remote sensing

Review

Advancements and Applications of Drone-Integrated Geographic Information System Technology—A Review

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Abstract: Drones, also known as unmanned aerial vehicles (UAVs), have gained numerous applications due to their low cost, ease of use, vertical takeover and landing, and ability to operate in high-risk or hard-to-reach areas. The contribution of this review is that of building the bridge between drone technology and its application and advancements in the field of Geographic Information System (GIS). The integration of drones and GIS is valuable as it reduces costs and improves accessibility for geospatial data collection. Traditional methods involving aircraft for aerial photography are expensive, requiring the hiring of aircraft, pilots, and photographers. Drones equipped with advanced cameras and artificial intelligence software can replace the conventional technique and at the same time, be economical and time-efficient. The integration of drones and GIS is expected to bring revolutionary benefits in the fields of precision agriculture, urban planning, emergency health response, disaster management, the development of smart cities, food delivery, etc. In this paper, a state-of-the-art review of the deployment of drone-integrated GIS applications in different fields is presented. Numerous techniques and associated challenges related to their development, formulation, implementation, and regulation are highlighted. It has been concluded that drone-integration solutions in GIS improve efficiency and accuracy, enhance the decision-making process, and facilitate better real-time monitoring. The findings of this review paper are intended to help and benefit researchers, business developers, emergency service providers, industrialists, and policymakers.

Keywords: drone; GIS; mapping; aerial photogrammetry; GPS; smart city; urban planning; precision agriculture; supply chain

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1. Introduction

Geographic Information System (GIS) refers to a field of science that involves the study of the lands, features, inhabitants, and phenomena of the Earth. GIS is a comprehensive framework that includes the processes of acquiring, retaining, modifying, examining, and presenting geographical data in an effective and streamlined way [1]. The software package under consideration may be described as a tool that effectively establishes a connection between graphical information and attribute data recorded in a database, and vice versa [2,3]. GIS provides a range of tools that may enhance operational efficiency and effectiveness in handling both spatial and non-spatial characteristic data [4,5].

The integration of drones with advanced technologies such as artificial intelligence (AI), machine learning (ML), cutting-edge equipment including high-definition (HD) cameras, precision lenses, light detection and ranging (LiDAR), and the computational efficiency afforded by cloud storage and computing has witnessed exponential growth across diverse domains. Accordingly, GIS has revolutionized the field of data collection and analysis. Drones help to procure high-resolution images and collect a plethora of data. GIS, on the other hand, is a technology that captures, manages, analyzes, and displays spatial or geographic data [6]. A simple pictorial representation highlighting the different functions of drones and GIS as well as their potential integrated applications is shown in Figure 1. The integration of these two technologies has brought numerous benefits, especially in areas such as mapping, surveying [7], disaster management [8], and agriculture [9].

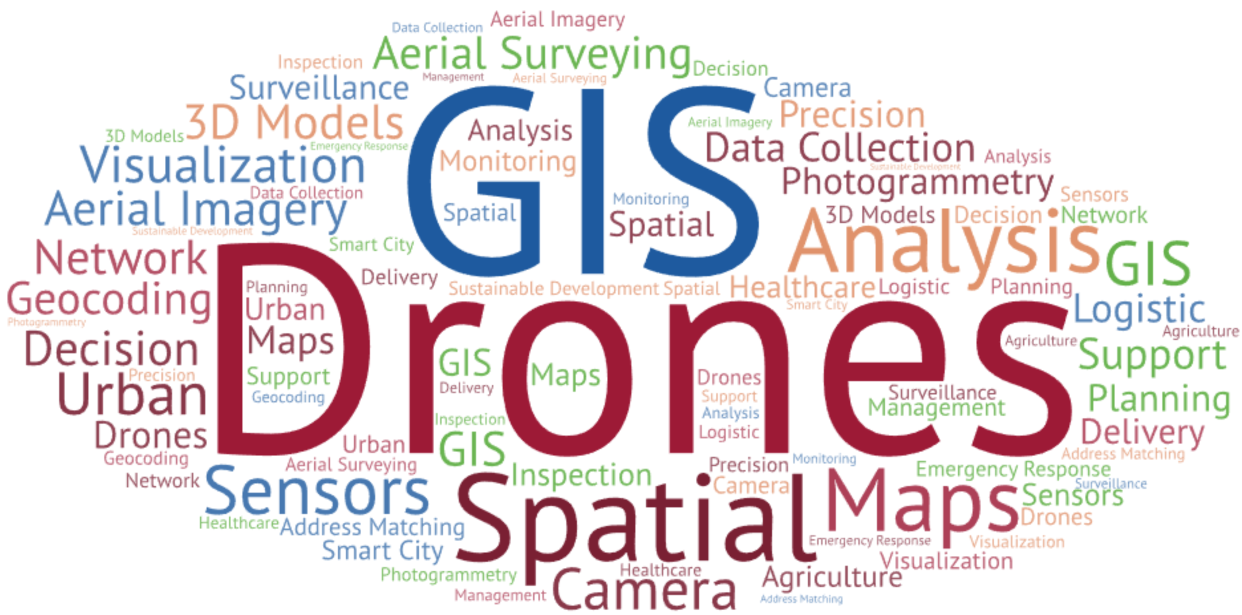

Figure 1. The potential functions and applications of GIS-integrated drone technology.

1.1. Incorporation of GIS–Drone Technology

Drones equipped with high-resolution cameras can capture detailed images of the terrain and produce accurate maps of an area. These maps can be used in urban planning, land-use management, and environmental monitoring [10]. Surveyors can also use drones to capture topographic data and produce digital elevation models (DEMs) that are useful in various fields such as civil engineering and mining [11,12]. Another important application of GIS-integrated drone technology is disaster management and emergency response assistance [8]. Drones equipped with thermal cameras can be used to detect and monitor wildfires and other natural disasters [13]. Drones can also be used to assess the damage caused by disasters and identify areas that need immediate attention [14]. GIS can be used to analyze the data collected by drones and produce maps that show the extent of the damage and the areas that need assistance.

1.2. Use Cases and Applicative Scope

In agriculture, drones integrated with GIS can be used to monitor crop growth and health [15]. Drones can capture multispectral images of crops, which can be used to detect the early signs of disease or stress. GIS can then be used to analyze data and produce maps that show the areas that need attention. This can help farmers take timely action and improve their yields [16,17]. Apart from these applications, drone-integrated GIS can also be used in wildlife monitoring, infrastructure inspection, and search and rescue operations. In wildlife monitoring, drones can be used to capture images of animals and track their movement [18,19]. In infrastructure inspection, drones can be used to inspect bridges, power lines, and other structures that are difficult to access [20,21]. In search and rescue operations, drones can be used to search for missing persons or to locate stranded individuals [22,23].

Furthermore, drones integrated with GIS can play a crucial role in smart city management and sustainable development [24,25]. GIS is a technology that captures, manages, analyzes, and presents geographical data in a way that helps decision-makers make informed choices. By integrating drones with GIS, city managers can collect and analyze data on various aspects of the city such as traffic management [26], public safety [27], and environmental monitoring [28]. Drones integrated with GIS have the ability to map and monitor changes in urban landscapes [29]. By capturing aerial imagery and analyzing it using GIS, city planners can track changes in land use, detect illegal construction, and identify areas in need of development. This information can be used to develop more sustainable urban planning strategies that promote environmentally friendly and socially equitable growth [30]. A generalized flowchart for the implementation of GIS–drone technology is depicted in Figure 2 [31].

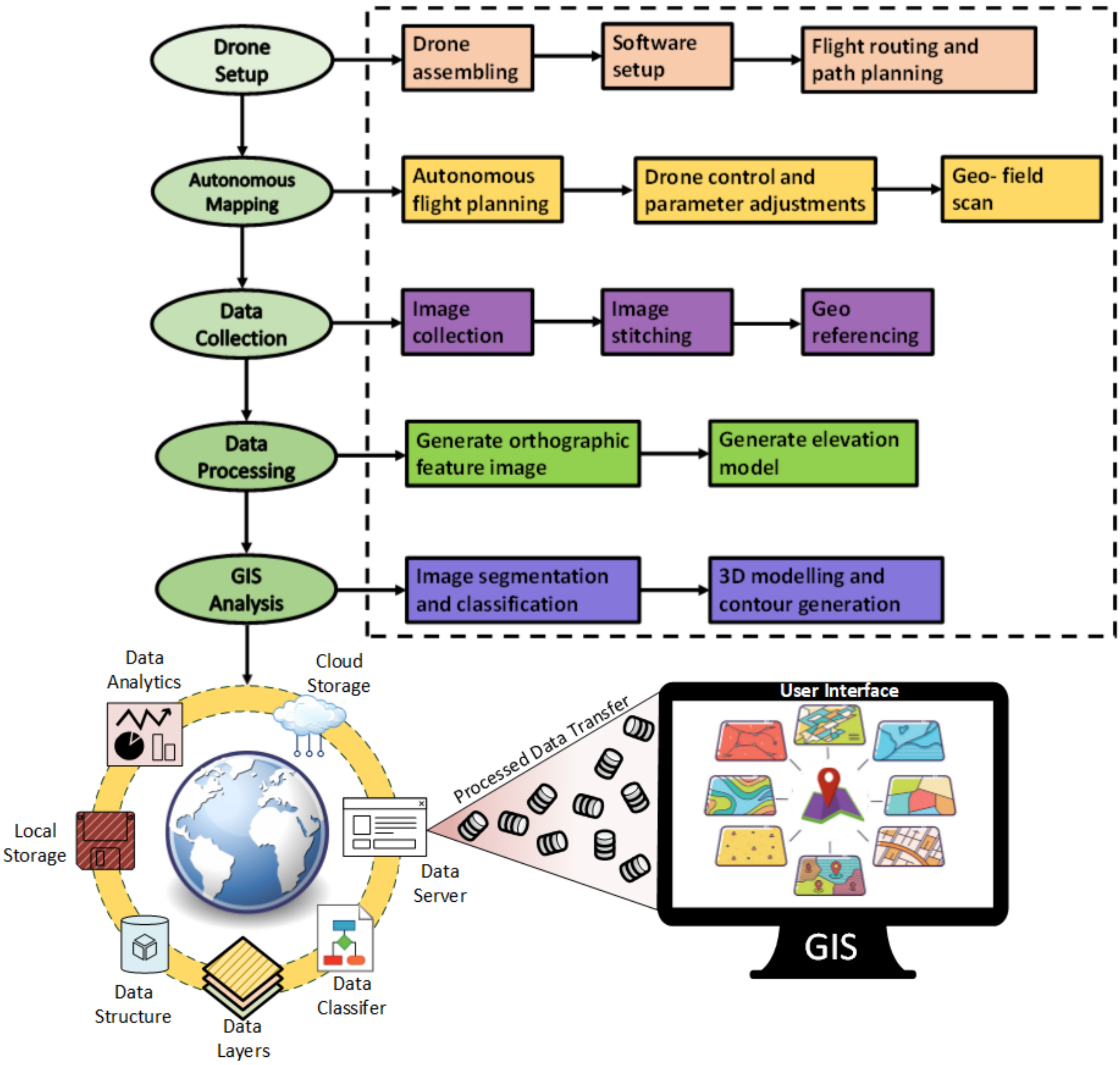

Figure 2. Process and formulation of GIS using drones.

1.3. Motivation

Numerous review and research articles have been presented related to drones and GIS [32–36]. This review aims to present the multi-faced applicative potential of GIS–drones through presenting a comprehensively exhaustive review of their many applications achieved, their processes, and innovations while highlighting their collective major challenges. The motivation of this review are as follows:

- To help understand the utilization of drones towards complementing and augmenting data acquisition, and their implementation towards geographical and geospatial analysis.
- To review multiple sectors, including agriculture, smart cities, advanced supply chain management, mapping, monitoring, surveillance, and tracking while highlighting their respective use-cases to visualize a comprehensive scope of GIS–drone technology.
- To facilitate a resource for students, academics, researchers, and legislators to access the latest developments in this field and progress towards necessary standardization and innovation.

1.4. Paper Organization

The organization of this article is as follows. Section 2 includes a brief background on the evolution of GIS technology. Section 4 presents the technological advancement associated with precision farming. Section 5 defines the use case of GIS drones in the development of resilient smart cities. Section 6 presents the utilization of combined GIS–drone technology in the formulation of the smart supply chain industry, outlining its enhancement in the health sector, disaster management, and delivery services. The enhancement of security surveillance, wildlife and forest monitoring, military applications, and oil and gas pipeline monitoring through GIS–drone applications through mapping, tracking, and monitoring is discussed in Section 7. Section 8 includes various challenges related to GIS–drone technology, followed by the conclusion in Section 10.

2. Background

As a powerful tool, GIS technology has a wide range of applications in various fields, including urban planning, environmental management, health, agriculture, transportation, and emergency response. Although GIS was traditionally used for spatial data analysis and visualization for several decades, with evolving technologies, GIS has also evolved and has significantly contributed to different fields and applications. For example, the integration of remote sensing technology with GIS in the 1980s and 1990s was a significant milestone in the evolution of GIS technology. Remote sensing technology uses satellite imagery to collect data on the Earth's surface. These data are then integrated into GIS systems to create detailed maps of the environment. This integration allowed for the creation of more accurate and comprehensive maps, which were used for a wide range of applications, including environmental monitoring, land-use planning, and natural resource management [6,30].

Another breakthrough integration was that of global positioning systems (GPSs) and GIS. GPS technology uses satellite signals to determine the location of objects on the Earth's surface. The integration of GPS technology with GIS allowed for the creation of real-time maps that could track the movement of objects, including vehicles, people, and animals. The GIS and GPS integration revolutionized the transport and logistics industry [37]. One of the earliest applications of GIS and GPS integration was in the field of wildlife tracking [38]. Researchers used GPS technology to track the movement of animals and GIS technology to analyze the spatial data collected. This helped to understand the behavior and movement patterns of animals and inform wildlife conservation efforts [39,40]. The recent development in GIS technology integrated with mobile devices such as smartphones and tablets has further revolutionized GIS applications. Computing devices allow us to collect spatial data in the field and transmit these to a central database for analysis. For example, in the field of emergency response, mobile devices equipped with GIS technology allow emergency responders to collect real-time data on the location and extent of emergencies, which is then transmitted to a central database for analysis. This helps inform emergency response efforts and improve response times [41].

An interesting cross-pollination of GIS is drone technology. The technology of drones has evolved over time with numerous upgrades, installations, and optimizations increasing its potential as well as application in numerous different studies [42–45]. Drones or unmanned aerial vehicles (UAVs) have revolutionized the field of GIS by providing high-resolution, accurate, and up-to-date imagery data that can be used for a variety of GIS applications [46]. Initially, drones were used for aerial photography and videography, but with the introduction of specialized sensors such as LiDAR and hyperspectral cameras, drones can now collect data on vegetation health, topography, and water quality [47]. These sensors can provide highly accurate and detailed data that can be used for a variety of GIS applications, including precision agriculture, land-use planning, and natural resource management. The integration of drone technology with GIS has also become more streamlined, with the development of software and platforms that can process and analyze drone-collected data. This has made it easier for GIS professionals to incorporate drone data into their existing GIS workflows and analysis [12,48].

The use of drones in GIS applications is on the rise and is a popular topic for future research. The global GIS–drone mapping market is expected to reach a valuation of USD 349.5 million in 2023 and is projected to grow at a compound annual growth rate of 16.5 %, reaching up to USD 1609.6 million in the next ten years [49]. Therefore, in this paper, we present an insightful review of the integration of drone technology with GIS in different fields of study.

3. Integration of Drone with GIS Technique—Use Cases

Drone-integrated GIS is a rapidly evolving technology that combines the capabilities of drones with GIS software to generate spatial data and maps for various sectors. This technology has proved to be a game-changer in various industries, including agriculture, health, disaster management, security and surveillance, wildlife monitoring, delivery services, and military applications. In the following section, the drone-integrated GIS application for various fields is comprehensively discussed, as shown in Figure 3.

Figure 3. Pictorial representation of drone-integrated GIS applications.

4. Precision Farming

In the agricultural sector, drone-integrated GIS has revolutionized farming practices by enabling farmers to identify crop diseases, monitor crop growth, and optimize water usage. Drones equipped with multispectral cameras can capture high-resolution images of crops, which can be used to identify areas that require attention, such as irrigation and fertilization. This information is then processed by GIS software to generate accurate maps, allowing farmers to make informed decisions and maximize yields.

A detailed survey on UAV application in precision agriculture (PA) was performed in [41]. The author explicitly addressed the different GIS applications in PA. PA applications rely on numerical data that describe specific parameters, field observations, and agrochemical quantities, along with geolocation data from GPS systems, to create production maps. Due to the vast amount of data, appropriate software, such as ArcGIS, is necessary to process, organize, analyze, and visualize the information as digital maps [12,46,48,50]. These systems can also include statistical analyses, simulation data, and information extracted from various databases to support decision making [51]. A GIS generally comprises several components, including a spatial data input system that integrates various types of data such as maps, satellite imagery, and multi-spectral imagery. Additionally, this includes a data storage system to store the collected information. Furthermore, a data visualization system is employed to present the data in the form of maps, tables, and shapes. Moreover, a data analysis system is utilized to identify and rectify potential data errors, as well as analyze geospatial data. Lastly, a user interface system is implemented to facilitate user interaction with the GIS system [52]. An illustrative image showing PA using the quasi zenith satellite system [53] by Hitachi is shown in Figure 4.

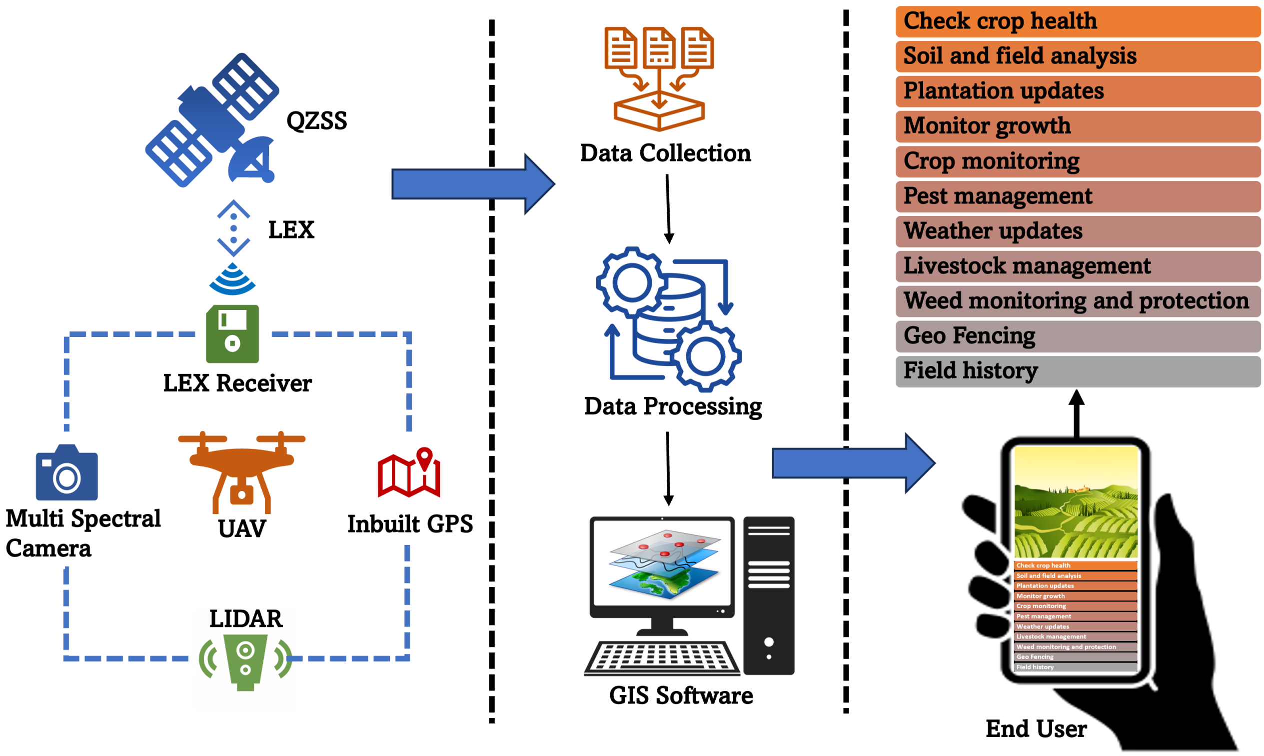

Figure 4. Precision agriculture using the quasi-zenith satellite (QZS) system.

Drone-integrated GIS applications in agriculture offer numerous benefits, such as:

- **Improved crop monitoring:** Drones can capture high-resolution images of crop fields and use GIS to create accurate maps of crop health, density, and yield potential. This helps farmers monitor crop growth and identify any potential issues early on.

- **Precision farming:** Drone-integrated GIS applications allow farmers to apply fertilizers, pesticides, and other inputs precisely where they are needed, reducing costs and improving crop yield.
- **Time and cost savings:** Drones can cover large areas of farmland in a short amount of time, allowing farmers to identify potential issues quickly and efficiently, saving time and reducing costs.
- **Enhanced data collection and analysis:** GIS technology can be used to collect and analyze data from drones, weather stations, and other sensors to provide insights into soil health, weather patterns, and crop performance.
- **Better decision making:** By providing real-time data and imagery, drone-integrated GIS applications can help farmers make more informed decisions about irrigation, fertilization, and other management practices.
- **Increased safety:** Drones can be used to monitor farmland and identify potential safety hazards, such as areas with poor drainage or uneven terrain.
- **Reduced environmental impact:** By providing more accurate data and analysis, drone-integrated GIS applications can help farmers reduce their use of fertilizers, pesticides, and other chemicals, leading to a reduction in environmental impact.

A summary table with some recent research work performed on drone-integrated GIS applications in the field of agriculture is presented in Table 1.

Table 1. Drone-integrated GIS application for agriculture.

Ref.	Year	Type	Study Design/Concept	Main Findings	Context
[32]	2019	Observational study	A comprehensive outline on the utilization of drones in agriculture, item delivery, and GIS, focusing on methods like pesticide spraying and mapping.	• Drones aid precision farming by providing aerial monitoring of crops and livestock. • Agriculture benefits from drones for pesticide spraying and mapping. • Advanced drone technology and software enable precision farming advancements.	Delivery of pesticide and insecticide in agricultural fields
[54]	2023	Experimental study	An experimental study that used unmanned helicopters' image sensors and laser range finders to survey crop status and topography.	• A precise map was created using RTK-GPS and INS as positioning and posture sensors. • A field map was generated with the help of an imaging sensor and laser range finder. • Parameters from the sensors were utilized to develop a transformation method for generating the map.	Surveying agricultural land
[55]	2020	Descriptive study	A descriptive research that introduces a drone-based autonomous trajectory generator for ground robots. The map detects agricultural borders and generates ground robot paths.	• Drone photos are utilized to rebuild a more precise terrain model and automatically produce ground robot tracks. • A contour detector to determine farm borders and ground robot trajectories might enhance crop yields and quality while reducing labor costs. • A novel technology that uses drone-captured overhead photos to construct a detailed terrain map and develop pathways for ground robots might boost agricultural output and quality and reduce labor expenses.	Create maps and generate trajectories

Table 1. *Cont.*

Ref.	Year	Type	Study Design/Concept	Main Findings	Context
[56]	2021	Descriptive study	A descriptive study that examines the monitoring of agricultural areas using UAVs or drones.	• The proposed system uses UAVs or a drone with swarm communication capabilities to monitor an agricultural field. • The drones control system uses a CC2520 RF transceiver and GPS module for swarm communication while monitoring a part of land. • The drone is equipped with sensors to monitor the water level, check the health of the crops, and keep away pests.	Monitor Farmlands
[57]	2019	Observational study	A case study that shows how GIS can analyze sensor data to produce themed maps that help farmers make agricultural choices.	• GIS can spatialize soil sensor data and create themed digital maps to help farmers plan agricultural activities. • Drone (eBee Classic UAV) images were used to create maps for placing Teralytic soil parameter sensors. • Precision farming uses modern machinery and technology to expedite the agricultural process and regulate productivity.	Precision farming

5. Resilient Smart City

5.1. Optimal Site Selection and Asset Deployment

GIS and drones have revolutionized the process of optimal site selection and asset deployment such as finding the best region for harnessing solar or wind energy farms [58] or the implementation of smart grids [59]. By integrating GIS data with drone technology, governments and agencies can collect real-time geospatial data, enabling them to make informed decisions. In site selection, GIS aids in identifying suitable locations based on factors like accessibility, proximity to resources, and environmental impact. Drones play a crucial role in this process by capturing high-resolution aerial imagery and surveying terrains, offering unparalleled insights. In particular, for the optimal site selection for the development of solar and wind energy farms, GIS enables the analysis of vast datasets, such as terrain, solar irradiance, wind patterns, and environmental constraints, to identify the most suitable locations for renewable energy installations. By integrating drone imagery into GIS, detailed and up-to-date aerial views of potential sites can be obtained, allowing for accurate topographical assessments and the identification of obstacles. This combination facilitates informed decision making, reducing development risks and maximizing energy output. The synergy between GIS and drones streamlines the site selection process, promoting the expansion of sustainable solar and wind energy projects, and contributing to a greener and more efficient energy landscape [60]. Moreover, in asset deployment, GIS allows for efficient resource allocation by visualizing infrastructure and understanding its interconnectivity. When it comes to smart grids, the combination of GIS and drones assists in monitoring power distribution, analyzing energy consumption patterns, and facilitating maintenance. This seamless integration enhances operational efficiency and promotes sustainable energy management [61].

5.2. Urban Planning

The integration of drones and GIS has transformed the way urban planning is carried out in many cities around the world. In recent years, drones have become increasingly popular due to their ability to capture high-resolution aerial imagery and collect data in a non-invasive and cost-effective manner. This technology has allowed urban planners to better understand the dynamics of built environments, identify key areas of concern, and make informed decisions about land use and development [62]. Drones provide high-resolution aerial imagery for urban planning, allowing planners to analyze building footprints, road networks, and land use patterns with GIS software to identify areas for improvement. Additionally, drone-integrated GIS technology enables non-invasive and cost-effective data collection on air quality, noise pollution, and pedestrian flow to create detailed maps for identifying areas of concern and prioritizing interventions [63,64].

Drone-integrated GIS technology has been used in a number of urban planning projects around the world. A route planning technique for multi-UAV cooperative data collection for 3D building model reconstruction in response to emergencies was presented in [65]. In Singapore, drones were used to collect data on the condition of the city's green spaces, which was then analyzed using GIS software to identify areas where improvements were needed [66]. In Kota Bharu, multi-rotor drones were used to create 3D models of the city for the purpose of studying urban development and conserving the city heritage [67].

There are several benefits of using drone-integrated Geographic Information System (GIS) applications for urban planning:

- Accurate and detailed data collection: Drones equipped with high-resolution cameras and sensors can capture the accurate and detailed data of urban areas, which can be used to create accurate GIS maps. These data can help urban planners make informed decisions about land use, transportation, and infrastructure development.
- Improved efficiency and cost savings: drone technology can significantly reduce the time and cost involved in collecting data for GIS applications. With drones, data can be collected faster and more efficiently than with traditional surveying methods, resulting in cost savings for urban planning projects.
- Enhanced data visualization: drone imagery can be integrated with GIS applications to provide the 3D visualizations of urban areas. This can help urban planners better understand the spatial relationships between different features and infrastructure and make more informed decisions about urban planning.
- Improved public participation: Drone imagery and GIS applications can be used to engage the public in urban planning processes. By providing detailed visualizations of proposed developments and infrastructure, the public can better understand the potential impacts of urban planning decisions and provide feedback to planners.
- Better disaster response: Drones can be used to quickly assess damage and collect data in the aftermath of natural disasters, providing critical information to aid in disaster response and recovery efforts.

A summary table with some recent research work performed with drone-integrated GIS applications in the field of urban planning is presented in Table 2.

Table 2. Drone-integrated GIS application in urban planning.

Ref.	Year	Type	Country	Study Design/Concept	Main Findings	Context
[68]	2018	Experimental study	South Korea	GIS-based framework for drone trajectory planning that considers trajectory and 3D modeling constraints as well as flight map data like visibility, wind, and risk.	• Developed a GIS-based drone trajectory framework. • Planning the trajectory can enhance the utilization of resources by minimizing the search area during drone flight while modeling. • Drones can create high-resolution 3D cityscape models to reveal a smart city structure. • The effectiveness of the proposed approach is tested on South Korea open data.	3D urban model for smart city

Table 2. *Cont.*

Ref.	Year	Type	Country	Study Design/Concept	Main Findings	Context
[62]	2020	Descriptive study	Taiwan	Research on the development and utilization of UAVs for building 3D urban maps.	• UAVs can produce 3D urban land use maps in Tainan City, Taiwan. • Drones are good for mapping since they are cheap, simple to use, and can avoid clouds. • The utilization of GIS can aid in the subsequent handling and application of the 3D maps.	3D maps for urban land use
[33]	2021	Observational study	Dominican Republic	A case study that discusses the application of unmanned aerial systems (UASs) in urban planning. It presents a case study of how UAS data can be used to make better decisions in urban communities.	• This paper showcases the use of UASs to detect house growth in the councils of the Dominican Republic. • The model presented highlights how UAS can provide visual information about the community's current state and its potential applications for council operations. • The model could also be replicated in other countries. • It allows faster and safer urban planning.	Urban planning
[69]	2020	Observational study	Malaysia	Research on the utilization of fixed-wing UAVs to verify royal land boundaries. UAV and GIS outputs were used to combine aerial mapping and vector digitization in organized geographical databases.	• UAVs with GIS can precisely determine any land boundary. • Aerial mapping UAV and vector digitalization GIS provide trustworthy spatial databases. • Urban planning with UAVs ensures sustainability and resilience.	Heritage land mapping
[70]	2020	Experimental study	Sofia, Bulgaria	This experimental paper examines how remote sensing, UASs, and GIS were integrated to map and evaluate urban heat island effects in Sofia, Bulgaria.	• The urban heat island effects in Sofia, Bulgaria, were mapped and evaluated using remote sensing, UASs, and GIS. • High population density and the city center had more significant urban heat island effects, according to the results. • The study concluded that integrating remote sensing, UASs, and GIS is an effective method for mapping and assessing urban heat island effects.	Land mapping

5.3. Smart City Management

In smart city applications, drone-integrated GIS technology can be used to collect data on various aspects of the city's infrastructure, such as traffic flow, building density, and energy usage. This information can be fed to the GIS software for different types of smart city management applications [71]. This information can be used to optimize resource allocation, improve public safety, and enhance the overall quality of life for residents. For example, drones equipped with thermal imaging cameras can be used to detect heat loss from buildings, which can help city planners to identify areas that require insulation or other energy-saving measures [72]. Drones can also be used to monitor traffic flow, identify congested areas, and optimize traffic signal timings to reduce traffic congestion and improve public transportation [73]. An graphical representation of smart city management using the integrated GIS-drone technology is shown in Figure 5.

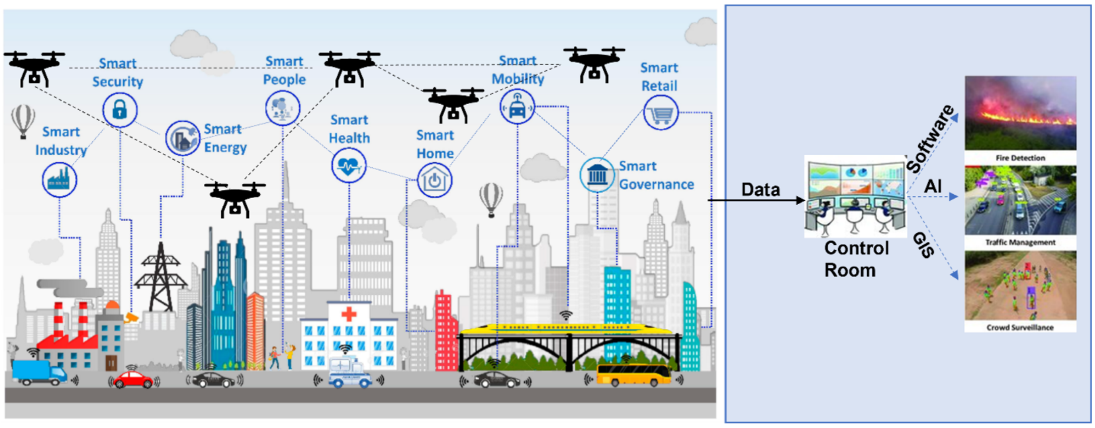

Figure 5. Conceptual representation of drones and GIS application in smart cities management [72].

There are several benefits of using drone-integrated GIS applications for smart city development and management:

- **Accurate and detailed data collection:** Drones equipped with high-resolution cameras and sensors can capture the accurate and detailed data of urban areas, which can be used to create accurate GIS maps. These data can help city planners make informed decisions about infrastructure development, traffic management, and environmental management.
- **Improved efficiency and cost savings:** Drone technology can significantly reduce the time and cost involved in collecting data for smart city development and management. With drones, data can be collected faster and more efficiently than with traditional methods, resulting in cost savings for smart city projects.
- **Enhanced data visualization:** Drone imagery can be integrated with GIS applications to provide 3D visualizations of urban areas. This can help city planners better understand the spatial relationships between different features and infrastructure and make more informed decisions about smart city development.
- **Improved traffic management:** Drones can be used to monitor traffic patterns and identify areas in need of traffic management interventions. This can help reduce traffic congestion and improve the overall efficiency of transportation systems.
- **Better environmental management:** Drones can be used to monitor environmental indicators such as air quality, water quality, and noise levels. This can help city planners to make informed decisions about environmental management and ensure that smart city development is sustainable and environmentally friendly.

A summary table with some recent research work performed on drone-integrated GIS applications in the field of smart city management is presented in Table 3.

Table 3. Drone-integrated GIS applications for smart city management.

Ref.	Year	Type	Country	Study Design/Concept	Main Findings	Context
[74]	2018	Observational study	Jinu-Do, South Korea	Use of UAVs, photogrammetric tools, and GIS for mapping the coast of Jinu-do in Nakdong River Estuary.	• The integration of UAV, photogrammetric software, and GIS analysis tools can provide detailed information about coastal morphologic changes and vegetation migration. This information can be used to support the Sustainable Development Goals required for smart cities. • Using ground control points, the vertical accuracy of the digital surface model was found to be 5 cm or better. • The vegetation area was increased about 5% more than the topography.	Beach volume change, vegetation area migration

Table 3. *Cont.*

Ref.	Year	Type	Country	Study Design/ Concept	Main Findings	Context
[75]	2020	Descriptive study		Research on the components of a smart city using building information modeling. This highlights various tools such as GIS, UAVs, and building energy model (BEM) that could be used to make a smart city.	• The integration of affordable UAVs and structure from motion algorithms provides increased versatility, wider area coverage, and better documentation capabilities. • The use of a GIS framework has the potential to facilitate the establishment of an effective data management system in transportation design, hence minimizing accidents, mitigating the impact of earthquakes, and eliminating fire dangers, all of which are crucial elements in the development of a smart city. • BEM could be an innovative concept to make a smart city.	Smart building management for smart cities
[72]	2020	Experimental study	National Cheng Kung University (NCKU), Taiwan	Application of Web 3D GIS to display urban models and solar energy analysis. It describes how the UAV data are collected and processed to obtain the 3D campus model in NCKU, Taiwan.	• UAV data combined with GPS and IMU technology were used to create a 3D campus model of NCKU. • Autodesk Insight 360 and Autodesk Revit were used to process the building footprint data. • ArcGIS Pro was used to calculate the solar energy potential of NCKU, and the results were displayed in a Web 3D GIS. • In the future, every spatial detail can be recorded in a cloud-based big data repository, enabling analysis, cloud-based browsing, and downloading. This will constitute a noteworthy advancement in smart city infrastructure.	Solar energy of buildings, 3D GIS analysis
[76]	2022	Experimental study	Zagreb	A 3D city model for spatial planning has been made since 2008. It is used for land use planning and architectural competitions. The city wants to enhance the model and merge it with real-time data for a digital city twin.	• The 3D model was created by UAV photogrammetry and later updated using airborne LiDAR data. • The city of Zagreb intends to enhance the current 3D city model and the ZG3D application in order to transition towards a digital city twin.	Smart city, digital twin
[77]	2022	Observational study	Mansoura University campus, Egypt	Methods for creating and analyzing 3D city models using GIS technology and free data sources. Procedural modeling generates the model, and a flood impact scenario is simulated through spatial analysis.	• The Mansoura University campus's 3D city model was created using a digital elevation model (DEM), manual digitization from high-resolution photography, and deep learning structural algorithms. • The trained deep learning model has accuracies of 0.78 for buildings, 0.62 for streets, and 0.89 for landscape regions. • The 3D city model simulated flood impact.	Smart city, Digital twin

Table 3. *Cont.*

Ref.	Year	Type	Country	Study Design/ Concept	Main Findings	Context
[78]	2019	Experimental study	Andhra Pradesh, India	Utilizing UAVs for automatic information gathering on buildings and their transformation into a 3D point cloud that can be used to identify details about urban structures.	• UAVs can autonomously harvest building data and describe urban building types under the APCRDA area. • UAVs can measure the site acreage, built-up area, building measurements, setbacks, and height. • UAVs may replace manual inspections and reports, saving money and time. • The experimental study exhibited its capabilities by presenting building models on GIS-based maps and allowing the interactive manipulation of large building point cloud datasets, such as rotation, scaling, and extracting setback, height, and dimension measurements.	Urban e-Governance, smart city development
[79]	2022	Simulation study		Utilization of GIS information integration to accurately expand the digital virtual environment in reality to the level of the digital twin.	• Accurate digital twins are created by integrating GIS data into the actual world. • The method explores available GIS data, deploys these in the simulator, uses GIS-based real-world environment transformation algorithms, and collects drone data. • The field-tested approach improves UAV inspection deployment.	Smart city, digital management

6. Smart Supply Chain

The utilization of GIS–drone technology has the potential to enhance the ever-increasing landscape of supply chain management. The combined technology associated with GIS and drones entails harnessing the power of spatial data analysis and unmanned aerial vehicles to optimize supply chain operations in diverse sectors, such as healthcare, disaster management, and delivery services. By leveraging GIS and drone technology, researchers aim to enhance the efficiency, accuracy, and responsiveness of supply chain processes, thereby revolutionizing the way logistics are managed. This section explores the transformative capabilities of smart supply chains and sheds light on the manifold benefits they bring to these critical areas, paving the way for more effective and agile supply chain management practices (Figure 6).

6.1. Health

The innovative study conducted by John Snow about the cholera epidemic that occurred in London in 1854 serves as a prominent and well-recognized illustration of the efficacy of mapping and spatial methodologies within the field of public health. Shiode et al. in 2015 [80] recreated the London cholera outbreak using modern GIS technology. GIS has become increasingly prevalent in the healthcare industry for investigating the influence of distance and non-spatial variables on healthcare accessibility and usage [81]. The use of GIS enables researchers to understand the complex relationship between the physical environment and healthcare outcomes. However, there are differing methodological perspectives employed when exploring the spatial and temporal patterns of healthcare utilization. For instance, some researchers focus on measuring the accessibility of healthcare services and facilities by analyzing the distance between them and the population they serve. Others explore the spatial distribution of healthcare resources and the utilization patterns of these resources by analyzing demographic and socioeconomic factors, such as income and education level. Furthermore, some researchers examine the temporal patterns of healthcare utilization, such as seasonal variations or changes over time due to policy interventions.

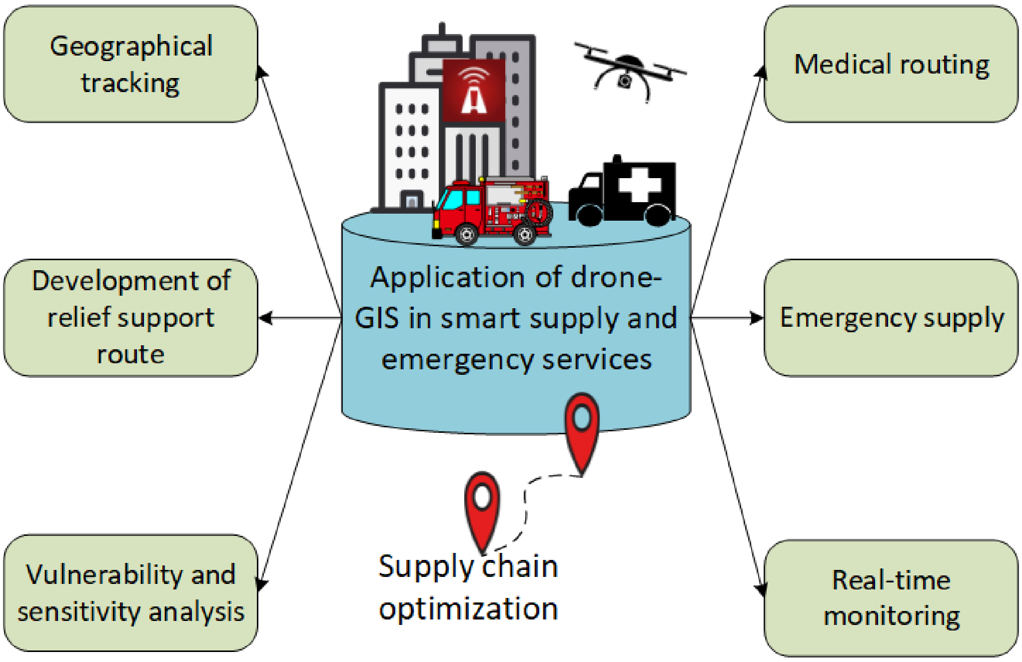

Figure 6. GIS–drone utilization in various fields of supply chain enhancement.

In recent years, drone-integrated GIS technology has been adopted for disease surveillance and control in the healthcare industry. GIS-equipped drones can be used to map and track disease outbreaks and the spread of viruses, including the COVID-19 pandemic. By collecting information on high-risk areas and populations, healthcare professionals can take preventive measures to mitigate the spread of disease. Additionally, drones can deliver vaccines to remote and inaccessible areas, such as rural regions or areas affected by natural disasters, where access to healthcare services is limited. This helps to reduce the spread of diseases and improve the overall health outcomes of these populations. The integration of GIS and drone technology is an innovative approach that is transforming the healthcare industry, enabling more effective disease surveillance and control, and improving healthcare access and utilization in remote and underserved areas.

- Faster response times: Drones equipped with medical supplies can be used to quickly respond to medical emergencies in remote or hard-to-reach areas. This can significantly reduce response times, and potentially save lives.
- Improved supply chain management: Drone technology can be used to monitor the supply chain of medical equipment and supplies, ensuring that they are delivered to the right place at the right time. This can help to reduce waste, optimize inventory levels, and improve the overall efficiency of healthcare supply chains.
- Enhanced data visualization: Drone imagery can be integrated with GIS applications to provide detailed visualizations of healthcare facilities and infrastructure. This can help healthcare managers to better understand the spatial relationships between different facilities and make more informed decisions about healthcare management.
- Improved disease surveillance: Drones can be used to collect data on disease outbreaks and monitor the spread of infectious diseases. This can help healthcare managers to better understand the patterns of disease transmission and develop effective response strategies.
- Better disaster response: Drones can be used to quickly assess damage and collect data in the aftermath of natural disasters, providing critical information to aid in disaster response and recovery efforts. This can help ensure that medical resources are deployed where they are needed most.

A summary table with some recent research work performed with drone-integrated GIS applications in the field of healthcare management is presented in Table 4.

Table 4. Drone-integrated GIS applications in healthcare management.

Ref.	Type	Year	Country	Study Design/ Concept	Main Findings	Context
[82]	Observational study	2023	Ghana	Drone deployment for COVID-19 vaccine distribution in Ghana. It concludes that drones were utilized to deliver vaccines to deprived areas, and those areas that were more marginalized due to structural demographic factors received a higher number of vaccine doses.	• UAVs were used to deliver over 2 million doses of COVID-19 vaccines to 497 health facilities in Ghana. • Analysis was performed for an entire set of information on vaccine deliveries by drones in Ghana, along with demographic and socioeconomic data from the Ghana Statistical Service. Using GIS analysis and demographic information, health facilities and distribution centers were categorized into rural and urban groups. • Districts with a higher number of socioeconomically disadvantaged households received a larger quantity of vaccines at their health facilities.	COVID-19 vaccine delivery
[83]	Descriptive study	2022		This article presents pre-hospital medical emergency security using UAVs.	• Pre-hospital security for medical emergencies can be enhanced by utilizing UAVs, which can offer capabilities such as surveillance, monitoring, and communication. • Real-time information about the location and condition of patients can be provided to medical personnel through the use of UAVs. • UAVs can provide logistic support for emergency medical equipment needed in remote locations, while the mapping can be performed using the GIS tool.	Pre-hospital-emergency medical assistance
[84]	Comparative study	2020	Ireland	This study examines the possibility of using UAVs to map mosquito breeding grounds and compares the effectiveness of the UAV method to GPS receivers. This study finds that GPS receivers outperformed UAVs in identifying small artificial containers.	• This study compared the efficiency of UAVs and GPS receivers in surveying a study area for mosquito breeding grounds. • The GPS method was found to be more effective than the UAV method in identifying small artificial containers. • This study used statistical methods, such as two-tailed, paired t-test, to compare the performance of the two technologies.	Assessing UAV impact on public health

Table 4. *Cont.*

Ref.	Type	Year	Country	Study Design/ Concept	Main Findings	Context
[85]	Observational study	2023	Libya	The significance of GIS in visualizing, monitoring, and tracking spatial data is explored in this article. It introduces a model for constructing a GIS dashboard, utilizing a case study of tracking the transmission of COVID-19 in Libya.	• The analyzing and processing of geospatial data can be conducted effectively and with precision using GIS software. • GIS programs have become even more efficient and accurate thanks to recent developments in AI and ML. • Small businesses now have access to GIS software due to the decreased cost resulting from the use of cloud computing.	GIS application in monitoring epidemics
[86]	Descriptive study	2018		Utilization of drones in medicine, categorizing their potential applications as: (1) emergency care; (2) faster lab testing; and (3) surveillance.	• The medical field could use UAVs and GIS for pre-hospital emergency care, faster laboratory diagnostic testing, and surveillance purposes. • UAVs have delivered vaccines, automated external defibrillators, and hematological products. • Using UAVs may improve healthcare access for patients who cannot afford, reach, or have limited infrastructure for proper care.	Pre-hospital-emergency medical assistance

6.2. Disaster Management

Drones have been widely used in disaster management for rescue operations, emergency delivery, and monitoring the extent of damage. A detailed review of drone applications in the field of disaster management is presented in [87]. Drones coupled with GIS software will be an amalgamation of two powerful tools that can allow swift action based on accurate and precise location. Drones can be used to assess the extent of damage caused by natural disasters such as hurricanes, earthquakes, and floods. The integration of drones and GIS technology provides a comprehensive platform for capturing, analyzing, and visualizing data in real time. Drones can be equipped with sensors and cameras that capture data and transmit these to the GIS system, where they are analyzed and visualized in real time. GIS technology can provide a spatial analysis of the data captured by drones, which can help disaster management agencies in decision making. Spatial analysis can help in identifying the affected areas, the extent of the damage, and the resources required for relief operations. For example, during a flood, drones can be used to capture the images of the affected areas, which can be analyzed by the GIS system to identify the extent of the damage and the areas that require immediate relief. The drone-integrated GIS application provides several benefits in disaster management, some of which are as follows:

- **Real-time data:** Drones equipped with GIS technology can provide real-time data that can help disaster management agencies in decision-making. Real-time data can help in identifying the affected areas and the resources required for relief operations.
- **Accurate data:** Drones equipped with sensors and cameras can capture accurate data, which can help in identifying the extent of the damage and the areas that require immediate relief.
- **Cost-effective:** The use of drones equipped with GIS technology is cost-effective compared to traditional methods of data collection and analysis.
- **Time-saving:** Drones equipped with GIS technology can capture data in a short period, which can help in decision making and relief operations.

- **Improved safety:** The use of drones equipped with GIS technology can improve safety during relief operations, as they can capture data from a safe distance.

A summary table with some recent research work performed with drone-integrated GIS applications in the field of disaster management is presented in Table 5.

Table 5. Drone-integrated GIS application for disaster management.

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[88]	Observational study	2020	Taiwan	Observational study of high-resolution aerial photographs of Laishe River from 2009 to 2015.	• Applications used to analyze photos are Pix4Dmapper, DEMs and ArcGIS. • This study highlights the potential applicability of UAVs in quantifying the movement of landslide debris and assessing morphological variations in a river situated in a hilly region.	Typhoon and landslide
[89]	Experimental study	2020	Dominica	UAV surveys collected aerial imagery from 44 hurricane-affected key sites in Dominica over a period of 4 months.	• Low-cost UAV surveys can be used to accurately quantify geomorphological changes in the aftermath of a natural disaster. • A purpose-built Python script can be used for automated processing, enabling rapid data turnaround. • Pre-disaster baseline surveys can be used to provide baseline data reference points in areas that might undergo future change.	Hurricane
[90]	Experimental study	2020	Xiamen, China	UAV aerial imagery data analysis based on ArcGIS.	• UAV aerial photography has the potential to expedite the evaluation and examination of loss and catastrophe recovery in affected regions. • The establishment and generation of image interpretation marks for multi-objective catastrophe-impacted bodies may provide an accurate reflection of the state of losses due to a disaster. • The Model Builder tool may be used to conduct a preliminary analysis of surface characteristics using multi-period DSM and DOM data collected at multiple time intervals.	Typhoon
[91]	Experimental study	2021		Use of UAVs, GNSS, GIS, and petrographic analyses for landslide mapping and monitoring.	• UAVs, GNSS measurements, GIS, and petrographic analyses can be used to map and monitor landslides. • A novel, cost-effective methodology was devised for estimating the direction and velocity of displaced material. • The lithology and petrographic characteristics of the material are significant factors influencing the occurrence and behavior of landslides.	Landslide mapping and monitoring

Table 5. *Cont.*

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[92]	Experimental study	2017	Utah, USA	Experimental study.	• UAVs can be used to acquire high-resolution aerial imagery of wetlands for wetland mitigation. • The multiclass relevance vector machine algorithm was used to classify the georeferenced UAV imagery of the study area. • The results showed considerable accuracy and good agreement with the actual classes, indicating that UAVs may be a viable and cost-effective option for wetland mitigation.	Wetland mitigation for highway development

6.3. Delivery Services

Delivery services have also embraced drone-integrated GIS technology. Drones equipped with GPS technology can be used to deliver packages quickly and efficiently, reducing delivery times and costs. GIS technology allows users to collect, analyze, and visualize geographic data, while drones offer the ability to navigate through difficult terrain and areas with limited accessibility.

Research has shown that drone-integrated GIS applications have the potential to significantly reduce delivery times and costs. In a survey study conducted in [93], the use of drones for delivery has shown considerable economic and environmental implications. Specifically, the implementation of drone-assisted delivery has resulted in a reduction in carbon emissions by 24.90%, a decrease in overall cost by 22.13%, and a reduction in delivery time by 20.65% when compared to conventional delivery methods. Furthermore, GIS technology can be used to optimize delivery routes and improve delivery accuracy [94].

There are several benefits of UAV-integrated GIS applications in delivery and logistics, including:

- **Efficient delivery:** UAVs equipped with GIS technology can be used to optimize delivery routes, reducing delivery times, and costs. This can lead to improved customer satisfaction and increased efficiency in delivery operations.
- **Improved accuracy:** GIS technology can be used to map and analyze delivery routes, enabling delivery companies to identify potential obstacles and optimize their routes accordingly. This can help reduce delivery errors and improve accuracy.
- **Remote access:** UAVs equipped with GIS technology can be used to deliver goods to remote areas that are difficult to access by traditional delivery methods. This can open up new markets and increase the reach of delivery services.
- **Reduced environmental impact:** UAVs have a smaller carbon footprint compared to traditional delivery vehicles, which can help reduce the environmental impact of delivery operations. Additionally, by optimizing delivery routes, UAVs can help reduce fuel consumption and emissions.
- **Real-time tracking:** UAVs equipped with GIS technology can provide the real-time tracking of deliveries, enabling customers to track their packages and delivery companies to monitor their operations.

A summary table with some recent research work performed with drone-integrated GIS applications in the field of logistics delivery is presented in Table 6.

Table 6. Drone-integrated GIS application for logistic delivery.

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[95]	Observational study	2022	Shanghai, China	Analyzes the usage of a drone delivering emergency medicine in cities, utilizing heuristic algorithms and ArcGIS software to plan secure 3D routes that adhere to regulations.	• When planning drone routes for emergency medicine delivery, 3D path routing can be utilized. • To collect the location data of chronically ill patients in locked down areas of Shanghai, heuristic algorithms and ArcGIS software were employed to map the terrain and complex airspace. • An improved ant colony optimization (ACO) was applied to 3D route planning to create a suitable emergency medicine delivery plan, which could serve as a guide for similar complex urban environments.	Emergency medicine delivery
[96]	Observational study	2022	China	Investigation of the spatial heterogeneity and driving factors of UAV logistics networks in Hangzhou, China.	• The UAV logistics networks in Hangzhou; China exhibits spatial heterogeneity across different areas. • Population density, land use, and economic development are factors that drive the development of UAV logistics networks in Hangzhou, China. • The expansion of UAV logistics networks in Hangzhou, China is anticipated to persist in the future.	Logistic planning
[97]	Comparative study	2017	Los Angeles, USA	Assesses the emissions and vehicle-miles traveled for truck and drone delivery models using ArcGIS. Drones can potentially reduce CO2 emissions under certain conditions, and the VMT for both modes align with existing literature.	• The emission outcomes of drone delivery are largely influenced by the energy consumption of the drone, the travel distance, and the number of deliveries it makes. • Proximity of the service zones to the depot, fewer stops, or both can potentially enable drones to reduce CO_2 emissions. • The VMT of both the truck and drone delivery methods align with existing literature that compares passenger travel and truck transport.	Carbon (CO_2) emission reduction using drone delivery
[98]	Descriptive study	2020	China	Novel operation study that proposes an innovative system for prompt delivery utilizing vehicles and UAVs. It proposes integrating GIS for accurate route planning	• The article showcases a new approach for immediate delivery, utilizing vehicles and UAVs. • A capacity-constrained set covering a location model is created to ascertain the optimal number of vehicle stops and their feasible locations. • The study proposes two cutting-edge ACO algorithms to optimize the decision-making process for the remaining stages.	Logistic planning

Table 6. *Cont.*

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[99]	Experimental study	2019	San Francisco, California	Utilization of small UAVs to deliver medicine and goods swiftly and efficiently, particularly for critical medical and emergency applications where time is of the essence and traffic congestion is a problem.	• This paper introduces a stochastic bi-objective mixed-integer nonlinear programming model for a discrete mobile FLP, where demand generation for each network edge conforms to the Poisson distribution. • The model views each facility as a distribution center furnished with several UAVs functioning as delivery vehicles, and nodes are obtained from ArcGIS software.	UAV supported delivery

7. Mapping, Tracking, and Monitoring

7.1. Crowd Management and Control

Drone-integrated GIS can also help in crowd management and control [57,100]. Overcrowding in public areas, particularly stadiums, and concerts, can result in stampedes. GIS allows the mapping and visualization of crowd flow patterns, enabling organizers to identify potential bottlenecks and plan effective evacuation routes in the case of emergencies. By integrating real-time drone surveillance, event organizers can monitor crowd density, identify potential overcrowded areas, and respond proactively to ensure crowd safety. Drones equipped with high-resolution cameras provide live feeds to security personnel, allowing them to closely monitor the situation and detect any suspicious activities. The combination of GIS and drones revolutionizes crowd management practices, enhancing the overall event experience by ensuring the safety and security of attendees in large gatherings. In [101], a drone with a GIS technique and remote sensing were used for crowd management and risk mitigation during the COVID-19 pandemic and lockdowns.

7.2. Security and Surveillance

UAVs have revolutionized the way security and surveillance tasks are performed [102]. With the integration of GIS, drones provide accurate and real-time spatial information, enhancing situational awareness and decision-making capabilities.

GIS integration with drones enables the mapping of critical infrastructure, high-value targets, and areas of interest. Drones equipped with high-resolution cameras can be used to monitor large areas, providing real-time data that can be used to detect potential threats and respond quickly. The drones can provide real-time video and thermal imagery to enhance the ability to identify and track targets. The integration of GIS allows for the creation of 3D models, which enable the better visualization and analysis of the area under surveillance. This capability is particularly useful in large areas, where ground surveillance can be difficult. Drones can also be used for border patrol, allowing authorities to monitor and secure borders more effectively. The U.S. Customs and Border Protection Agency (CBP) uses drones equipped with GIS technology to monitor and secure the borders of the United States [103]. The drones can cover vast areas and provide real-time video and thermal imagery to detect and track illegal activity. The drones also enable the CBP to quickly respond to breaches of security.

A model for a command control communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) system with a focus on detection and reconnaissance using drone technology and GIS was developed in [104]. A drone-integrated GIS technique was used in to examine the archeological site of Nineveh, situated in Mosul, Iraq [105]. The researchers employed drone data and GIS technologies to examine surface morphology. Satellite images, drone images, and digital surface models (DSMs) were visually and digitally analyzed to identify any possible discovery that could contribute to the comprehension of the site's original surface.

There are several benefits of using drone-integrated Geographic Information System (GIS) applications for security surveillance and monitoring:

- **Improved situational awareness:** Drones equipped with cameras and sensors can provide real-time situational awareness of a given area, allowing security personnel to respond quickly to potential security threats. This can help to prevent crime and improve public safety.
- **Enhanced data visualization:** Drone imagery can be integrated with GIS applications to provide detailed visualizations of security risks and vulnerabilities. This can help security personnel to better understand the spatial relationships between different security features and infrastructure and make more informed decisions about security management.
- **Cost-effective surveillance:** Drone technology can significantly reduce the cost of security surveillance and monitoring. With drones, large areas can be monitored quickly and efficiently, reducing the need for expensive manned security patrols.
- **Reduced risk to personnel:** Drones can be used to collect data in hazardous or inaccessible areas, reducing the risk of injury or harm to security personnel. This can help to improve safety and security for security personnel.
- **Improved emergency response:** Drones can be used to assess damage and collect data in the aftermath of security incidents, providing critical information to aid in emergency response efforts. This can help to ensure that emergency resources are deployed where they are needed most.

A summary table with some recent research work performed with drone-integrated GIS applications in the field of security and surveillance is presented in Table 7.

Table 7. Drone-integrated GIS application for surveillance application.

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[106]	Simulation study	2021	Nigeria	Utilization of UAVs for identifying individuals in the deepest jungle using AI, ML, IoT, and GIS for human detection to prevent illegal activities of bandit abduction.	• Ability of the autonomous UAV system to detect humans within the thickest forest region using precision laser range detectors. • Accuracy of the individualized 3D map of the UAV's surroundings. • Scientific opportunities available for AI-based UAV modeled with ML (convolution neural network) on the Internet of Things (IoT) framework. • Potential for AI-based UAV to extradite terrorists within the Lake Chad basin.	Human detection in thick forest
[107]	Experimental study	2020	Nigeria	Case study.	• UAVs are effective for intelligence gathering, aerial surveillance, and security monitoring. • The use of drones or UAVs for effective aerial surveillance, mapping systems, and intelligence gathering is recommended for combating insecurity in Nigeria.	Effective aerial surveillance, intelligence gathering and monitoring of security activities

Table 7. *Cont.*

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[108]	Observational study	2021		Case study.	• This paper explores how integrating UAV images can be used to generate cadastral maps. This is an alternative to the production of cadastral maps that can be utilized to prevent the spread of informal settlements.	-

7.3. Wildlife and Forest Monitoring

Wildlife monitoring is another area where drone-integrated GIS has proved useful. Drones can be used to monitor wildlife populations, track migration patterns, and identify critical habitat areas [109]. This information is essential in conservation efforts and helps wildlife officials to develop effective management strategies. In [108], drones are used to investigate and analyze forest geospatial information. The technique is useful for efficiently calculating the area and volume of forest damage while saving time and resources. While remote sensing, GIS, and UAVs are employed in [110] to study the deforestation in the mangrove forest of the Niger Delta.

In [111], drone technology was used to identify potential sites for healing forests. Analyzing the vegetation density was accomplished with GIS and the green-red vegetation index (GRVI), while the slope classification was analyzed using a digital terrain model (DTM). A survey on the use of drones for monitoring wildlife during forest fires is presented in [112]. The utilization of satellite remote sensing and GIS assistance in visualizing the size and devastation caused by forest fires at varying time intervals and scales is also presented.

There are several benefits of using drone-integrated Geographic Information System (GIS) applications for wildlife and forest monitoring and management and conservation:

- **Improved data collection:** Drones equipped with high-resolution cameras and sensors can collect data on wildlife and forest ecosystems more efficiently and accurately than traditional methods. This can help identify patterns and changes in the ecosystem over time and inform conservation strategies.
- **Reduced disturbance to wildlife:** Drones can collect data on wildlife without disturbing them, which is particularly important for monitoring sensitive or endangered species. This can help to minimize human impact on the ecosystem.
- **Enhanced data visualization:** Drone imagery can be integrated with GIS applications to provide detailed visualizations of wildlife and forest ecosystems. This can help wildlife and forest managers to better understand the spatial relationships between different species and habitats and make more informed decisions about conservation management.
- **Improved forest management:** Drones can be used to monitor forest health, detect forest fires, and identify areas in need of reforestation. This can help forest managers to make informed decisions about forest management and ensure the long-term sustainability of forest ecosystems.
- **Improved law enforcement:** Drones can be used to monitor wildlife populations and detect illegal activities such as poaching and deforestation. This can help law enforcement agencies to better protect wildlife and forest ecosystems.

A summary table with some recent research work performed with drone-integrated GIS applications in the field of wildlife monitoring is presented in Table 8.

Table 8. Drone-integrated GIS application for wildlife monitoring.

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[113]	Experimental study	2020	Kalamazoo, Michigan	GIS-based approach to the automatic flight planning of camera-equipped UAVs for building a fire emergency response.	• Camera-equipped UAVs for building fire emergency response may be automatically flown using GIS. • Geometrical and spatial information from GIS data and Haversine formula automate flight planning. • The suggested method quickly generates fire emergency flying missions.	Emergency fire response.
[18]	Descriptive study	2022		GIS remote sensing uses satellite and UAV imagery.	• GIS remote sensing is increasingly using satellite and UAV platforms. • UAVs collect high-resolution GIS data efficiently and cheaply. • Remote sensing data may be utilized to produce detailed environmental maps and models for many applications such as forest and wildlife monitoring, environmental management, and precision agriculture.	Wildlife monitoring, environmental management, and precision agriculture.
[114]	Observational study	2022	Zambezi region, Namibia	Wildlife's influence on northeast Namibia's plant cover change was examined from 2002 to 2021 using MODIS satellite images, UAV photogrammetry, and GIS analytic tool.	• An assessment of the wildlife impact—especially that of elephants—on vegetation was performed for the period 2002-2021. • High elephant density areas show more vegetation browning, particularly along their migration paths in national parks and conservation areas due to human exclusion and harassment. • It is also found that growth in human settlements and artificial barriers like fences have impacted the behavior and movement of wildlife populations.	Wildlife migration pattern study; vegetation change assessment
[115]	Experimental study	2021	Panama	Experimental study.	• Using GIS and UAV technologies, students integrated rainforest fieldwork with aerial views of interrelated ecosystems and human influence. • GIS projects enable students to grasp the interconnectedness of natural systems and the interdependence of life on Earth.	Landcover mapping of pastures and forests
[116]	Experimental/ simulation study	2021		Wildlife monitoring using a multi-UAV system with optimum transport theory, GPS trackers, and the spatio-temporal evolution of animal locations.	• The optimum transport theory-based multi-UAV system monitors animals. • GPS trackers were added to the scheme to improve animal detection. • Combining the spatio-temporal evolution of animal locations with the suggested monitoring strategy increased wildlife detection rates.	Wildlife monitoring

7.4. Military Application

Drone plays an important role in different military applications such as the monitoring and surveillance of borders, delivery of essential equipment in war zones, and most importantly, supporting air combat. All the applications require precision and the key technology that supports drone applications is GIS [117]. Drones equipped with cameras and sensors can be used to collect real-time data on enemy movements and positions, providing critical information to military planners. Using UAVs, a technique for evaluating the hidden regions and military targets in mountainous terrain was developed and proposed through quantitative methods in [118]. The main objective of this work was the assessment of invisible areas and military objects in mountainous terrain and the successful execution of UAV reconnaissance flights in mountainous combat situations. An IoT-based UAV network for military applications supported by GPS and GSM is proposed in [119] for geographic surveillance, security monitoring, the radar detection of unwanted signals, and the tracking of UAVs.

The integration of drones and GIS offers several benefits for military applications, including:

- **Enhanced situational awareness:** By collecting aerial data, drones can provide a detailed and up-to-date picture of the terrain, buildings, and other features in the area of operation. When this information is integrated with GIS technology, it can help military personnel gain a better understanding of the situation and make more informed decisions.
- **Improved accuracy:** Drones can capture high-resolution images and data that can be used to create highly accurate maps and 3D models of the terrain. This level of detail can be especially useful for military applications where precise measurements and analysis are required.
- **Increased efficiency:** traditional methods of mapping and data collection can be time-consuming and labor-intensive. Drones can cover large areas quickly and efficiently, reducing the time and resources required for data collection.
- **Reduced risk:** By using drones to collect data, military personnel can avoid putting themselves in harm's way. This can be especially important in dangerous or hostile environments.
- **Flexibility:** Drones can be deployed quickly and easily, making them a flexible tool for a wide range of military applications. They can also be equipped with a variety of sensors and cameras to meet different operational needs.

A summary table with some recent research work performed with drone-integrated GIS applications in the field of military application is presented in Table 9.

Table 9. Drone-integrated GIS applications for military applications.

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[118]	Simulation study	2019	Azerbaijan Republic	Analysis and discussion of the use of UAVs in military GIS. These demonstrate the effectiveness of UAVs in visualizing hidden military objects in the mountainous terrain of Azerbaijan.	• UAVs are effective in detecting hidden military objects in mountainous terrain from a single observation point. • A method has been developed using UAVs to assess the hidden area and military objects in mountainous terrain. • The use of GIS technology has been explored to study the observation conditions between two points on a mountain terrain during a battle operation. • Successful UAV reconnaissance flights in hilly battlefield environments were numerically estimated.	Detection of military object in hilly terrain

Table 9. *Cont.*

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[120]	Simulation study	2018	Azerbaijan Republic	The significance of GIS and photogrammetry technologies in determining target coordinates for military decision making.	• GIS and photogrammetry play a critical role in military operations, including combat control. • A 3D model of mountainous terrain in Azerbaijan was created using GIS technology. • The feasibility of controlling observable and unobservable areas along a supervision line from point of observation to target was explored using ArcGIS software.	Terrain orthophotomap
[121]	Descriptive study	2020		The research explores the factors influencing the proliferation of weaponized UAVs and the potential threat they pose as a growing tool of terrorism.	• The utilization of GIS-supported weaponized UAVs is on the rise, creating an escalating terrorist threat. • Technological advancements, cost reduction, and increased accessibility are among the factors contributing to the proliferation of weaponized UAVs. • The likelihood of weaponized UAVs being utilized as a terrorist weapon is genuine, necessitating government and security force attention.	-
[122]	Descriptive study	2020		Assesses the latest abilities of UAVs, integrates information from their sensors, and applies this to spatial information systems for military purposes.	• Integrates UAV sensor data to generate spatial information system for military and defense purposes. • UAVs were used to survey and collect images which were processed using Pix4dmapper software to produce highly accurate 3D products. • Some of the novel applications of GIS in command-and-control systems have been evaluated.	-
[123]	Observational study	2020	Sri Lanka	Military GIS decision-making. It advises that the Sri Lankan Army should use the terrain trafficability concept.	• GIS can assist military decision making. • GIS model builder created a terrain trafficability model. • Manual terrain analysis is less accurate than GIS. • UAVs can assist in aerial photogrammetry.	Terrain trafficability analysis

7.5. Oil and Gas Pipeline Monitoring

Drone-integrated GIS technology is being increasingly used in the oil and gas industry for pipeline monitoring and inspection [124,125]. The technology has proven to be an effective solution for improving safety, reducing costs, and increasing operational efficiency. Similarly, it has also found its use in the smart city application, where it helps city planners to better understand the city's infrastructure and optimize resources.

In the oil and gas industry, drone-integrated GIS technology can be used to inspect pipelines and detect leaks, corrosion, and other defects that could lead to a potential spill or pipeline failure. Drones equipped with high-resolution cameras and sensors can capture detailed images of pipelines and their surroundings, which can be analyzed by GIS software to identify potential problem areas [126]. Additionally, drones can also be used for pipeline surveillance, monitoring activities such as excavation and construction near pipelines, and ensuring that safety protocols are being followed [127]. GIS software can then be used to generate accurate maps, which provide a comprehensive view of the pipeline network, including its location, condition, and potential risks. The integration of drones and GIS technology can bring numerous benefits to oil and pipeline monitoring. Some of these benefits include:

- **Improved safety:** Drone-integrated GIS applications can help oil and pipeline companies monitor their infrastructure from a safe distance. This can help to identify potential safety hazards, such as leaks or spills before they become a major issue. This can also help to reduce the need for manual inspections, which can be dangerous for workers.
- **Cost savings:** Drone-integrated GIS applications can help to reduce costs associated with traditional monitoring methods, such as manual inspections or helicopter flyovers. Drones can cover large areas quickly and efficiently, which can help to save time and reduce labor costs.
- **Real-time monitoring:** Drones can provide real-time data on pipeline and oil infrastructure conditions. This can help companies quickly identify issues and respond to them in a timely manner, reducing the risk of damage or downtime.
- **Increased accuracy:** GIS technology can help to accurately map and track pipeline and oil infrastructure. This can help companies identify potential issues and more effectively plan maintenance and repairs.
- **Improved environmental monitoring**: Drone-integrated GIS applications can help monitor the environmental impact of oil and pipeline operations. Drones can collect data on air and water quality, as well as wildlife habitats, helping companies to minimize their impact on the environment.

A summary table with some recent research work performed with drone-integrated GIS applications in the field of oil and gas pipeline monitoring is presented in Table 10.

Table 10. Drone-integrated GIS application for oil and gas pipeline monitoring.

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[128]	Observational study	2021	Yunnan Province, China	An observational research that explores the use of UAVs to efficiently capture the multi-phase images of oil pipelines for detecting landform changes and deformation.	• UAV and photogrammetry tech can quickly and accurately capture oil pipeline images. • Using UAV point cloud filtering methods, DTMs can identify landform changes and deformation. This is performed using ArcGIS10.5. • Numerical simulations can provide scientific support for future geological hazard prevention and mitigation in oil pipeline areas.	Identify landform changes and deformation
[129]	Experimental study	2019	Gävle, Sweden, and Datong, China	An experimental study that proposes a novel technique for detecting DHS pipeline leakage using remote sensing, GIS data, and saliency analysis is proposed in this paper.	• A technique based on saliency analysis is introduced for detecting leakage in DHS pipelines, utilizing remotely sensed infrared and visible imagery, as well as GIS data. • The proposed method was evaluated using three datasets, which consisted of both infrared imagery collected by manned aircraft and UAV, visible imagery, and a GIS layer specific to pipelines. • The improved leakage detection technology reduces false alarms and improves accuracy.	Pipeline leakage detection

Table 10. *Cont.*

Ref.	Type	Year	Country	Study Design/Concept	Main Findings	Context
[130]	Descriptive study	2020	Bahrain	A descriptive study showcasing the optimal procedures for leveraging drone technology to capture orthophotos as needed, produce 3D models, update spatial data, and furnish essential inputs for analytical investigations.	• Using drones, surveyors and cartographers can gather vast amounts of aerial data with absolute precision. • Drones offer the significant benefit of acquiring aerial data as needed for tasks such as terrain mapping, stockpile volume calculations, site planning, and preventing encroachments in the field. • The data collected by drones is processed and analyzed to serve the needs of petroleum engineers, geologists, and geophysics experts, as well as GIS professionals. • Drones are crucial in updating spatial data, merging findings with the spatial data infrastructure for regular operations in the Bahrain Field, and executing optimal GIS methodologies.	Surveying and mapping oilfields

8. Challenges for GIS–Drone Applications

Drone-integrated GIS technology is a powerful tool for collecting and analyzing geospatial data. However, there are several technical challenges associated with this technology, such as:

- **Data acquisition:** One of the primary challenges with drone-integrated GIS technology is acquiring accurate and reliable data. The quality of data depends on the accuracy of the drone's sensors and the quality of the camera used to capture the images. The drone's battery life, flight stability, and wind conditions can also affect data acquisition [131].
- **Data processing:** Another challenge is that of processing the vast amounts of data collected by the drone. Large datasets generated by drone-integrated GIS technology require significant computational resources for processing and analysis. The data processing software must also be capable of handling different types of data formats and sources [132]. The cost associated with data storage and processing makes it a challenge.
- **Data management:** Managing the data generated by drone-integrated GIS technology is another challenge. The data need to be efficiently stored, organized, and accessed to ensure that these are available when needed. Proper data management also requires security protocols to protect sensitive data [133].
- **Data safety and security:** Drone and GIS both may be vulnerable to cyberattacks, data interception, and hacking, which may lead to a loss of crucial data or incorrect data manipulation. Therefore, it is necessary to implement robust cybersecurity protocols, encryption techniques, and secure communication channels for both the drones and the GIS systems. Regular security assessments, updates, and employee training are also crucial for maintaining the integrity and privacy of drone-based GIS data [101].
- **Accuracy and precision:** Drone-integrated GIS technology requires high levels of accuracy and precision to generate reliable data. Factors such as sensor calibration, GPS accuracy, and image resolution can affect the accuracy of the data [41].
- **Environmental factors:** Environmental factors such as weather, terrain, and vegetation can also pose technical challenges for drone-integrated GIS technology. For example, vegetation can obstruct the view of the drone's camera, making it difficult to capture accurate data. Wind, rain, and other weather conditions can also affect the drone's stability and data quality [37,39].
- **Drone regulation:** The main hurdle to the widespread utilization of drones is inadequate drone regulations. Despite an estimated 7 million drones being shipped worldwide by 2020, only 57 out of 174 recognized countries have publicly available

drone regulations, and these regulations often outright ban commercial drones. Furthermore, regulatory requirements lack harmonization across national boundaries, which is problematic for isolated communities that may need drones the most and lie along these borders [134].

- **Lack of trained drone operators:** Drone control relies on human operators who may make mistakes, leading to accidents or unintended flights. Typically, the majority of risks and mishaps associated with drone operations are attributed to human operators. While there seems to be a lack of specialized drone operators, standardized training and user-friendly control interfaces are pertinent towards technological readiness as well as accelerate its implementation and usage [135].

9. Discussion and Future Recommendation

Drone technology represents a cutting-edge innovation that provides highly efficient and sustainable solutions to complex conventional methods. In this direction, different drone-based methodologies are collaborated with multi-domain technologies to achieve, optimize, enhance and accomplish challenging tasks with higher efficiency. In this review, we discussed an exemplary instance of such integrated technical cooperation between drones and GIS technology across various domains.

In the realm of precision farming, drone technology is poised to revolutionize the agriculture sector. Drones are rapidly becoming the industry norm for tasks such as area mapping and GIS applications. Future research endeavors should prioritize the development of innovative land use and crop management methods, as well as the optimization of supply chains within the agricultural sector. It is strongly recommended that the GIS data analytics are enhanced in order to contribute towards enhanced and informed decision-making processes based on the vast data available from various sources that requires a meticulous and thorough analysis to unearth hidden insights. Alternatively, lack of information or incomplete information can lead to future short-term as well as long-term challenges, as misinformed decisions can have irreversible impacts on crop production and the environment.

Drone flight path modeling introduces an innovative, GIS-based approach to enhance monitoring and surveillance efforts. The benefits of employing UAVs become evident when we compare their surveillance flight time interval to the time it would take for ground patrols to cover the same territory. The recorded response times in guard post analysis highlight how GIS methods contribute towards achieving comprehensive and efficient coverage in protected areas. This type of analysis has the potential to aid conservation planners in identifying optimal ground crew station placements, consequently reducing response times to high-risk zones and enhancing the ability of ground personnel to combat intrusion and poaching. Furthermore, it can uncover vulnerabilities in the current protection coverage by assessing response times based on the locations of existing guard stations. Similarly, the technological development in this field has the potential to be applied in large crowd management during social events.

In urban planning and resource allocation, integrated GIS–drone technology proved to be a formidable asset, offering potent capabilities for spatial analysis. In light of the rapid depletion of land resources, the imperative of judicious land use planning to identify novel urban development zones has become increasingly apparent. Drones, in this context, will be utilized as an invaluable tool for crafting high-resolution 3D urban models, thereby furnishing comprehensive insights into the intricacies of smart city infrastructure. Therefore, augmented reality technology could be integrated with GIS–drone technology to provide urban planners with immersive, real-time visualizations of proposed developments. Better planning and deployment will be achieved wherein developers, designer, and shareholders could "walk through" digital models of future urban landscapes, making it easier to assess the impact of design choices on the environment and community. Furthermore, establishing a global drone network for disaster management will enable local as well as international collaboration and the rapid deployment of resources in the affected regions.

Accordingly, the large-scale implementation of GIS and drone technology has ushered in a transformative operational era in terms of supply chain management, encompassing inventory tracking, route optimization, risk assessment, and sustainability endeavors. Therefore, it is imperative to underscore the significance of seamlessly integrating GIS data with existing supply chain management systems. This integration facilitates the continuous flow of data between GIS platforms and enterprise resource planning systems, paving the way for real-time decision making and in-depth analysis. Moreover, it is necessary to leverage GIS and drone technology, not only for route optimization, but also as pivotal tools in the pursuit of reduced carbon emissions and minimized environmental impact.

Considering the extensive collaboration between the drone and GIS in different domains and applications, the future prospects of GIS and drone technology are highly promising. Given the continuous advancements in both technologies and their potential synergies with other sectors, it is imperative to look for futuristic applications. Therefore, some considerations are needed to accelerate and appropriately utilize this combined technology:

- Enhance the interoperability between different GIS software and hardware platforms. Promote the development and adoption of standardized data formats and protocols to ensure seamless data sharing and integration between systems. This will facilitate collaboration and data exchange across organizations and industries.
- Incorporate AI and ML algorithms into GIS and drone technology. This will enable these systems to analyze and interpret data more effectively, automate repetitive tasks, and provide actionable insights. For example, AI can help in the automated recognition of objects in drone imagery.
- Explore edge computing solutions for processing GIS and drone data in real-time, closer to the data source. This reduces latency and allows for quicker decision making, making it particularly useful for applications that require a rapid response, such as autonomous drones or emergency response systems.
- Work closely with regulatory bodies to shape drone and GIS regulations that foster innovation while ensuring safety, privacy, and security. Advocate for the responsible and ethical use of these technologies and collaborate with authorities to develop guidelines for data collection, storage, and sharing.
- Foster collaboration between the public and private sectors to leverage GIS and drone technology in the interest of public welfare. This can include initiatives for disaster response, infrastructure development, and environmental conservation.

10. Conclusions

A comprehensive review of the increased potential applications of combining GIS and drone technology has been presented. By incorporating GIS–drone applications, this review facilitates insights into comprehending and leveraging the advancements in GIS. This review expands on the technological advancements achieved in the fields of precision farming, the development of resilient smart cities, the enhancement of smart supply chains, and monitoring associated with the oil and gas industry, forestry, and military. Furthermore, with a categorized and sub-categorized review of GIS–drone implementation, the challenges associated with the processes of GIS–drone technology and applications are also discussed. Drone-integrated GIS technology is becoming increasingly valuable in various sectors. The technology provides accurate and real-time data, enabling informed decision making and improving efficiency. As technology continues to evolve, it is expected that the use of drones in conjunction with GIS technology will become even more widespread. By providing accurate and timely data, GIS software will allow governments, organizations, and individuals to make informed decisions, optimize resources, and enhance safety and quality of life. While the future research associated with drone GIS is interdisciplinary, the standardization and increased functionalities of drones are among the key drivers for their successful integration and implementation.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial intelligence
ACO	Ant colony optimization
BEM	Building energy model
BIM	Building information modeling
C4ISR	Command control communications, computer, intelligence, surveillance, and reconnaissance
CBP	Customs and Border Protection Agency
DEM	Digital elevation models
DSM	Digital surface model
DTM	Digital terrain model
EEE	Experiential environmental education
GRVI	Green-red vegetation index
GIS	Geographic Information System
GPS	Global Positioning System
IoT	Internet of Things
NCKU	National Cheng Kung University
PA	Precision agriculture
UAV	Unmanned aerial vehicle

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