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Integration of UAV Photogrammetric Data and SDSS: An Innovative Approach for Environmental Hazard Management in Iran

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Abstract

The increasing frequency of environmental hazards such as floods, landslides, earthquakes, and wildfires has highlighted the need for innovative risk management solutions, particularly in countries with diverse climates like Iran. This study aims to explore the potential for integrating UAV-based photogrammetry technology with Spatial Decision Support Systems (SDSS) to improve environmental hazard management processes. The methodology is both review-based and analytical, involving a systematic review of reputable domestic and international scientific sources from 2015 to 2023, and a comparative analysis of the application of these technologies in Iran and other countries. Findings show that integrating precise UAV data with the analytical capacities of SDSS can play a significant role in the stages of hazard identification, prediction, and impact mitigation. This combination, leveraging machine learning algorithms, significantly enhances real-time analysis capabilities, crisis scenario modeling, and prioritization of high-risk areas. However, challenges such as high costs, legal restrictions on UAV flights, and a shortage of skilled personnel remain significant barriers to practical implementation in Iran. Ultimately, the study emphasizes the necessity of developing localized frameworks, specialized training, and supportive policies to effectively utilize these technologies.

Keyword: UAV, Spatial Decision Support Systems (SDSS), Machine Learning, Risk Management

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1.Introduction

Environmental hazards, including floods, earthquakes, landslides, wildfires, and climate change, pose increasing threats to human communities, infrastructure, and natural ecosystems. According to a United Nations report, natural disasters over the past two decades have caused damages exceeding $1.5 trillion and affected more than 1.3 billion people (UNDRR, 2020). These hazards not only lead to economic and human losses but also threaten environmental sustainability through intensified climate change and the degradation of natural resources. In Iran, its geographical location along the Alpine-Himalayan seismic belt, diverse climate conditions, and increasing pressure on natural resources make it one of the world's high-risk regions (Zare et al., 2019). For example, the devastating floods of 2019 in Golestan, Lorestan, and Khuzestan provinces caused widespread damage to infrastructure and agriculture, emphasizing the urgent need for advanced tools to manage such hazards (Rahimi et al., 2020).

Effective environmental hazard management requires the collection of accurate data, advanced spatial analysis, and evidence-based decision-making. In recent decades, geospatial technologies such as photogrammetry and Spatial Decision Support Systems (SDSS) have attracted attention due to their ability to process complex data and provide practical solutions (Keenan & Jankowski, 2019). Photogrammetry, a method for extracting 3D information from 2D images, enables high-quality data collection from remote or hazardous areas through UAVs (Gomez & Purdie, 2016). This technology helps identify hazard-prone areas and assess damage by producing accurate 3D models. On the other hand, SDSS, using Geographic Information Systems (GIS) and spatial analysis, facilitates data-driven decision-making for planning and emergency response (Singh et al., 2023). Integrating these two technologies can lead to unified frameworks for hazard management, where UAV data serve as inputs for SDSS analyses.

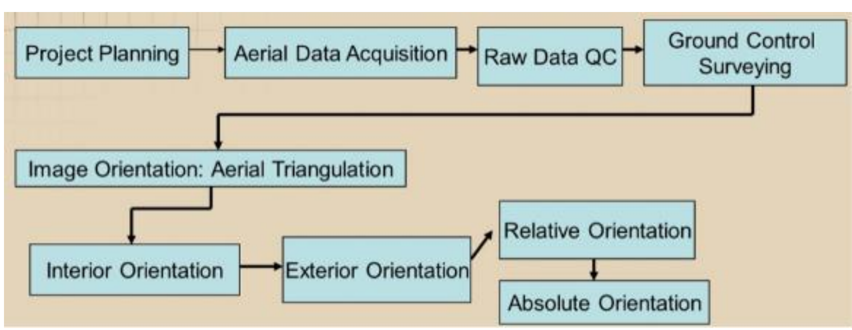

Figure 1. Photogrammetry process (generating imagery or digital elevation models)

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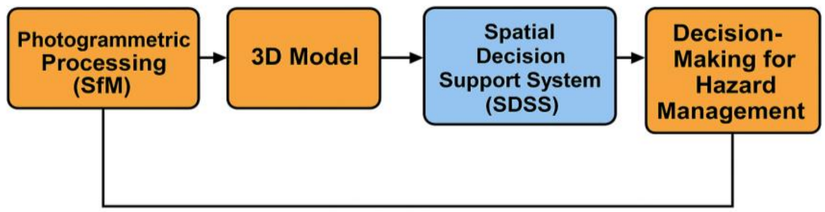

Figure 2. Conceptual process of integrating UAV photogrammetric data with SDSS in environmental hazard management

Despite recent advances, integrating photogrammetry and SDSS in environmental hazard managementstill faces scientific challenges and gaps. Many existing studies focus on the separate application of these technologies, but integrated frameworks that utilize both simultaneously—especially in disaster management—remain limited (Ekiyama et al., 2020). In Iran, this scientific gap is even more pronounced due to the lack of localized studies that consider the country's unique geographical, climatic, and infrastructural conditions (Hosseini et al., 2018). For example, while UAV data has been used in assessing the damage from the Bam and Kermanshah earthquakes, the absence of integrated SDSS for analyzing this data has reduced the overall efficiency of these technologies (Zare et al., 2019; Hosseini et al., 2018). Furthermore, practical challenges such as high equipment costs, lack of technical expertise, and legal restrictions on UAV flights have limited widespread adoption of these technologies in developing countries like Iran (Mohammadi et al., 2021).

In recent years, the development of machine learning and artificial intelligence algorithms has significantly enhanced the capability to analyze complex and large-scale UAV data. Algorithms such as Random Forest, Support Vector Machine, and Artificial Neural Networks have enabled accurate land use classification, detection of environmental changes, and hazard prediction (Zhu et al., 2017; Li et al., 2020). Integrating these algorithms with SDSS can lead to smarter decision-making and faster crisis response. Additionally, the development of advanced multispectral and thermal sensors on UAVs has improved the ability to detect thermal hotspots, vegetation cover changes, and early signs of landslides or wildfires (Colomina & Molina, 2014). These advancements not only improve the accuracy of input data for SDSS but also enable real-time modeling for critical scenarios. Consequently, there is an increasing need for data-driven frameworks capable of operationally integrating the analytical capabilities of UAVs and SDSS, particularly in countries like Iran with diverse geography and climate.

The importance of this integration is amplified in Iran due to the diversity and intensity of environmental hazards. Frequent earthquakes, seasonal floods, wildfires in the Zagros region, and landslides in the Central Alborz are only some of the challenges that demand innovative solutions

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(Yousefi et al., 2022). These technologies can assist by generating precise maps and predictive analyses, thus contributing to damage reduction, improved crisis response, and protection of fragile ecosystems. However, the lack of operational frameworks for integration and the absence of international collaboration for knowledge transfer remain key barriers (USDA, 2018). This study aims to explore the potential of integrating photogrammetry and SDSS and to offer solutions for overcoming these challenges.

In addition to the increasing technological possibilities, public policy and community engagement play an essential role in the successful integration of UAV and SDSS in environmental management. For instance, Japan's disaster risk reduction framework emphasizes community participation alongside advanced geospatial technologies (Okazaki & Nakasu, 2015). Similarly, integrating citizen-generated data through mobile platforms with SDSS could complement UAV data, creating hybrid models for rapid assessment. These participatory approaches enhance situational awareness, particularly in developing countries where governmental response capacities may be limited.

Research Questions:

1. How can photogrammetry and SDSS be effectively integrated into environmental hazard management?
2. What are the challenges and opportunities associated with UAV data usage in Iran?
3. How can these technologies be utilized for managing specific hazards in Iran, such as floods and earthquakes?

2. Literature review

In recent decades, the increasing intensity and frequency of environmental hazards such as floods, droughts, landslides, and forest fires have prompted researchers and policymakers to seek accurate and technological solutions for monitoring, analyzing, and managing these phenomena. One of the most significant developments in this area is the emergence of UAV (drone) technology and its widespread application in remote sensing and photogrammetry. These tools, capable of capturing high-resolution spatial data, have rapidly replaced many traditional methods and enabled more accessible high-precision mapping, 3D modeling, and environmental index extraction (Gomez & Purdie, 2016).

On the other hand, Spatial Decision Support Systems (SDSS), with their capabilities for multi-criteria analysis, scenario modeling, and integration of spatial and temporal data, have emerged as effective tools in natural resource management and response to environmental crises. Various studies have shown that integrating UAV data with the analytical capabilities of SDSS can make the decision-making process more accurate, faster, and evidence-based (Shi et al., 2019, Baghestani et al., 2025)

For instance, a project at West Virginia University aimed to use UAV data in designing decision-support models for assessing environmental hazards. The results demonstrated a significant improvement in the accuracy of predictions and spatial analyses (West Virginia University, 2023). In another study, Srivastava et al. (2022) utilized UAV-based photogrammetry to monitor forest biophysical parameters such as tree height and canopy density, and their findings confirmed the high accuracy of this technology in environmental studies.

Additionally, Rahman et al. (2023) used UAV data to estimate the population of Sumatran elephants, showing that this method is an effective and low-cost alternative to traditional endangered species census techniques. In agriculture, the use of SDSS alongside multispectral UAV data led to optimized water usage and increased crop productivity (Shi et al., 2019).

Recent studies have highlighted the application of UAV-based photogrammetry in post-disaster urban planning. For example, in the aftermath of the 2020 Beirut explosion, UAVs were employed to rapidly assess damage and plan for infrastructure recovery (Hosseini et al., 2021). Moreover, in flood-prone regions of Bangladesh, community-based UAV deployment strategies have shown that local pilots, trained with minimal investment, can gather critical geospatial data. This approach reduces dependency on external expertise and fosters resilience at the community level (Ahmed et al., 2020).

Furthermore, integration of UAV data into cloud-based SDSS platforms, such as Google Earth Engine or ArcGIS Online, enables collaborative data sharing among agencies, enhancing coordination during emergency response. These tools are especially useful in multi-agency contexts where timely data access is critical.

Collectively, these studies underscore the importance of integrating modern technologies such as UAV photogrammetry and spatial decision support systems in the sustainable management of environmental hazards, providing a scientific foundation for the present research.

3. Methodology

This research adopts a review-based approach, aiming to analyze scientific and practical resources related to the topic. Sources were selected from reputable scientific databases such as Springer, PubMed, ScienceDirect, and Civilica (for Persian resources). Selection criteria included:

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- Direct relevance to photogrammetry, SDSS, or UAV data.
- Focus on environmental hazard management or related fields like disaster and natural resource management.
- Scientific credibility (published in reputable journals or by recognized institutions).
- Inclusion of localized studies in Iran to ensure relevance to national conditions.
- Recency (sources mostly post-2015).

To ensure comprehensiveness, a mix of scientific articles, project reports, and expert web pages was reviewed. Ultimately, 20 key sources were selected for their coverage of both global and local aspects of the subject. The analysis was conducted qualitatively and comparatively to identify strengths, weaknesses, and research gaps.

4.Results and Discussion

4.1. Capabilities of UAV Photogrammetry in Disaster Monitoring and Assessment

One of the key advantages of UAV-based photogrammetry is its ability to produce high-precision 3D maps. Using techniques like Structure from Motion (SfM), it generates highly detailed 3D models of terrain features (Westoby et al., 2012; Gomez & Purdie, 2016). These models are especially valuable for identifying high-risk areas such as unstable slopes and low-lying flood-prone zones. In Iran, this technology has been used in earthquake-affected areas like Kermanshah for precise damage mapping (Hosseini et al., 2018).

Moreover, UAV data can generate spatiotemporal time series, revealing gradual trends such as soil erosion, landslides, and unauthorized construction. This information can be highly effective in prioritizing recovery and relief actions.

4.2. Role of Spatial Decision Support Systems (SDSS) in Analysis and Decision-Making

SDSS integrates spatial data, analytical tools, and decision-support models to facilitate complex crisis scenario analysis (Jankowski & Nyerges, 2001). Within SDSS, multi-criteria decision-making methods like AHP and fuzzy analysis are used to prioritize high-risk areas. For instance, Rahimi et al. (2020) used SDSS in the Gorganrud watershed to provide more accurate flood forecasts. This tool can combine indicators such as slope, rainfall patterns, vegetation type, and population density in models that support critical decision-making.

4.3. Synergy Between Photogrammetry and SDSS in Environmental Hazard Management

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Combining UAV data with SDSS capabilities leads to powerful systems for hazard identification, prediction, and mitigation. This integration can utilize real-time data to forecast future crisis scenarios (Singh et al., 2023). The successful experiences of countries like Japan and Indonesia in concurrently using these technologies highlight their effectiveness in improving disaster response (Ekiyama et al., 2020). In Iran, the joint application of these technologies has been proposed for earthquake assessment in Bam and wildfire monitoring in the Zagros region (Mohammadi et al., 2021; Zare et al., 2019).

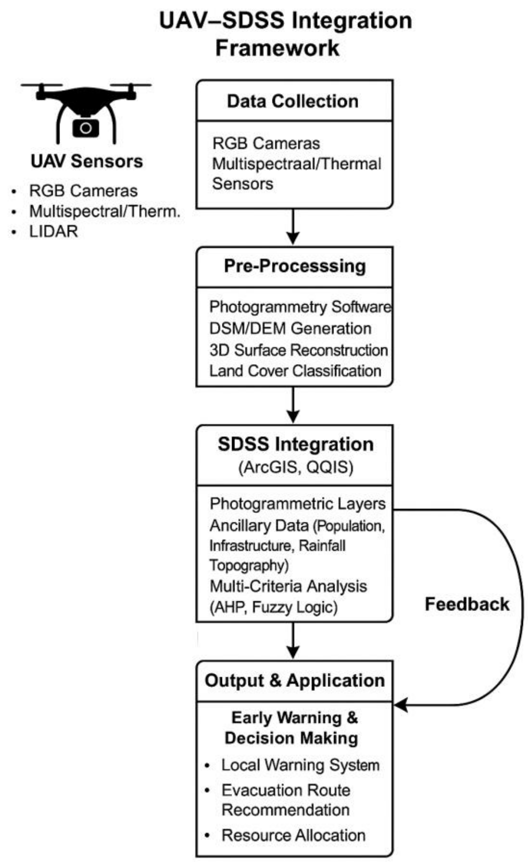

Figure 3. Conceptual Model of UAV–SDSS Integration Framework in Environmental Hazard Management

4.4. International Case Studies in UAV and SDSSIntegration

Several countries have successfully implemented integrated UAV-SDSS systems for disaster management. In Indonesia, UAVs are now used as a standard tool for early detection of volcanic activity around Mount Merapi. The real-time imagery is fed into a centralized SDSS platform that models potential lava flow and affected population zones (Nugroho et al., 2022).

In the U.S., the Federal Emergency Management Agency (FEMA) uses UAV-SDSS integration for flood mapping and evacuation route optimization, with cloud-based access provided to local responders. In Turkey, the AFAD (Disaster and Emergency Management Authority) uses machine learning-enhanced UAV-SDSS platforms to predict landslide risks in mountainous regions (Korkmaz & Gokceoglu, 2019).

Table1. Applications, Challenges, and Opportunities of Photogrammetry and SDSS in Environmental Hazard Management

Technology	Application	Advantages	Challenges	Future Opportunities
Photogrammetry	Earthquake and flood mapping	High accuracy; access to hard-to-reach areas	High cost; weather condition impact	Early warning systems
SDSS	Flood prediction, wildfire management	Advanced spatial analysis	Lack of technical expertise; need for accurate data	Integration with artificial intelligence

4.5. Main Challenges in the Implementation of These Technologies in Iran

The implementation process of these technologies is accompanied by challenges such as high costs for purchasing UAVs, specialized software, and computing infrastructure (González et al., 2020). In addition, legal restrictions on UAV flights in certain areas constitute one of the main obstacles to their development (Mohammadi et al., 2021). The lack of skilled human resources is another serious challenge that limits the effective use of these technologies. Under adverse weather conditions or in areas with dense vegetation, the accuracy of photogrammetric data decreases (Bichou et al., 2019).

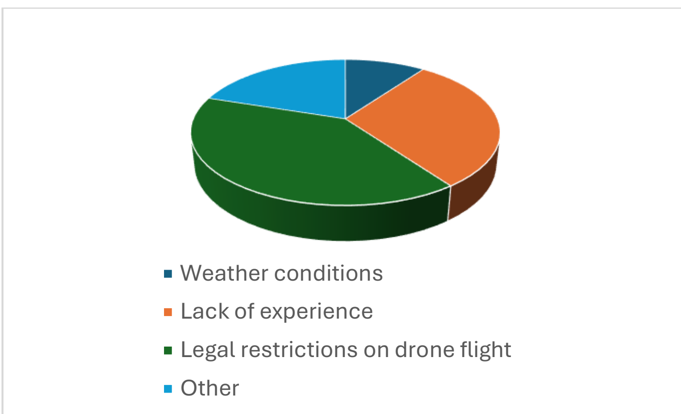

Figure 4. Percentage Distribution of the Main Challenges in the Implementation of UAV and SDSS Technologies in Environmental Hazard Management in Iran

4.6. Emerging Opportunities Through the Integration of Novel Technologies

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Advancements such as multispectral and thermal sensors on UAVs have increased the capability to identify thermal hotspots, changes in vegetation cover, and early signs of crises (Colomina & Molina, 2014). Additionally, machine learning algorithms such as Random Forest, SVM, and CNN have enabled the automated analysis of large-scale UAV data (Zhu et al., 2017; Li et al., 2020). Integrating these algorithms with SDSS can operationalize early warning systems, real-time monitoring, and behavioral prediction for critical environments in Iran.

5. Conclusion and future work

This research has shown that integrating UAV-based photogrammetry with Spatial Decision Support Systems (SDSS) offers an innovative and efficient approach for managing environmental hazards. By generating highly accurate 3D maps and advanced spatial analyses, these technologies enable the rapid identification of high-risk areas, hazard prediction, and the formulation of protective plans. In Iran, which faces numerous challenges such as floods, earthquakes, and wildfires, these tools can play a key role in reducing both human and financial losses. For example, the use of UAV data in assessing earthquake damage in affected regions and managing wildfires in vulnerable areas demonstrates the high potential of these technologies under local conditions. However, challenges such as high equipment costs, a shortage of technical expertise, and legal restrictions on UAV flights remain significant obstacles. Overcoming these challenges requires investment in the development of cost-effective technologies, training of specialists, and reform of existing regulations. This study emphasizes the need to establish integrated frameworks for the effective use of these technologies. Ultimately, the integration of photogrammetry and SDSS not only supports sustainable environmental hazard management but also, by strengthening early warning systems and protecting ecosystems, paves the way for a safer future for communities—especially in high-risk areas such as Iran.

In addition to the key findings of this study, it is important to situate these results within an international perspective. Countries such as Japan, Indonesia, and the United States have demonstrated the successful integration of UAV and SDSS through structured regulatory frameworks, strong institutional capacity, and active public-private partnerships (Ekiyama et al., 2020). In comparison, Iran's use of these technologies remains primarily exploratory and limited to academic or pilot-level applications.

A critical observation is the absence of real-world experimental testing of UAV-SDSS integration in Iran's hazard-prone regions. To validate the conceptual models discussed, pilot projects should be conducted in vulnerable zones such as the Gorganrud floodplain, Kermanshah earthquake-prone zones, or Zagros wildfire corridors. These field trials would provide valuable feedback for refining operational models and tailoring decision-support tools to local realities.

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Moreover, the current frameworks often focus heavily on geospatial data and overlook socio-demographic factors that are crucial in effective disaster response. Including population density, access to infrastructure, age distribution, and economic vulnerability in SDSS layers can significantly improve the accuracy and fairness of hazard mitigation planning.

From a governance perspective, the institutionalization of UAV-SDSS systems requires the formation of interdisciplinary expert teams, capacity-building programs, and the establishment of centralized environmental intelligence platforms. These systems should be connected with real-time data repositories, integrate citizen reports, and support multi-agency coordination.

Therefore, future research should prioritize the development of hybrid models that integrate remote sensing data, ground-level information, and artificial intelligence into adaptive, predictive, and participatory systems for disaster risk management.

Recommendations:

To better utilize these technologies, the following recommendations are proposed:

1. **Develop cost-effective technologies:** Design more affordable UAVs and software to improve access for developing countries like Iran.
2. **Training and capacity building:** Organize training courses for specialists in photogrammetry, SDSS, and UAV data processing.
3. **Formulate supportive regulations:** Facilitate UAV flight regulations for environmental applications and disaster management.
4. **Future Research:**
    - Conduct case studies in various regions of Iran, such as northern watershed basins or seismically active areas.
    - Explore the application of artificial intelligence in analyzing UAV data for hazard prediction.
5. **International Collaborations:** Leverage global experiences, such as USDA projects, to develop localized technologies.

Future Opportunities:

The integration of UAV-based photogrammetry and SDSS is poised for further expansion through convergence with other emerging technologies and innovative governance models. The following opportunities highlight the future direction of these systems in environmental hazard management, especially within the Iranian context:

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1. Integration with Internet of Things (IoT):

The deployment of sensor networks (e.g., river gauges, weather stations, seismic sensors) in combination with UAVs and SDSS can create smart, interconnected early warning systems. These IoT-enabled platforms can automatically trigger UAV flights upon detecting anomalies, such as sudden rises in water level or seismic activity, allowing real-time data collection and rapid modeling.

2. Use of Cloud Computing and Edge AI:

Cloud-based platforms like Google Earth Engine or Amazon Web Services allow for large-scale, collaborative analysis of UAV data. In parallel, Edge AI – running machine learning models directly on UAVs – reduces reliance on internet connectivity and enables real-time decision-making in remote or rural disaster zones (Zhu et al., 2017).

3. Participatory Disaster Mapping:

Engaging local communities through mobile apps that collect geo-tagged photos and field observations complements UAV imagery. Combining citizen science with SDSS can strengthen situational awareness and accelerate emergency responses, particularly in low-resource settings (Ahmed et al., 2020).

4. Automated Multi-Hazard Prediction Systems:

By combining meteorological, hydrological, geological, and remote sensing data, next-generation SDSS can simulate multi-hazard interactions, such as landslides triggered by earthquakes or floods following dam failures. UAV-derived high-resolution terrain models improve the spatial accuracy of these simulations.

5. Customized Early Warning Systems for Rural Areas:

In rural and high-risk zones like the Zagros and Alborz regions, localized UAV-SDSS frameworks can provide targeted alerts via SMS, local radio, or community centers. These alerts can be tailored based on terrain, accessibility, population density, and infrastructure vulnerability.

6. Climate Change Adaptation and Monitoring:

Long-term UAV monitoring allows the tracking of ecosystem degradation, glacier retreat, desertification, and coastline shifts. These data sets, integrated into SDSS, support national adaptation planning and international reporting obligations (e.g., for the Paris Agreement).

7. National-Level Environmental Intelligence Platforms:

By integrating data from satellites, UAVs, IoT sensors, and public reports, Iran could develop a

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centralized, AI-powered "Environmental Intelligence Platform" that continuously monitors hazards, forecasts risks, and advises policymakers in real-time.

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