters are being gained through the combination of numerical modelling and integrated satellite-based data. In situ as well as field observations, as well as data from satellite remote sensing, are increasingly being used to "supplement ground-based network data" and aid in the evaluation and response to disasters. As resources are secured over technological and infrastructure improvement, there will be more advancements in satellite remote sensing, all aimed at bridging the gap between study on natural hazards and improved operational capability within "disaster management". Monitoring earthquake and volcanic hazard is one of the mission objectives of "the Advanced Synthetic Aperture Radar (ASAR)", which is operating at "C-band onboard ENVISAT", which was launched by "the European Space Agency" in March 2002. "The Japanese Advanced Land Observing Satellite (ALOS)" is equipped with a "phased array L-band SAR (PALSAR)", "a visible and near I/R radiometer", and "a panchromatic stereo imager for digital elevation mapping". The goal of "the PALSAR system" is to continuously capture photos of land deformation. Along with solving concerns of data access continuity, interoperability, completeness, as well as validation, methods for producing information products also need to be designed through integration, assimilation, modelling, and realistic computation based simulations. The potential benefits of these sensors and their related products for operational decision-making that affects the capacity to minimise losses in life and property must be further demonstrated by "the solid Earth science research community". An essential stage is the integration of science, model outputs, and satellite data using applications, confirmation, and performance evaluation into "decision support tools and systems". The improved "decision support systems", "geospatial information products", "model-based forecasts", and "visualisations" will be used by "policy and decision-makers", "emergency managers", and "responders". In this way, these can help in planning long-term emergency services and lifelines, conducting thorough disaster assessments, and prioritising response efforts. Due to the limited resources available, cost-effective strategies will be required, with the commercial industry participating in specific components of an overall "observational architecture".

It is anticipated that international collaborations and cross-agency relationships will make it easier for civil space agencies to produce several observations as well as shared data sets. It can further effectively address important issues associated with "the solid Earth research community". Additionally, it can also be helpful in meeting the needs of the functioning as well as policymakers in disaster management.

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Data Availability Statement

The data utilized in this study was obtained from publicly available sources on the internet. The specific websites and platforms from which the data was collected have been appropriately cited and acknowledged within the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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