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Research Article

INTEGRATION OF GIS, UAV, AND GEOPHYSICAL METHODS IN DISASTER RISK ASSESSMENTS: THE CASE OF BUCA/IZMIR

AFET RİSK DEĞERLENDİRMELERİNDE CBS, İHA VE JEOFİZİKSEL YÖNTEMLERİN ENTEGRASYONU: BUCA/İZMİR ÖRNEĞİ

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ABSTRACT

This study investigates the integration of Geographic Information Systems (GIS) and Unmanned Aerial Vehicle (UAV) technologies in geosciences, focusing on geophysical applications. While GIS enables the management and spatial analysis of various data layers, UAVs allow for the rapid and cost-effective acquisition of high-resolution surface data. The synergy between these technologies enhances the modeling of geophysical processes and improves the effectiveness of risk assessment efforts. This integrated approach is supported by relevant literature, and this is exemplified through a case study conducted in Buca-İzmir, Turkey. This application used photogrammetric methods to produce a digital surface model (DSM), followed by slope analyses in a GIS environment to identify potential landslide and ground failure zones. Subsequently, geophysical surveys were conducted to model the subsurface structures associated with these risks. The findings demonstrate that integrating GIS and UAVs provides a fast, precise, and holistic framework for geophysical engineering applications. Furthermore, the study presents a practical example of how these technologies can be effectively utilized in disaster risk reduction and land-use planning.

ÖZ

Bu çalışma, Coğrafi Bilgi Sistemleri (CBS) ve İnsansız Hava Araçları (İHA) teknolojilerinin yerbilimleri ve özellikle jeofizik uygulamalardaki kullanımını incelemektedir. CBS, mekânsal verilerin yönetilmesini ve analiz edilmesini sağlarken, İHA teknolojisi yüksek çözünürlüklü yüzey verilerinin hızlı ve ekonomik bir biçimde elde edilmesini mümkün kılmaktadır. Bu iki teknolojinin entegrasyonu, yerbilimsel süreçlerin daha doğru modellenmesini ve risk analizi çalışmalarının etkinliğini artırmaktadır. Literatürdeki uygulamalar ışığında değerlendirilen bu bütünleşik yaklaşım, İzmir-Buca'da yürütülen bir örnek çalışma ile somutlaştırılmıştır. Söz konusu çalışmada, fotogrametrik yöntemlerle üretilen sayısal yüzey modeli ve eğim haritaları CBS ortamında analiz edilerek potansiyel heyelan/göçme alanları belirlenmiş, ardından gerçekleştirilen jeofizik ölçümler ile yer altı yapılar modellenmiştir. Sonuçlar, CBS ve İHA teknolojilerinin jeofizik mühendisliğinde hızlı, hassas ve entegre analiz süreçleri sunduğunu ortaya koymaktadır. Ayrıca bu çalışma, doğal afetlerin önlenmesi ve arazi kullanım planlamasında söz konusu teknolojilerin nasıl etkin kullanılabileceğine dair uygulamalı bir örnek sunmaktadır.

1 | INTRODUCTION

In today's geosciences discipline, particularly in geophysical research, significant progress has been made in data collection, analysis, and modeling processes, thanks to the opportunities provided by technology. At the heart of these advancements lie Geographic Information Systems (GIS) and Unmanned Aerial Vehicles (UAVs), which enable the production of multidimensional, high-accuracy, and integrated data related to both the Earth's surface and subsurface (Longley et al., 2015; Colomina & Molina, 2014). These technologies have enhanced the quantitative and spatial depth of geological, geomorphological, and geophysical analyses.

Geographic Information Systems are computer-based systems that allow for spatial data collection, processing, analysis, and visualization. GIS integrates multi-layered data from various disciplines, making it possible to spatially model and analyze complex natural processes (Burrough & McDonnell, 1998). GIS is a powerful tool in geosciences, particularly in mapping geophysical data (gravity, magnetic, electrical, seismic, etc.) and interpreting their spatial relationships (Kılcı et al., 2020). It has many applications, from geothermal site analyses and earthquake risk assessments to landslide potential studies and mineral exploration (Demir & Yomralıoğlu, 2017).

On the other hand, UAVs, which are systems capable of flying at low altitudes and controlled either automatically or remotely, have become widely used in geoscientific studies over the past decade. Equipped with various sensors (RGB cameras, LiDAR, multispectral, thermal, magnetometers, etc.), UAVs can generate high-resolution imagery and measurements, allowing for faster, more cost-effective, and more accessible data acquisition in hard-to-reach areas compared to traditional methods (Nex & Remondino, 2014; Malehmir et al., 2017).

In geophysical applications, UAVs have become particularly common in magnetic, electromagnetic, and thermal surveys. For instance, digital elevation models (DEMs) and orthophoto maps produced using photogrammetric techniques allow for detailed analysis of surface expressions related to geological structures (Tahar, 2012). Such data are critically important in identifying fault lines, areas at risk of collapse, landslide zones, and other natural hazard-prone regions.

The integrated use of these two technologies—analyzing spatial and geophysical data collected via UAVs within a GIS environment—enriches the data and enhances the accuracy of decision-support systems (Kavzoglu & Yildiz, 2021). As a result, more effective models can be developed in engineering practices and academic research, and geophysical events can be modeled and predicted with greater precision.

This study examines the contributions of the combined use of GIS and UAV technologies to geophysical applications, especially on current practices in fields such as mineral exploration, disaster management, and subsurface modeling. Examples from the literature will be used to evaluate the advantages provided by these technologies and the challenges encountered. The aim is to scientifically present the role and potential of GIS and UAV integration within geophysical science.

2 | GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND GEOPHYSICAL APPLICATIONS

With technological advancements, the scope of geophysical studies has evolved beyond merely measuring surface and subsurface properties. It now encompasses a multidimensional process involving adequate data storage, processing, analysis, and visualization. In this context, Geographic Information Systems (GIS) have become an indispensable tool for comprehensively managing complex spatial data (Longley et al., 2015).

GIS is fundamentally a system composed of software, hardware, data, human resources, and methodologies that facilitate the collection, storage, analysis, and presentation of geographically referenced (coordinate-based) data (Burrough & McDonnell, 1998). This holistic approach allows for the mapping of spatial data and the development of multi-layered analyses, modeling, and decision-support systems.

2.1. Integration of GIS with Geophysical Data

Geophysical data are typically complex, multi-layered datasets obtained in various formats. These datasets, collected through seismic, gravity, magnetic, electromagnetic, electrical resistivity, and ground-penetrating radar, may vary in terms of time, scale, and density, creating challenges in the interpretation process. GIS addresses these challenges by enabling data integration from different sources within the same spatial reference system, thus streamlining the analysis process (Kılcı et al., 2020).

For example, seismic refraction studies, magnetic anomaly maps, and electrical resistivity distributions from a region can be overlaid and analyzed within a GIS environment to obtain more accurate and reliable insights into subsurface structures. Such multi-source data integration is particularly valuable in mineral exploration, geothermal energy research, and geotechnical engineering projects (Zhou et al., 2015).

2.2. GIS-Supported Mapping and Visualization

One of GIS's most potent aspects is its ability to transform collected data into detailed thematic maps. For example, maps displaying magnetic intensity, resistivity distribution, surface deformation, or seismic intensity can all be generated within a GIS environment. These maps allow for straightforward interpretation of the spatial distribution of various physical properties (Lee et al., 2011).

Combining surface models like Digital Elevation Models (DEM) and Digital Terrain Models (DTM) with geophysical data helps clarify the relationship between surface morphology and geophysical anomalies. For instance, direct spatial relationships can be established between topographic features, such as fault lines or landslide areas, and seismic activity intensity (Kavzoglu & Yildiz, 2021).

2.3. GIS-Based 3D Modeling

Regarding visualizing subsurface structures, GIS-supported 3D modeling techniques offer far more effective tools for analysis and presentation than traditional 2D maps. These models use geophysical cross-section data collected at various depths to create the three-dimensional geometry of the subsurface. In particular, seismic tomography and geo-electrical cross-section data can be analyzed in 3D models to examine subsurface reservoirs, voids, and potential fracture zones in detail (Zhou et al., 2015).

Such models are used in engineering geology projects (e.g., tunnels, dams, metro lines) during preliminary design and risk assessment phases. Additionally, these models aid education and public awareness by presenting complex subsurface structures in an understandable format.

2.4. GIS and Geophysical Disaster Studies

GIS also plays a critical role in disaster risk analysis and disaster management. Temporal and spatial analysis of seismic data allows for the creation of earthquake risk maps. These maps serve as strategic planning tools for local governments and disaster management agencies (Demir & Yomralıoğlu, 2017). Similarly, GIS-supported analyses can identify risk areas for other geological hazards such as landslides, floods, and subsidence. Hazard zoning maps can be produced by analyzing factors such as topography, lithology, slope, precipitation, and groundwater levels within GIS.

GIS-based multicriteria decision analysis (MCDA) is an effective method for such risk analyses. Weighting various data layers to calculate risk values brings a scientific foundation to decision-support processes in earth sciences (Malczewski, 2006).

3 |UNMANNED AERIAL VEHICLES (UAVs) AND GEOPHYSICAL APPLICATIONS

Traditional geophysical studies often involve lengthy field data collection processes, difficulties in accessing remote regions, and limitations in measurement density. To overcome these challenges and enhance the efficiency of data acquisition, Geographic Information Systems (GIS) and Unmanned Aerial Vehicles (UAVs) have increasingly been adopted in geophysical research in recent years (Colomina & Molina, 2014; Malehmir et al., 2017) (Figure 1).

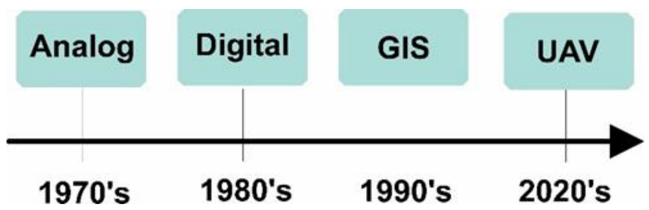

Figure 1. Technological Evolution of Geophysical Applications

UAVs equipped with advanced sensor technologies enable the rapid and cost-effective collection of high-resolution data related to the Earth's surface and subsurface.

3.1. General Characteristics of UAV Technology

UAVs are aerial platforms controlled via ground stations or software supported by GPS/IMU systems and can work in integration with various sensors. Due to their low-altitude flight capabilities, maneuverability, and mobility, UAVs offer significant advantages, especially in mountainous or hard-to-reach regions. There are two primary types of UAVs: fixed-wing and rotary-wing (multi-rotor). Fixed-wing UAVs are more suitable for covering large areas, while multi-rotors are preferred for precise and stationary data collection (Nex & Remondino, 2014).

3.2. Sensors Used for Geophysical Purposes

Sensors integrated into UAV systems are selected based on specific geophysical objectives. These can include direct physical measurement tools (e.g., magnetometers, electromagnetic sensors) and imaging systems supporting indirect geophysical analysis.

- **Magnetometers:** Measure variations in the Earth's magnetic field. They are commonly used for mapping geological structures and locating mineral deposits. UAV-mounted fluxgate or optically pumped magnetometers can generate high-precision magnetic anomaly maps (Malehmir et al., 2017).
- **Electromagnetic (EM) Sensors**: Measure electrical conductivity differences, which are helpful in identifying groundwater, saltwater intrusion, and geothermal sources.
- **Thermal Cameras**: Detect surface temperature differences, effectively monitoring volcanic activity, geothermal zones, and collapse risk areas (Casana et al., 2017).
- **Multispectral and Hyperspectral Cameras**: Analyze the spectral characteristics of surface materials, facilitating mineral identification and differentiation of surface features.
- **Photogrammetric Cameras**: High-resolution aerial imagery captured using onboard RGB cameras can be processed to produce Digital Elevation Models (DEMs), orthophotos, and surface deformation analyses.
- **LiDAR Systems**: Laser scanners generate highly accurate 3D surface models, enabling topographic analyses and detecting microstructural geological features.

3.3. Use of UAVs in Geophysical Application Fields

3.3.1. Mineral Exploration and Resource Estimation

Magnetometers and EM sensors integrated into UAVs allow for rapid and low-cost surveys of extensive areas. Magnetic maps are particularly effective in identifying magnetic minerals such as iron, nickel, and cobalt. In addition, photogrammetric volume calculations can be performed using UAVs to determine reservoir sizes (Van der Meer et al., 2012).

3.3.2. Geothermal Energy and Thermal Monitoring

UAV systems with thermal cameras can map high-resolution surface temperature distributions, supporting geothermal site investigations. These maps are valuable for identifying hot water sources and interpreting subsurface thermal anomalies. They also aid in detecting heat leaks along active fault zones (Farr et al., 2007).

3.3.3. Post-Earthquake and Landslide Damage Assessment

Following disasters such as earthquakes or landslides, UAVs offer significant advantages for safely and rapidly mapping affected areas. High-resolution imagery obtained by UAVs enables the identification of cracks, deformations, and collapse zones. These data can be analyzed in GIS environments to generate hazard zones (Casagli et al., 2017).

3.3.4. Digital Terrain Model Production and Micro-Geomorphological Analyses

Photogrammetric images collected by UAVs can be processed to produce detailed Digital Surface Models (DSM/DTM) at millimeter-level resolution. These models are essential in surface geophysics for slope analysis, flow direction modeling, and detection of surface expressions of fault lines. They are particularly critical in studies requiring detailed examination of surface morphology (e.g., active fault traces, collapse risks, flood zones).

3.4. Advantages and Limitations of UAV Technology

UAV technology has revolutionized fieldwork in geophysical research by offering innovative contributions to data collection and assessment processes. In large or challenging terrains, UAVs provide significant mobility, efficiency, and precision advantages compared to traditional methods.

One of the most significant benefits of UAVs is the ability to collect data safely and quickly in inaccessible or hazardous areas. For example, in active volcanic zones or steep slopes with landslide risks, UAVs can remotely survey the area and gather necessary data without risking human lives. A 2010 study in the Philippines demonstrated that UAVs with thermal cameras successfully mapped surface temperature anomalies around Taal Volcano, helping identify potential pre-eruption risk zones (Casana et al., 2017).

Moreover, UAVs can collect data over vast areas in a short time. In conventional magnetic surveys, only a few kilometers can be surveyed daily on foot. In contrast, a fixed-wing UAV with a magnetometer can cover much larger areas with denser measurement intervals, saving time and labor. A geophysical survey in Sweden found that UAV-based magnetometer scans identified 35% more magnetic anomalies than ground-based measurements, offering more precise delineation of structures (Malehmir et al., 2017).

Another key advantage is the production of high-resolution data. Digital surface models generated from UAV photogrammetry can achieve millimeter-level accuracy, allowing the detection of micro deformations, fault traces, or ground settlements. For example, after the 2020 Elazig earthquake in eastern Turkey, surface rupture lengths and slope changes were thoroughly analyzed using models produced from UAV imagery.

Despite these advantages, UAV technology has certain limitations and operational challenges. Most notably, UAVs are highly sensitive to weather conditions. Windy, rainy, or foggy environments can endanger flights and severely degrade data quality. In EM surveys, high humidity and precipitation can introduce noise into measurement signals.

Additionally, UAVs typically rely on batteries, limiting their flight durations. A standard multi-rotor UAV can remain airborne for only 20–40 minutes, necessitating frequent takeoffs and battery replacements during large-area surveys. The payload capacity of UAVs also limits the types of sensors that can be onboard, restricting the use of heavier systems like LiDAR or advanced EM instruments.

Legal regulations present another constraint. In most countries, UAV usage is subject to specific rules. In Turkey, for example, UAVs over a certain weight must be registered with the Directorate General of Civil Aviation (SHGM), and operators must be certified. Moreover, flight permissions are required in restricted areas such as borders, military zones, and airports.

Finally, measurements using magnetometers or EM sensors in urban areas with high electromagnetic interference may produce inaccurate results. This issue frequently arises near power lines, large metal structures, or industrial facilities.

Despite these limitations, the contributions of UAV technology make it a valuable investment for geophysical studies. UAVs support geophysical engineers in every stage—from pre-survey planning to data collection and result visualization—offering safer, faster, and more detailed analysis capabilities. As such, the continued development of UAV systems and improved sensor compatibility will further expand their use in earth sciences.

UAV integration into geophysical applications accelerates data collection, enhances spatial resolution, and enables access to previously unreachable areas. When combined with GIS, UAV technologies have evolved beyond measuring tools to become robust decision-support systems. Thus, these technologies are expected to become standard practice in more geophysical applications shortly.

4 | INTEGRATION OF GIS AND UAV TECHNOLOGIES

In contemporary geoscientific research, the effectiveness of spatial decision-support systems directly depends on how well the technologies employed can function in an integrated manner. At this point, the combined use of Geographic Information Systems (GIS) and Unmanned Aerial Vehicles (UAVs) brings about a significant transformation in data collection, analysis, modeling, and interpretation in geophysical applications. When both technologies' strengths are merged in a complementary fashion, it becomes possible to conduct comprehensive, multi-layered spatial analyses in earth sciences (Colomina & Molina, 2014; Longley et al., 2015).

4.1. Core Dynamics of Integration

UAVs can produce large amounts of spatial data, such as high-resolution aerial photographs, digital elevation models (DEMs), orthophotos, and outputs from geophysical sensors. These data are directly transferred into GIS environments, where they are used for spatial analysis, classification, mapping, and 3D modeling (Remondino et al., 2011). Thanks to this integrated structure, researchers can go beyond mere measurement data and evaluate their spatial and temporal significance from a broader perspective.

For instance, a magnetic anomaly map obtained from UAV magnetometry in geophysical studies can be integrated with topographic data, lithological maps, and fault zones in a GIS platform to make more reliable inferences about the geological causes of the anomalies. This approach is particularly valuable in areas with complex geological structures (Malehmir et al., 2017).

4.2. Fields of Application and Literature Examples

The integration of GIS and UAV technologies has been successfully applied in numerous geophysical application areas. This integration's most significant contribution is the ability to meaningfully overlay spatial data collected at different scales and scientifically analyze their relationships.

4.2.1. Mineral Exploration and Resource Mapping

Orthophotos and DEMs obtained via UAVs map surface expressions of potential ore deposits in mineral exploration. Magnetic anomaly measurements are evaluated in GIS environments, enabling the interpretation of anomalies alongside geological maps and historical exploration data. Numerous studies in countries like Australia and Canada have shown that this method allows for the precise delineation of copper and iron ore bodies (Van der Meer et al., 2012).

4.2.2. Earthquake and Landslide Risk Analysis

Damage assessments following earthquakes and landslides are among the most critical applications of GIS and UAV integration. High-resolution UAV imagery acquired shortly after disasters can be analyzed using GIS software to identify the spatial distribution of damage, surface ruptures, and deformation zones (Casagli et al., 2017). For example, after the 2016 Amatrice earthquake in Italy, high-resolution orthophotos produced by UAVs were analyzed in GIS to correlate building collapses successfully with topography and soil types.

4.2.3. Monitoring of Geothermal Fields

Surface temperature maps obtained from UAVs equipped with thermal cameras can be analyzed within GIS to map geothermal anomalies, flow directions, and change trends. These applications allow for evaluating the geothermal potential of a site by combining slope, geology, drainage networks, and thermal imagery in a GIS environment. In studies conducted in geothermal regions of Western Anatolia, Turkey, this method has been effectively used to identify correlations between hot spring outputs and new geothermal sources (Kavzoglu & Yildiz, 2021).

4.2.4. Production of Surface and Volume Models

High-resolution photogrammetric images obtained via UAVs can be used in GIS to create DEMs and orthophotos, which are applicable in numerous spatial analyses such as volume calculations, erosion analysis, and sediment transport modeling. In open-pit mining, for example, land volumes before and after extraction can be compared with high accuracy using this approach (Remondino et al., 2011).

4.3. Strategic Contributions to Integration

The combined use of GIS and UAV technologies directly contributes to strategic decision-making processes in geophysical studies. This contribution is not limited to data richness alone but also relates to the ability to process and interpret these data spatially. GIS, as the foundation of spatial decision-support systems, gains a more dynamic and up-to-date analytical infrastructure through UAV-acquired data, enabling more accurate decisions in planning, disaster prevention, and resource management (Malczewski, 2006).

For example, a geophysicist analyzing groundwater potential in a given area can improve the accuracy and relevance of their analysis by simultaneously considering UAV-acquired electromagnetic conductivity data and geological formation data in a GIS environment. Likewise, a researcher modeling earthquake risk can generate more robust scenarios by combining deformation maps obtained from UAV imagery with GIS-based active fault data.

Integrating GIS and UAV technologies enables the production of high-resolution, temporally synchronized, and spatially integrated data in geosciences, especially in geophysical applications. While each system is robust, their combined use allows for more comprehensive and effective results. Thanks to this integration, the accurate modeling of geophysical processes, preventive planning against natural disasters, and sustainable management of natural resources are based on a much more solid scientific foundation. Therefore, it seems inevitable that the joint use of GIS and UAV technologies will soon become a standard geophysics approach.

5 | CASE STUDY: GIS AND UAV-SUPPORTED GEOPHYSICAL INVESTIGATION IN BUCA-İZMİR

Presenting concrete examples of the joint use of GIS and UAV technologies is highly valuable in evaluating the effectiveness and applicability of this integration in the field. In this context, a study was conducted in the Buca district of İzmir, covering an area of approximately 87 hectares. The primary objective of this study was to identify areas prone to landslides, slips, or collapses and to model the subsurface structures in those areas using geophysical methods. This application is a unique example of integrating surface data generated through UAV technology into a GIS environment and combining these analyses with subsurface data. A flowchart illustrating the coordinated and effective use of GIS, UAV, and geophysical applications is provided in Figure 2.

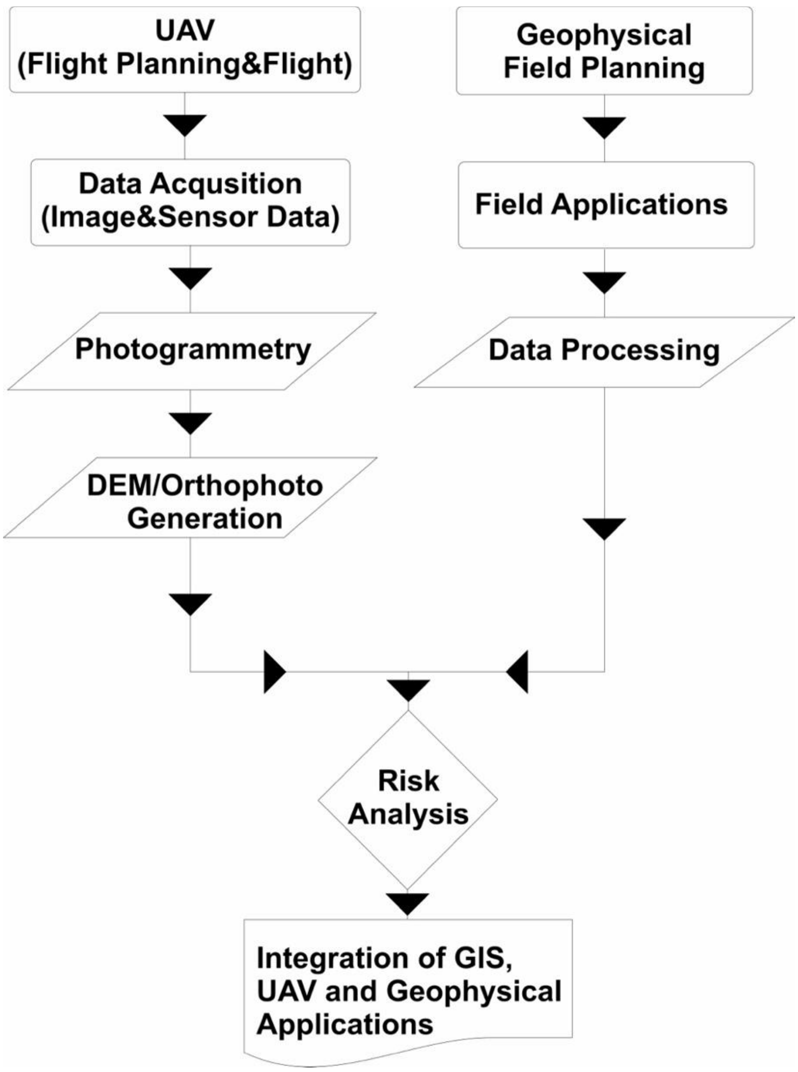

Figure 2. Case Study Workflow Diagram

5.1. UAV-Supported Photogrammetric Data Collection and Processing

In the first phase of the fieldwork, a DJI Phantom 4 UAV was used to capture high-resolution images of the study area. Flight planning was carried out using DJI GS Pro software, and 289 aerial photographs were autonomously captured from a height of 100 meters, with 80% forward and 60% side overlap. These overlap rates are critically crucial for obtaining high-accuracy point clouds during the photogrammetric processing (Remondino et al., 2011).

Figure 3. Study Area Orthophoto

To ensure precise georeferencing of the field data, 12 ground control points (GCPs) were established in the region, and their coordinates were measured using high-precision GPS devices. The images were then processed using photogrammetry software to produce a dense point cloud, triangulation mesh, orthophotography (Figure 3), and digital surface model. To reduce error margins in topographic analyses, non-topographic elements such as trees, buildings, and vehicles were filtered out of the dataset using advanced techniques (Figure 4).

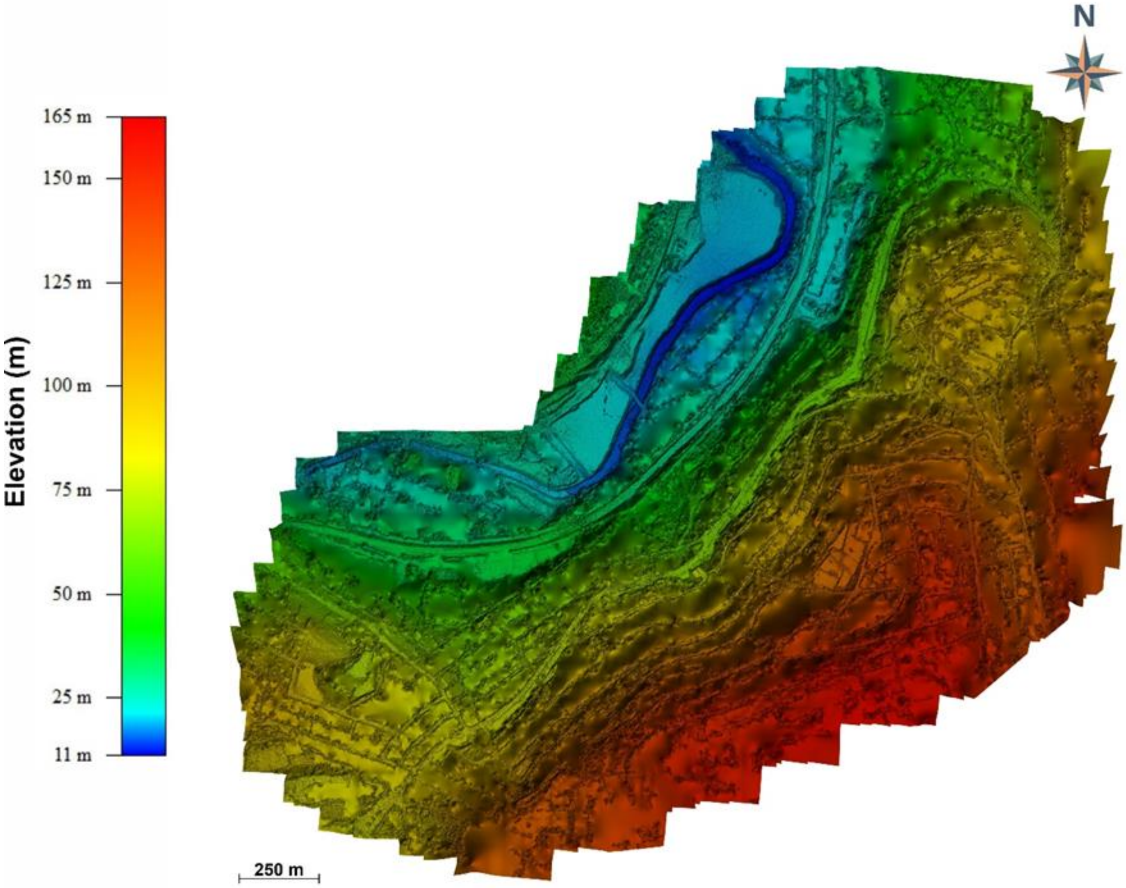

Figure 4. Digital Elevation Model of the Study Area

Using the resulting digital surface model, a 3D topographic map was created, and slope analyses were performed (Figure 5). These analyses helped identify high-slope areas as potential landslide/collapse zones (Red Rectangle in Figure 5), guiding the planning of geophysical survey points (Cyan line and stations in Figure 5) in these critical regions.

5.2. GIS-Supported Slope and Risk Analysis

The DEM and orthophotos obtained via UAVs were transferred into a GIS environment for spatial analysis. Parameters such as slope, aspect, and drainage structure were evaluated using ArcGIS software, and a risk analysis map was produced based on the combination of these factors to identify critical zones. In particular, areas with high slope values coinciding with poor drainage conditions were considered geomechanically unstable and were subjected to detailed geophysical investigations.

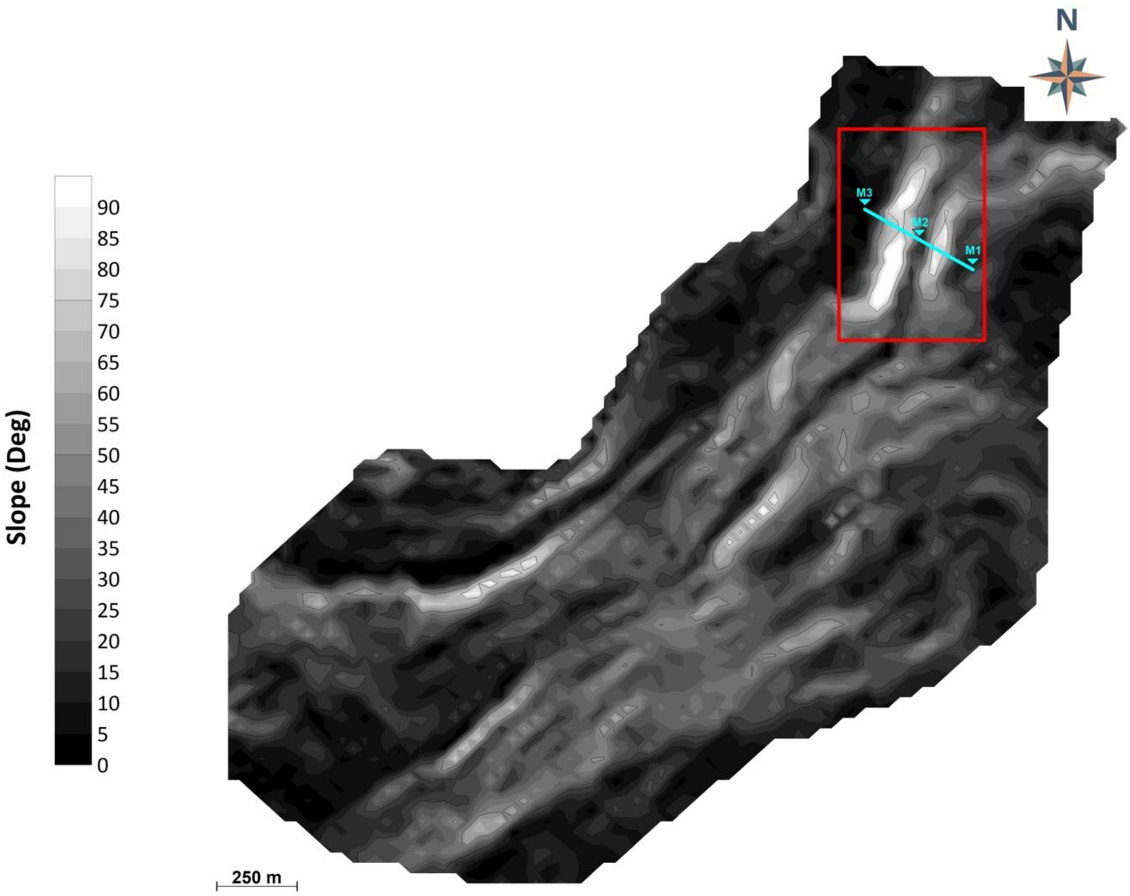

Figure 5. Slope Map of the Study Area

5.3. Subsurface Modeling with Geophysical Methods

As part of the geophysical study, single-point microtremor measurements were conducted in the areas identified as risky. The Horizontal-to-Vertical Spectral Ratio (HVSR) curves derived from these measurements were inverted to produce 2D models of the subsurface geological structure in terms of S-wave velocity (Nakamura, 1989; Bignardi et al., 2016). This modeling helped detect soil types and potential weak zones; near-surface weathered layers and zones likely weakened by groundwater were also identified (Figure 6).

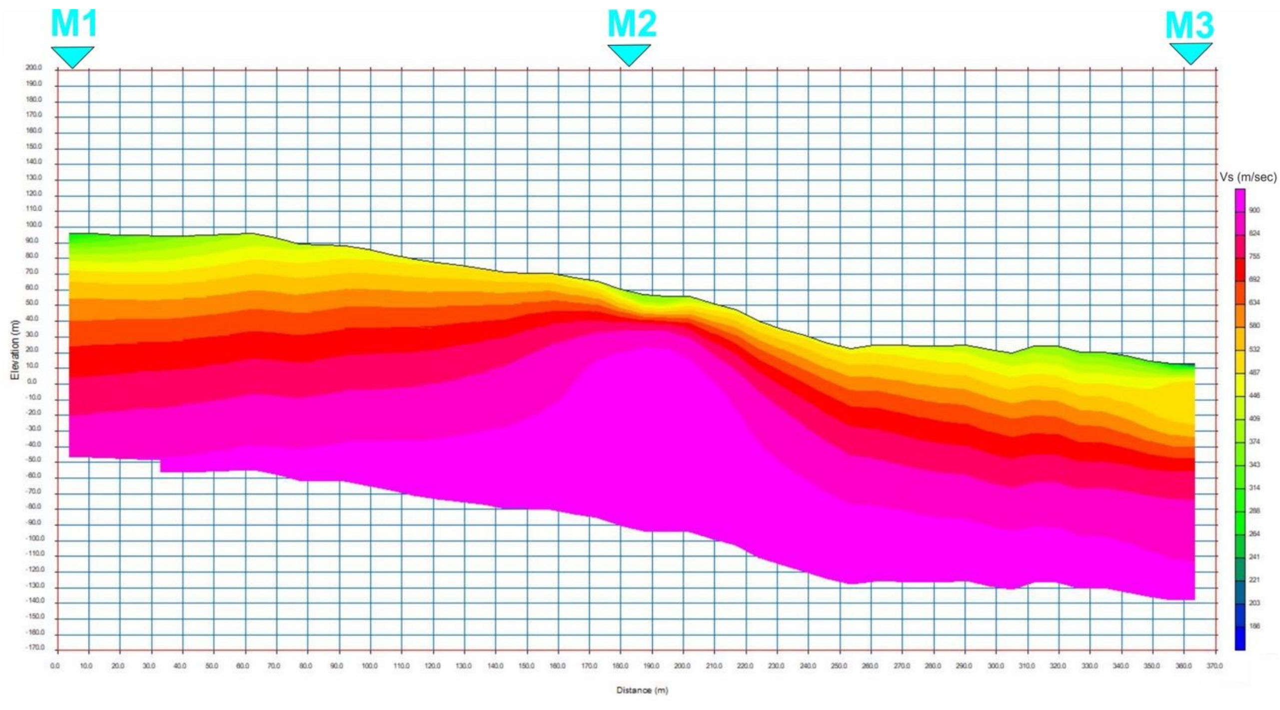

Figure 6. 2D S-Wave Velocity Depth Model Along Profile P1

The data obtained from these methods were integrated with the previously created topographic data in the GIS environment, resulting in a multi-layered analysis from both surface and subsurface perspectives. The findings revealed that the hazardous areas were risky due to surface topography and weak geological structures beneath the surface.

5.4. Interpretation and Evaluation

This study demonstrates how GIS and UAV technologies can be transformed into a holistic approach to geophysical risk analyses. Rapid and cost-effective field data collection, high-resolution 3D models, and risk analyses supported by surface and subsurface data offer significant advantages, especially for disaster management planning in urban settlements.

The Buca application, conducted in the İzmir region, provided original contributions from scientific and practical perspectives by integrating multiple disciplines. The data obtained at the end of the study formed a concrete decision-support infrastructure that local authorities can utilize for urban planning and disaster risk reduction efforts.

6 | CONCLUSION AND DISCUSSION

This study comprehensively addressed the opportunities presented by combining Geographic Information Systems (GIS) and Unmanned Aerial Vehicle (UAV) technologies in geophysical applications. Supported by literature examples and evaluated through a case study in Buca-İzmir, the integration of these two technologies contributed significantly to data production and decision support, risk analysis, and planning processes.

In particular, UAV technology offers excellent advantages in geophysical work due to its speed, accessibility, and ability to generate high-resolution data. Its low-cost, mobile, and flexible operational capabilities allow for safer and more effective field studies in hard-to-reach locations. Conversely, GIS provides an environment for temporal and spatial analysis of this data, enabling meaningful interpretation and integration of UAV-derived datasets with various data layers for multidimensional insights (Longley et al., 2015; Burrough & McDonnell, 1998).

As demonstrated in the Buca-İzmir case study, photogrammetric data obtained via UAVs and the detailed digital terrain models created played a critical role in identifying high-risk areas and guiding the planning of geophysical measurements. Slope analyses and other spatial assessments in the GIS environment enabled the visualization of topography-related risks. Subsequently, geophysical measurements linked these surface features with subsurface structures, resulting in a complex and comprehensive risk evaluation model.

Another key point to emphasize in the discussion is the multidisciplinary collaboration enabled by this technological integration. Fields such as geomatics engineering, geophysics, remote sensing, computer science, and disaster management come together in such studies, facilitating more comprehensive and accurate analyses (Malczewski, 2006; Casagli et al., 2017). In this regard, GIS and UAV technologies are transforming traditional field studies in the earth sciences into innovative tools that support data-driven strategic planning.

That said, certain limitations of the current technologies must also be acknowledged. UAVs are sensitive to weather conditions, have limited battery life, and face restrictions regarding sensor payloads—factors that can limit the scale and duration of some applications. Additionally, legal regulations and data privacy concerns can sometimes hinder the widespread use of UAVs. Similarly, the effective use of GIS platforms requires high-quality, up-to-date, and interoperable datasets, demanding continuous improvements in data standards and infrastructure.

Artificial intelligence-supported data processing algorithms are expected to play a more significant role in GIS environments and UAV data analysis. Machine learning and deep learning techniques will enhance the integration by contributing to geological feature classification, automated risk zone detection, and dynamic disaster scenario modeling.

In conclusion, combining GIS and UAV technologies represents a modern, integrated, and decision-oriented approach to the earth sciences. These technologies will continue to add value across a broad spectrum in current research and future areas, such as sustainable urban planning, disaster risk management, and natural resource conservation.

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