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Budgetary Unoccupied Aerial Systems for Environmental Surveying: A Social Perspective

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BUDGETARY UNOCCUPIED AERIAL SYSTEMS
FOR ENVIRONMENTAL SURVEYING:
A SOCIAL PERSPECTIVE

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ABSTRACT

Unoccupied Aerial Systems (UASs) have undergone extensive growth in the past decade. This growth has resulted in the application of these systems from highly niche application to application across many fields including consumer usage. This research explores the implementation of UASs for environmental surveying that has an impact on social groups. While much literature exists using custom UAS systems with large budgets, the use of budgetary consumer available UASs for these purposes is still in its infancy. This research suggests that budgetary and accessible consumer UAS systems can be used to benefit social groups that lack access to high-quality geographic data. Ultimately, the lower barrier-of-entry of cost, skill, and ease of access, allows research to be conducted that previously would have been unfeasible. Furthermore, the inclusion of Public Participation GIS can further benefit social groups through community input and participation with these systems. A systematic review was developed exploring existing studies that pertained to specific criteria that implements the themes of environmental surveying, the impact on a social group, and the use of a UAS. The systematic review is supplemented by survey responses from the authors of the specific studies explored in this research. Based on the explored studies, budgetary UASs has the potential to benefit social groups through environmental surveying that may have been previously limited by the previously higher barrier-of-entry. However, the most notable results of this research suggest that this field is still in its infancy and themes that pertain to this research are not always considered in the original explored studies. Furthermore, privacy and security concerns are seldom addressed. While the growth of this technology has significant potential, there are still many factors to consider when deploying these systems as means of data collection in communities.

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INTRODUCTION

Unoccupied Aerial Systems (UASs), commonly referred to as drones, have grown exponentially in the past decade, with an emergence into consumer usage expanding the reach and accessibility of these systems. This technology, once strictly for military use, has arisen as a commercial and consumer product providing a multitude of industries with a host of applications, including industrial inspection, security, precision agriculture, logistics, filming, broadcasting, mapping, remote sensing, as well as recreational usage in the past five years (Giones & Brem, 2017). Due to their portable structure and ability to mount high-resolution sensors of different spectral ranges, drone technologies have showcased their ability to apply to a host of fields as well as a variety of budgets. The diverse possibilities of drone technologies allow for use in projects of vastly differing budgets and constraints. Previously restricted to specialized usage, this technology has been commercialized by companies such as Parrot and DJI bringing drones into the consumer spotlight. The growth of this field is suggested to be driven by technological evolution and how the market perceives the technology, or as Giones and Brem (2017) structure it, concept validation to product growth to market growth. One of the most significant examples of this is DJI's implementation of cameras and sensors into their drone technology, sparking consumers' interest in exploring potential applications.

The culmination of technological advancements, market growth, and consumer interest has led to a drastic decrease in the price of drones as well as the skill level required to operate the drones. These factors have allowed drone technologies to enter a unique merging between consumer and commercial use, bringing drones' commercial application to a readily accessible means. Ultimately, technology once restricted by budget constraints and skill is now a viable means of analysis at a lower cost and higher ease-of-use and ease-of-access.

The emergence of consumer and professional drone technologies has brought a vast increase in literature and research conducted with this equipment for a host of differing purposes. These systems provide a revolution of data capture, not only feasible for large-budget research but also lower-budget research and community influence. Much literature exists on the social utilization of these systems with an environmental component (natural disaster response, climate change risk analyses, agricultural and landscape analyses). Yet, most literature focuses on conducting research utilizing drone systems – but little research exists on the efficacy of this use and addressing its rise of accessibility. This is where the social component of this research becomes paramount – are groups benefitting from this rise in accessibility? How are these groups utilizing these systems for environmental analyses? What are the benefits and drawbacks of these systems when used in this capacity?

This study's primary use case focused on environmental applications such as habitat monitoring, mapping, and management. The environmental focus of this entails the use of Geographic Information Systems (GIS) with spatial analysis through remote surveying. Limited research has been done establishing a connection between the advancement of drone technologies and its impact on environmental research that affects social groups.

This limitation is suggested to be due to the technology's infancy; this research seeks to act as a baseline for establishing the potential of these systems to act as a beneficial component of environmental research impacting social groups with an emphasis on budgetary constraints. Essentially, do unoccupied aerial systems, or drone technologies, provide more accessibility to environmental surveying that in turn benefits social groups? This study seeks to provide an empirical contribution by analyzing existing studies conducted with drone technologies for environmental and sociological purposes. This was done through a systematic literature review as well as a secondary data addition of a mixed-methods survey. The articles that were selected for review incorporated budgetary drone systems for environmental surveying, remote sensing, and other similar means and how lesser-developed communities may benefit through this evolving technology, be it access to the technology, access to the data, and the utilization of the data. This research seeks to develop an understanding of the inclusion of modern drone technologies in environmental research and understand if these factors have improved specific social groups' well-being. More concisely, does the evolution of modern UAS technology benefit social groups through more accessible environmental analyses?

LITERATURE REVIEW

Introduction to Drone Systems

Despite the relative infancy of the technology as a means of commercial and consumer use, drone technologies have evolved rapidly over the past decade. These systems go by a host of different terms, including Unoccupied Aerial Vehicles (UASs), Unoccupied Aerial Systems (UASs), Remotely Piloted Aircrafts (RPAs), and the widely recognized term, "drones" (Otto et al., 2018). For consistency, "UAS" and "drone" will be the terms used to describe these systems. In essence, drones are well described by their acronyms entailing an aircraft that is unoccupied (without an internal pilot). However, this general description ineffectively describes the multitude of diverse types and applications of drones. This study focuses on UASs that are budgetary, commercial and consumer means typically used for traditional photography, videography, and remote sensing as compared to industrial and militarized systems.

Drone technologies entail four interrelated dimensions: aerial capacity, flight control, position control, and communication (Giones & Brem, 2017). Aerial capacity includes the means of propulsion such as rotary wings or fixed wings as well as the fuel or battery such as a lithium-ion (drones in these studies will all be of a smaller nature and will be battery powered). Position control entails positioning through GPS (Global Positioning System) and waypoint navigation as well as visual accuracy, including a mounted sensor, camera, and stabilizing gimbal, which serves as the means of data collection. Flight control includes the Inertial Measurement Unit (IMU) such as the accelerometer, gyroscope, compass, and microcomputer as well as machine learning for object avoidance and image processing. The final dimension is communication, including remote control and signal such as radio frequency, avionics data, Wi-Fi, satellite, and remote networks, (Giones & Brem, 2017).

This study looked at emerging drone systems for the use of remote sensing and involves specific features applicable primarily to the surveying field. They are relatively smaller with the ability to be handheld with specific terminology, including small-scale aircrafts (SSAs). These drones are either fixed-wing platforms or rotary-wing platforms (quadcopters and hexacopters), with fixed-wing initially being the more common system for its better stability and longer flying capabilities; however, advancements in battery technology and gimbals have propelled rotary-wing platforms to the more common type of drone (Green et al., 2019).

The fixed-wing UAS is historically the most common and previously preferred due to its stability, slow-flying capabilities, and quiet operation (Green et al., 2019). Modern fixed-wing UASs are still used due to their higher-duration flight time, ability to carry larger payloads, and ability to cover large areas – however, they are met with complicated launching techniques and retrieval requirements (Green et al., 2019). Until the latter 2000s, rotary-wing helicopters were far less common due to their high cost, difficulty of flying, high vibration, instability, low payload, and risk possibilities from power failure (typically, cameras and equipment are attached, and a helicopter would fall straight down as compared to a fixed-wing aircraft which would glide) (Green et al., 2019). However, advancements in technology have mitigated many of these issues. Modern multirotor drones are equipped with autonomous flying capabilities and safety features, including spatial sensors to recognize and avoid flight impediments. DJI's return-to-home mode allows autonomous flight and landing capabilities when visual line-of-sight is lost or the battery is depleted to a critical amount. In addition, the evolution and implementation of a computing and deep learning technology for depth sensing in these systems has mitigated many of the previous drawbacks of quadcopter and hexacopter models (Wang et al., 2020).

Originally for military applications, UASs have evolved into a diverse array of applications. However, despite this fast-paced development, drone technologies are still in their infancy (Watts et al., 2012). The result of continued miniaturization of UASs was inspired by NASA's efforts in the late 1990s to modify and develop systems for differing research needs such as atmospheric sampling and rangeland vegetation monitoring (Watts et al., 2012). Consumer-based radio-control (RC) models were met with varying degrees of success for research purposes. Furthermore, these small-scale RC aircrafts met a niche that allowed bypassing of specific FAA (Federal Aviation Administration) regulations due to their small scale (Watts et al., 2012). Parrot, a popular manufacturer of civilian drone systems, introduced the Parrot AR drone in 2010, being the first ready-to-fly drone controlled entirely by Wi-Fi through the use of a smartphone. The introduction of the DJI Phantom 1 came in 2013 and set a precedent for consumer-level, ready-to-fly drone systems. However, the inclusion of a camera system on the DJI Phantom 2 facilitated a technological shift, which opened options for a new business model and assisted in the emergence of the industry (Giones and Brem, 2017). A change in drone applications' technological meaning sought for improvements in the processing power, camera technologies, sensor technologies, battery technologies to suit professional use for civilian drones (Giones and Brem, 2017). At this point, the 2000s brought a growing use of civilian drones for the purposes of mapping, aerial photography, videography, inspection, security, and logistics (Giones and Brem, 2017). The market has witnessed a tremendous growth in sUAS growing from $1 billion in 2014 to nearly $9 billion in 2019 – with the most significant growth in the commercial sector and the second-largest growth in the hobby and prosumer sector (Eriksson & Lundin, 2016).

Further popular manufactures in the worldwide drone market include 3DRobotics, AeroVironment, AAI Corporation, CAPECON, Ehang UAS, General Atomics, Israel Aerospace Industry, Northrop, Yamaha Motors and Zipline. In 2015, DJI dominated the field with a 42.9 percent share of registered drones by the FAA, AeroVironment with a 9.1 percent share, and 3DRobotics being the next leading manufacturer (Eriksson & Lundin, 2016). Ultimately, DJI has a strong market share over other brands due to their long-standing presence in the consumer market compared to other brands residing in the enterprise market with much higher budgets and meticulous applications.

Use for Remote Sensing

Drone systems have a myriad of applications across a variety of industries. The focus of this thesis was on small-UASs for environmental remote sensing. The flexibility of modern drone systems provides promising applications, especially when these applications entail repeated data collection that can be done safer, cheaper, and faster than with alternative systems such as manned aerial vehicles and satellite imagery (Wing et al., 2013).

The evolution of drone systems in the past decade have mitigated most previous limitations, including technological limitations and limitations imposed by federal regulations (in the United States) (Hardin & Jensen, 2011). Primarily, limitations of on-board power created difficult compromises for flights. However, advancements in battery technology have vastly increased flight time; for example, the DJI Phantom 4 provides about 27 minutes of flight time with its 5400mah battery dependent upon other factors. The original DJI Phantom, which was released in 2013, has a flight time of 10 minutes. Improved battery technology alongside software development has aided in increased flight efficiency and planning, with many flight planning applications incorporating autonomous return-to-home functions allowing for batteries to be swapped through the mapping process (Hardin et al., 2018).

For remote sensing, drone systems must incorporate a type of sensor. Originally, Hardin & Jensen (2011) suggested that the lack of commercially available sensors for small drone systems acted as a limitation for environmental remote sensing. However, revisiting this in 2019, integrated RGB cameras are incorporated into systems with the availability of stock and after-market multispectral, hyperspectral, and specialized vegetation sensors now being more commonly available (Hardin et al., 2018).

These systems allow for high-resolution spatial and temporal analysis of large areas (Klemas, 2015). Specific environmental components include the monitoring and mapping of a variety of differing extents, biomasses, vegetation cover, wetlands, forestry, and agriculture (Klemas, 2015). Ultimately, the applications are expansive, and more research is needed to determine different types of usage for environmental research as these systems are still in their infancy. A beneficial component of utilizing drones for environmental work compared to manned aircrafts is that these systems allow for safer and less disruptive surveying of environmental areas that may have been previously inaccessible due to these factors (Klemas, 2015). As a result, the severity of crashes is diminished for the operator as well as the area. Furthermore, the disturbance is also lessened due to quieter operation and smaller size.

The primary purpose of aerial surveying requires the use of different sensors to acquire data. The standard RGB (red-green-blue) sensors capture stills and video, ideal for high-resolution imagery. Larger platforms allow for larger camera systems or multiple systems for ultra-high-resolution imagery. While this standard RGB sensor is typical, multiple types of sensors have been integrated into UASs for differing purposes. Applicable to this study are multispectral, near-infrared (NIR), thermal sensors, and radar systems such as LiDAR (light detection and ranging). Multispectral sensors are capable of three or more band measurements simultaneously and are commonly utilized to analyze vegetation such as plant stress, distress, nutrient amounts, and water quality (Green et al., 2019). NIR is also utilized for this purpose and is measured with the Normalized Difference Vegetation Index (NDVI) to determine plant condition and status (Green et al., 2019). Recently growing in popularity is airborne light detection and ranging (LiDAR) systems, which were lesser used on UASs due to their large size and weight. As the technology has shrunk in size, they are more regularly used. One study showcases the use of LiDAR in estimating canopy height in Weihe, China, to understand biomass and vertical structures (Chen et al., 2017).

Sociological Components

This work sought to understand the social aspects of drone technologies. Due to the infancy of the technology, a wide range of literature has yet to be developed and in turn, the use of UASs for certain fields has yet to be fully established. Currently, there is already vast research on the use of drones for environmental surveying and remote sensing – but what is not widely discussed is how this new development in environmental surveying may impact social groups. Instead, most literature that can be related to this is focused on disaster management in developed areas. Common themes of that research entail governmental programs with large budgets in developed areas. Yet little exists for the use of budgetary drones in environmental surveying for more rural and indigenous communities. The focus here lies on this evolving UAS technology becoming more accessible, and therefore able to be utilized for surveying communities that previously would lack access for a multitude of reasons.

Our reliance on natural places and the biodiversity of these places is paramount to our survival and capacity to thrive – our economy is dependent upon environmental well-being (Butler, 2020). The research posed here seeks to showcase this through an analysis of studies where social groups are benefitted from environmental research through remote sensing means. There are reoccurring subjects where this criterion is met, including the participatory GIS, agricultural use, urban modeling, and Disaster Risk Reduction (DRR).

Public participation geographic information systems (PPGIS) entails utilizing GIS to encourage public involvement in policymaking and community decision-making across organizations, groups, and nongovernmental entities (Sieber, 2006). Evidence of the benefits of PPGIS has been well established through multiple studies. On the environmental side, a general summary of the benefits of this is the potential to understand further how environmental hazards impact communities through a personal scope. In turn, this has been proven to, in some instances, incentivize community stakeholders and further community responsibility – especially in areas that lack publicly accessible geographic data (Brandt et al., 2019).

PPGIS represents the spread of technology and the social impacts with it – it is the intertwinement of GIS and society (Obermeyer, 1998). The influence of GIS has provided the ability for individual input at a macro scale; however, despite the possibilities of this, GIS can be largely exclusive, barring poorer communities from participating (Obermeyer, 1998). The evolution of PPGIS similar to that of UAS technology allows greater use with a smaller budget that can involve local stakeholders in not only data collection but also personal input. The combination of PPGIS and remote sensing has the ability to provide improved self-sustainment to communities with fewer resources. In essence, PPGIS can provide a platform to communities and individuals that may commonly lack a platform.

Although PPGIS represents the inclusion of public participants, it also can further perpetuate injustice (Sieber, 2006). As seen in Hodgson and Schroeder (2002), countermapping exercises in the Masai in Tanzania, the explicit distinction of village boundaries and divisions in previously unrepresented detailed created rifts and disruption among local communities. Ultimately, PPGIS has the potential to be used in a beneficial social manner but simultaneously has the potential to do the opposing. This theme must be carefully observed – it is quick to construe work such as this as beneficial to one area yet disregard the rifts it may incentivize in other areas.

UASs can also be a cost-effective source of high spatial and temporal resolution imagery for agriculture use as compared to high-resolution satellite imagery (Zhang & Kovacs, 2012). Satellite imagery, while highly useful, comes with a significant access cost as well as being temporally inaccessible. Agriculture is a theme of this study as it provides livelihood and food security highly applicable to communities with fewer resources and development (Paudel et al., 2020). Paudel et al. (2020) developed a study in multiple villages in the Koshi river basin in the central Himalayas utilizing high-resolution sUAS imagery and social surveys to determine reasons for farmland abandonment in these areas. Farmers attributed climate change, crop damage, migration, lack of irrigation, and other reasons for farmland abandonment. The implementation of UAS imagery provided detailed findings such as specific locations of higher rates of abandonment and different types of land use. The utilization of social surveys and UAS remote sensing are potentially useful for influencing governmental policy regarding farmland abandonment by improving management and living conditions for farmers – protecting livelihoods and ensuring food security (Paudel et al., 2020).

Disaster risk management and reduction are benefitting from the rise in UAS technology and the growing potential of its application. One of these uses is identifying flood risk areas through mapping models derived from UASs (Rohman & Prasetya, 2019). Historically, satellites and manned aerial vehicles acted as the primary source for mapping of disaster sites. However, UASs have become common for this means due to their efficient means of data collection and ability to cover high-resolution imagery of disaster sites (Rohman & Praestya, 2019). Furthermore, adaptation to the effects of climate change is integral to developing solutions with not only adaption by the individuals affected but also by the overarching government of the area, (Adger et al, 2003). Rohamn and Prasestya (2019) seek to establish the use of budgetary UASs for crowdsourced community drone imagery. The study in Desa Way Galih, South Lampung, Lampung province in Indonesia, utilizes a DJI Phantom 4. With the element of budgetary UASs, they set a maximum drone budget of 20 million rupiahs which equates to $1,375 U.S. dollars. Furthermore, rather than utilizing an autonomous drone mapping process through a planned flight route, the study was conducted with manual flights to imitate the use of UAS mapping by community members, (Rohamn & Prasetya, 2019). Evidently, the capabilities of consumer drone systems, when utilized by community members with baseline knowledge, have the capacity to produce analyses that can benefit their community on a confined budget.

Consumer UASs, while toted for their autonomous capabilities, ease-of-flight, and built-in safety systems, still entail a degree of knowledge and skill to operate. Yang et al. (2020) emphasize a learning curve for introducing UASs into researchers, community organizations, and citizen scientists' workflows. Implementing consumer UASs for remote sensing means requires a background in drone operations, GIS, and analytical techniques (Yang et al., 2020). Ultimately, the evolution of UAS technologies and the implementation into consumer markets has made these systems readily accessible. However, utilizing them for the potential of public participants engaging these systems for environmental analysis requires the baseline skills and knowledge mentioned previously – to which, Yang et al. (2020) has developed a training program to provide a structured base for individuals and communities of differing expertise to engage in these operations. The training elements of this course involve drone basics, in-flight operations, autonomous mapping, drone image processing, GIS analysis, and post-training self-study (Yang et al., 2020). The developed course also keeps budget as a central element. Similar to other studies, it emphasizes consumer-level systems and uses the DJI Phantom 4 Pro as the system used for data collection with a retail value of $1,500 to $2,000 USD.

A central theme of this study promoted UAS use in a budgetary manner to be able to employ the technology for communities and studies with a limited budget, skill, and access. The literature presently reviewed emphasized the consumer budget of these UAS; however, the further technology required to make use of the data capture by the drone entails an additional cost with the potential to outweigh the cost of the UAS. Yang et al. (2020) incorporate ESRI Drone2Map and ArcMap as the primary programs used to process the imagery taken. Presently, the cost for ArcGIS Drone2Map retails at $1,500 per year, a severe price reduction from the previous cost of $3,500 per year (ESRI). Access to the cheapest tier of the primary ArcGIS programs is $800 per year or a perpetual license for $1500, providing access to ArcGIS Pro Basic and a host of ESRI's application suite, including ArcGIS Online (https://www.esri.com/en-us/store/overview). Rohamn and Prasestya (2019) used Agisoft software to produce their orthomosaic imagery and digital surface models (DSM), which would require the professional version costing $3,499.99 for a perpetual license (https://www.agisoft.com/buy/licensing-options/). DroneDeploy is another popular drone mapping and analysis software (web-based) that starts at $1,188 per year (https://www.dronedeploy.com/pricing.html). There is a cost barrier to the automated processing of drone imagery for analysis. However, free programs are allowing for similar capabilities, including WebODM by OpenDroneMap and DJI Ground Station Pro (for mission planning only). The construction of orthomosaic and drone imagery analysis is possible through non-automated techniques that require the use of a computer. The entry-level barrier is low but deeper processing, and automation capabilities typically come with a higher cost. It is important to note that the need of post-processing is crucial to producing accurate survey results – however, manual operation and analysis is possible to a limited degree. An example of this is GeoNadir, a culmination of PPGIS with drone technology in an effort to "mobilize the world's drone flyers to crowdsource high spatial resolution data" in an effort of "organi[z]ing the world's drone data to protect at-risk ecosystems," (https://www.geonadir.com/home). This service provides the ability for ordinary drone users to upload and share their sUAS surveying imagery through artificial intelligence and machine learning to develop a centralized repository of publicly generated content.

METHODOLOGY

Themes

To approach the research question, three key themes were determined which must be included in the chosen studies to qualify as articles to review: the use of drone technologies, an environmental component, and that component influencing a social group, narrow or broad. The fourth theme was not applicable to the study selection but instead integrates itself as further consideration for the studies that did meet the three themes: privacy and security. With the social factor being paramount to this study, it was valuable to understand the concerns that may arise alongside the use of UAS technology. How do community members feel about this technology utilized in their space? Did privacy concerns arise? Did security concerns arise? Figure 1 identifies each theme and the components of the specific themes. After completing an extensive overview of the selected articles, it is important to note that while some of the selected studies do not have an explicit mention of the certain themes, each of the selected studies have the potential to integrate these themes.

Figure 1: Mind-map constructed identifying each theme, the components of it, and examples and subcategories of the components.

For the first variable, a drone system's inclusion must have been a fundamental means of data collection in the research project and must have been a civilian system. This included budgetary consumer drone systems such as the DJI Spark (roughly, $350 budget) series to the Parrott Bluegrass series or DJI Survey Grade models (roughly, $7,000 budget). The DJI Phantom series was a popular medium often seen in fieldwork. Arguably, less expensive drones may be utilized. However, this entails questionable reliability with generic brands and systems less suited to surveying needs such as high-resolution imagery, GPS precision, and high duration power source. This variable's price component was essential as the purpose was to analyze research that uses commercial civilian drone systems at a more budgetary constraint than more expensive alternative systems. Of the selected articles, the DJI Phantom series was a commonly reoccurring UAS.

To quantify the specific theme of budgetary drone use, a defined budget was recommended to meet the criteria of a low-cost solution for remote surveying. This entailed two questions: at what point was a technical drone system incapable of producing the necessary criteria for surveying solutions, and at what point does the system extend beyond the budget and feature criteria that this study seeks out? More concisely, what were the feature and budgetary constraints at the lowest cost and the highest cost? Of the reviewed articles, 10 mention the use of the DJI Phantom series – a staple system for lower-end and "prosumer" drone needs. Utilizing Google Scholar, an advanced search with the extract phrase "*specific drone model*" and with at least one of the words being "remote sensing," "gis," "surveying," "environmental," the number of results indicates the popularity of specific drone models used across related studies. The exact query used for scholar.google.com was "' remote sensing' OR 'gis' OR , 'surveying' OR ,' environmental', *specific drone model.*" The DJI Mavic yielded 1,970 results, the DJI Matrice, 1960 results, the DJI Spark, 251 results, the 3DR Iris, 278 results, the Parrot Anafi, 138 results, the Parrot Bluegrass, 57 results, the Parrot AR, 1,180 results. Finally, the DJI Phantom yielded 8,120 results, nearly four times the amount of mentions than the next leading model. Evidently, the DJI Phantom series remains a standard in the remote sensing and surveying community. What was the reason for the high degree of usage and popularity of this system? Arguably, this system is a balance between price, feature set, and availability.

Recent years have brought a popularization and commercialization of UASs with manufacturers entering the consumer market – DJI being the leading manufacturer. A table was developed to compare the feature set and cost between different popular consumer and lower-end professional drone models. Table 1 compares different consumer and lower-end professional drone models that have the potential to be utilized for environmental surveying and remote sensing. The table was based on Giones and Brem (2017), who consider elements of a UAS focusing on aerial capacity, position control, and flight control. Originally, the sensor component was an aspect of flight control; however, due to the integral nature of the sensor for the study purposes, it has been placed in its own category. The aerial capacity category includes the type of aircraft, the payload it supports, the maximum flight time, and the energy source. These factors are fundamental for surveying purposes as they represent the aircraft's form, size, and capacity.

The position control category includes the type of Global Navigation Satellite System (GNSS) implemented in the aircraft as well as the degree of accuracy and resolution capabilities paramount to the intended use of these aircrafts in this study. In general, the more precise accuracy, the more advanced the positioning system was and, therefore, the more costly it is. The flight control section focuses on autonomous safety capabilities such as obstacle sensing and return-to-home functions as well as the quality of the live feed. While these features do not necessarily improve the data collection capabilities, they do act as valuable safety and use features. For example, obstacle sensing allows the UAS to autonomously avoid potential collisions while the return-to-home function provides autonomous aircraft recovery if physical or technical issues arise. While these features are useful for all remote pilots, they represent the lesser degree of skill needed to operate the systems – making UASs more accessible. The live feed resolution was a valuable feature as it indicates the quality of image transmission during flight allowing for a higher degree of in-field analysis to be completed while also providing a useful means of control while operating. Comparing price to features was most evident dependent upon the sensor type and capabilities. The largest feature versus cost differentiation between the given UASs was with the type of sensor – lower resolution and sensor size correlate positively with price. The smaller the sensor and its capabilities and the lower the entry cost. Ultimately, the inclusion of multispectral sensors was the largest driver in cost differentiation between models. This can be attributed to the demand for different sensor types. In general, typical CMOS sensors that capture the visible light spectrum are mass-produced and have a much lower entry cost as compared to multispectral sensors capable of capturing non-visible wavelengths – the need for multispectral sensors was specialized, while the demand for common sensor types was more general. However, for the purpose of environmental surveying, analysis, and remote sensing, multispectral imaging can be highly beneficial, allowing for much more intricate analysis through band math to determine qualities such as vegetation health. Despite this, the capabilities of a typical CMOS sensor are still highly useful for the mentioned use cases.

Table 1: Comparison of UAS Models

Drone Model	Aerial Capacity	Position Control	Flight Control	Sensor	Cost
SenseFly eBee X	Fixed Wing aircraft Max Flight Time: 90 min Battery: LiHV 3700mAh	GNSS: GPS+GLONASS w/RTK	Obstacle Sensing: LiDAR Ground Avoidance	MicaSense RedEdge-MX 3.6 Megapixels Global Shutter Blue + Green + NIR + Red+ Red Edge	Aircraft with Sensor: $19,800
Parrot Bluegrass	Rotary wing quadcopter Max Flight Time: 25 min Battery: LiPo 6700mAh	GNSS: GPS+GLONASS Vertical Accuracy: 0.1m - 0.5m Horizontal Accuracy: 0.1m - 1.5m Flight Distance: 18.6km	Obstace Sensing: Forward and Downward	Integrated: CMOS RGB 14 megapixels Parrot Sequioa (extra): 4x monochrome Green + Red + NIR + RedEdge Global Shutter RGB sensor with Roling Shutter	Aircraft Only: $4,500 With Sensor: $9,000
DJI Phantom 4 RTK	Rotary wing quadcopter Takeoff Weight: 1391 grams Max Flight Time: 30 minutes Battery: LiPo 4S 5870mAh	GNSS: GPS+GLONASS+Galileo+ w/RTK Vertical Accuracy: 0.1m (RTK enabled) Horizontal Accuracy: 0.1m (RTK enabled) Flight Distance: 14km	Obstace Sensing: Forward, Backward, Downward, Lateral Return-to-Home Function Live Feed Quality: 1080p at 30fps	1" CMOS RGB 20 Megapixels Mechanical Shutter Global Shutter 4K video at 100Mbps	$6,499
DJI Phantom 4 Pro V2.0	Rotary wing quadcopter Takeoff Weight: 1735 grams Max Flight Time: 30 minutes Battery: LiPo 4S 5870mAh	GNSS: GPS+Glonass Vertical Accuracy: 0.1m - 0.5m Horizontal Accuracy: 0.3m - 1.5m Flight Distance: 14km	Obstacle Sensing: Forward, Backward, Downward, Lateral Return-to-Home Function Live Feed Quality: 1080p at 30fps	1" CMOS RGB 20 Megapixels Mechanical Shutter Global Shutter 4K video at 100Mbps	$1,599
DJI Mavic 2 Pro	Rotary wing quadcopter (foldable) Takeoff Weight: 907 grams Max Flight Time: 31 minutes Battery: LiPo 4S 3850mAh	GNSS: GPS+Glonass Vertical Accuracy: 0.1m - 0.5m Horizontal Accuracy: 0.3m - 1.5m Flight Distance: 18km	Obstace Sensing: Forward, Backward, Downward, Upward, Lateral Return-to-Home Function Live Feed Quality: 1080p at 30fps	1" CMOS RGB 20 Megapixels Electronic Shutter 4K video at 100Mbps	$1,599
DJI Air 2S	Rotary wing quadcopter (foldable) Takeoff Weight: 595 grams Max Flight Time: 31 minutes Battery: LiPo 4S 3500mAh	GNSS: GPS+GLONASS+Galileo Vertical Accuracy: 0.1m - 0.5m Horizontal Accuracy: 0.1m - 1.5m Flight Distance: 18.6km	Obstace Sensing: Forward, Backward, Downward, Upward, Lateral Return-to-Home Function Live Feed Quality: 1080p at 30fps	1" CMOS RGB 20 Megapixels Electronic Shutter 5.4K video at 150Mbps	$999
DJI Mavic Pro	Rotary wing quadcopter (foldable) Takeoff Weight: 734 grams Max Flight Time: 27 minutes Battery: LiPo 3S 3830mAh	GNSS: GPS+Glonass Vertical Accuracy: 0.1m - 0.5m Horizontal Accuracy: 0.3m - 1.5m Flight Distance: 14km	Obstacle Sensing: Forward and Downward Return-to-Home Function Live Feed Quality: 720P at 30-60fps	1/2.3" CMOS RGB 12.3 Megapixels Electornic Shutter 4k video at 60Mbps	$600 - $900 (Discontinued)
Parrot Anafi	Rotary wing quadcopter Max Flight Time: 25 min Battery: LiPo 2700mAh	GNSS: GPS+GLONASS	Obstacle Sensing: Forward and Downward Return-to-Home Function Live Feed Quality: 720P at 30-60fps	1/2.4" CMOS RGB 21 megapixels Electronic Shutter Global Shutter 4K at 100Mbps	$599 - $899
DJI Spark	Rotary wing quadcopter Takeoff Weight: 300 grams Max Flight Time: 16 minutes Battery: LiPo 3S 1480mAh	GNSS: GPS+GLONASS Vertical Accuracy: 0.5m Horizontal Accuracy: 1.5m Flight Distance: 14km	Obstace Sensing: Forward, Backward, Downward, Lateral Return-to-Home Function	1/2.3" CMOS RGB 12 Megapixels Rolling Shutter 1080P at 24Mbps	$499 (Discontinued)

Comparison of different popular drone models used for consumer and professional that covers different integrated features necessary for surveying. While many studies incorporate custom made drone systems, this table focused on all-in-one models by common brands.

The second variable was that the research project must have a vital environmental component. Therefore, the purpose of the study was to produce an output that has environmental consideration. The recurring environmental themes include agriculture, disaster management and reduction, and environmental monitoring and surveying. As previously discussed, these themes all act as environmental work that entails a social impact – agriculture for food security and cultural heritage, disaster management and reduction for environmental disasters that directly and indirectly affect individuals and social groups, environmental monitoring for spatial and temporal analyses and predictions, monitoring and mapping of different extents, biomasses, vegetation cover, urban development and more. The environmental considerations are expansive, but to meet the criteria of this research, the environmental component must have a specific notable impact on social groups.

The third variable was the resounding criterion for this study, the impact of budgetary UAS systems for environmental monitoring on social groups. The majority of research on the use of UAS was for environmental sciences. However, when addressing the prevalent themes that exist in current literature with the use of UASs, the environmental components stem from and to social components – food security and cultural heritage in relation to agriculture, disaster management and reduction that impacts communities and affects quality-of-life, and surveying of land for determining extent and range(Chaudhary et al., 2018; Lin & Hsueh, 2019; McCall, 2014) as well activities occurring on the land. Ultimately, these environmental factors directly influenced social impacts. While literature does exist regarding the use of UASs for disaster purposes and related scenarios, the focus lied two-fold on elements that this study sought to avoid – enterprise solutions and use cases in highly-developed areas and countries. Despite seeking studies that avoided enterprise systems, valuable studies that do pertain to the social theme and environmental theme occasionally used enterprise systems. To address this, a small number of the chosen studies involve the use of higher-end drone systems such as the SenseFly eBee series. Regardless, the focus lied on budgetary solutions that can be utilized in lesser-developed areas and communities for the benefit of the residing groups. Furthermore, allowing these groups to utilize and access the technology for their own use and benefit. This also prompts the use of Public Participation GIS as well as the involvement of community stakeholders. As previously stated, PPGIS provides a platform for individuals and community members who may have previously lacked one. The potential of PPGIS was two-fold in relation to this study: providing the means of individual community members collecting data and then providing them the means to share their data. This could be surveying community members on their opinions and observations in relation to their community development to train community members to collect their own data via their personal UAS or community system. As evident in Sieber (2006), providing a means for community members to develop their own data has the potential to influence local policy.

The final theme, privacy and security, were integrated as a secondary addition to the three primary themes. While this study touts the promise of UASs for environmental and social means, concerns arose with its use. As seen in Hodgson and Schroeder (2002), these systems' viewpoint and high-resolution capabilities allow for improved spatial data previously impossible or inaccessible. As evident in Hodgson and Schroeder (2002), boundaries and territory concerns are instigated as a result of high-resolution imagery providing a level of accuracy and resolution unconsidered in initial development.

Sampling

The population was determined through a literature search in Google Scholar (scholar.google.com) with search variables including: "UAV," "UAS," "Drone," "Environmental," "Surveying," "Remote Sensing," "Low-Cost," and "Inequality." The purpose of these terms was to search and determine select studies that entail the variables given. A sample of the population was necessary due to the limited studies that involve these unique criteria.

Once the population was determined, the lead author(s) of the selected projects were contacted via email regarding their project and if they would be interested in taking a survey regarding the use of UASs in the specific research study. This was the targeted sample. At the completion of the survey, the respondents were asked if they are interested in participating in a virtual face-to-face interview where they can expand upon the qualitative social aspects of their study.

Thirty-six studies were selected that meet the criteria and involve the previously mentioned themes of the study, use of drone technology, an environmental component, that component affecting a social group, and privacy and concerns associated with it. The low selection number results from the limited studies that meet these criteria; however, this sample amount was focused on explicitly defined studies in a highly limited pool. However, after conducting the systematic review, ten of the studies were eliminated for the inconsistencies associated with the given themes.

Primary Data

Due to an inadequately low response rate, the study had to be reworked to alter the primary data means. To address the low response rate, instead, a systematic review was performed on the selected studies that were originally selected to contact the authors. This analysis used the selected themes to determine if the study incorporated those themes and the specific details of them.

Secondary Data

The study design for this project was originally meant to be a mixed-methods survey with a qualitative interview component. This incorporated specific pre-determined questions as well as the inclusion of open responses. This design was most suitable for this study as it allowed interviewees to provide unique information regarding the implementation of drone technologies in their specific research project. As there was a lack of existing frameworks to support this topic of study, pre-determined questions may not have produced completely reliable, informative, or applicable results. However, pre-determined questions were constructed to establish a baseline of information that was then sought to develop into an open response that showcased how drone technologies have impacted or allowed for the specific study. Qualtrics was utilized as the software to develop the survey as well as distribute, host, and conduct the initial quantitative analysis. A sample of questions were given (Fig. 2), including both structured and open-ended questions.

Budgetary Drone Use in Environmental Surveying: A Social Perspective

Start of Block: Use of Drone Technology

Q1.1 What type of physical drone was utilized in this study?

Fixed-Wing (1)

Quadcopter (2)

Hexacopter (3)

Other (4) ____

Q1.2 What specific drone model(s) was used?

____

Q1.3 In what ways were drone technologies utilized in this study?

Mission Planning (1)

Data Collection (2)

Post-Processing (3)

Q1.4 What program/method of mission planning was used?

Free Flight (Manual Flight) (1)

DJI Ground Station Pro (2)

Pix4D (3)

DroneDeploy (4)

ESRI PhotoScan (6)

ESRI Drone2Map (7)

Other (5) ____

Figure 2: Sample of the survey questions within Qualtrics that will be distributed via email and virtual face-to-face interviews to the lead authors of the selected research articles.

RESULTS

This research design entailed a primary systematic review of the selected studies with an additional survey component. Table 2 through 4 are the parts of the systematic review that identifies each study and how it aligns to the given themes mentioned previously. Each table is separated by the theme, table 2 being environmental, table 3 being the social, table 4 being the use of a UAS, and table 5 being the secondary theme of privacy and security. Due to a lack of necessary information to be used for the analysis that were expected to be derived in the survey and interview component of the original study design, Twenty-six of the studies included the necessary information to analyze for the systematic review.

For the results of the environmental theme as identified in Table 2 below, fifty percent of the studies pertained to Disaster Management and Reduction with majority focused on hazard assessment such as natural disaster risk management including flooding, coastal erosion, and landslide risk. Nineteen percent of the studies pertained to Agriculture with the specific category of Farmland Abandonment and Farmland Productivity.

Ultimately, a review of the literature suggested that the use of budgetary UAS has the potential to address developing environmental issues such as flood mitigation and erosion. One of the studies addressed natural disaster relief with real-time recovery. Another study pertained to documenting infrastructure of what was considered “Cultural Heritage” (Calantropio et al., 2018).

Table 2: Environmental Theme

Short Citation	Theme	Subcategory	Specific Theme
Afif et al., 2019 (1)	Disaster Management and Reduction	Hazard Assessment	
Ballari et al., 2016	Agriculture	Natural resource Management	
Calantropio et al., 2018	Environmental Surveying	Infrastructure	Cultural Heritage
Candiago et al., 2015	Agriculture	Farmland Productivity	
Caprioli et al., 2016	Disaster Management and Reduction	Hazard Assessment	Landslide Risk
Chaudhary et al., 2018	Agriculture	Farmland Abandonment	
Chingombe et al., 2015	Disaster Management and Reduction	Hazard Assessment	Flood Risk
Colloredo-Mansfeld et al., 2020	Agriculture	Food Security	
Cottray, 2018	Environmental Surveying	Land Use	
Darmawan et al., 2020	Environmental Surveying	Vegetation Analysis	Mangrove Health
Doukari et al., 2017	Disaster Management and Reduction	Hazard Assessment	Flood Risk
Feng et al., 2015	Disaster Management and Reduction	Hazard Assessment	Flood Risk/ Landslide Risk
Hardy et al., 2017	Public Health	Disease Control	
Hernina et al., 2021	Disaster Management and Reduction	Hazard Assessment	Climate Change Preparedness
Lee et al., 2020	Environmental Surveying	Land Use	Recreational Purposes
Lin & Hsueh, 2019	Disaster Management and Reduction	Hazard Assessment	Landslide Risk
Pagán et al., 2019	Disaster Management and Reduction	Hazard Assessment	Coastal Erosion
Paneque-Gálvez et al., 2017	Environmental Surveying	Environmental Surveying	Indigenous Protection
Paudel et al., 2020	Agriculture	Farmland Abandonment	
Pucino et al., 2021	Disaster Management and Reduction	Hazard Assessment	Coastal Erosion/ Flood Risk
Rohman & Prasetya, 2019	Disaster Management and Reduction	Hazard Assessment	Flood Risk
Schaefer et al., 2020	Disaster Risk management and reduction	Disaster Recover	Hurricane Recovery
Suroso, 2019	Disaster Management and Reduction	Hazard Assessment	Flood Risk
Suroso, 2020	Environmental Surveying	Environmental Health	Drought Risk
Widodo et al., 2019	Environmental Surveying	Orthomosaic Imagery	
Yalcin, 2018	Disaster Management and Reduction	Hazard Assessment	Flood Risk

The systematic review results of twenty-six studies that pertain to the environmental theme and its subcategories

Table 3 identifies the social themes present in the study. The two categories for this were related to Public Participation GIS and the involvement of Community Stakeholders. As mentioned previously, public participation GIS entails the use of community members providing input related to the study or by collecting data for the study. For the involvement of community stakeholders, a community member or official is provided data that has the potential to be used for the influence of implementing or changing policy and regulations. To meet the criteria of the social theme, the study had to have a component in which the surveying with a UAS had to influence a social group in some manner. Although, many of these studies do not specifically involve the use of public participation GIS or community stakeholders as a component of the study, all studies selected are related to a social group be it directly or indirectly.

Fifty percent of the studies directly contain a public participation GIS component in which social surveys are conducted with community members or community members were collecting data themselves. Fifty-four percent of the studies involved community stakeholders in which the data collected from the studies were used to influence a form of policy or regulation change.

Paneque-Gálvez et al. (2017) reviewed workshops that focused on community members collecting UAS survey data for influence of their indigenous territories. One of these workshops which took place in Harakmbut community of Puerto Luz in Peru where illegal gold mining was taking place on their land. Using a DJI Phantom 2. The results suggested that “the training workshop demonstrated that the utilization of this type of drone by communities themselves is feasible after short training,” however, limitations were identified such as a lack of internet access (Paneque-Gálvez et al., 2017).

Table 3: Social Theme

Short Citation	Involvement of PPGIS	Involvement of Community Stakeholders	Specific Involvement
Afif et al., 2019 (1)	No	No	
Ballari et al., 2016	No	No	
Calantropio et al., 2018	No	No	
Candiago et al., 2015	Yes	No	Interviews
Caprioli et al., 2016	No	No	
Chaudhary et al., 2018	Yes	Yes	Social Surveys
Chingombe et al., 2015	Yes	Yes	Interviews, PP Data Collection
Colloredo-Mansfeld et al., 2020	Yes	No	Interviews
Cottray, 2018	No	Yes	
Darmawan et al., 2020	No	Yes	Influence Mangrove Restoration
Doukari et al., 2017	Yes	Yes	Social Surveys
Feng et al., 2015	No	Yes	Stakeholders
Hardy et al., 2017	No	No	
Hernina et al., 2021	Yes	Yes	Interviews/ Stakeholders
Lee et al., 2020	No	Yes	Stakeholders
Lin & Hsueh, 2019	Yes	Yes	Stakeholders
Pagán et al., 2019	No	Yes	Stakeholders
Paneque-Gálvez et al., 2017	Yes	Yes	
Paudel et al., 2020	Yes	Yes	Social Surveys
Pucino et al., 2021	Yes	Yes	
Rohman & Prasetya, 2019	Yes	No	
Schaefer et al., 2020	No	No	
Suroso, 2019	Yes	No	Social Surveys
Suroso, 2020	No	No	
Widodo et al., 2019	Yes	Yes	Social Surveys/Stakeholders
Yalcin, 2018	No	No	

The systematic review results of twenty-six studies that pertain to the social theme and its subcategories

The results of table 4 in relation to the use of a UAS presented surprising results in which the variety of UASs used were both much higher than expected as well as multiple studies not indicating which system was used. Fifty-four percent of the studies used a DJI brand system with thirty-eight percent of the total studies using a version of the DJI Phantom series. Two of the studies utilized a DJI spark, originally, DJIs smallest and cheapest UAS retailing for $499.00 USD (www.DJI.com). While the studies that used this system were minimal, the potential to use a system at that cost for usable data is representative of what this study hoped to showcase. Despite some of these studies using the SenseFly eBee, a professional survey-grade fixed-wing UAS, the use of the system still pertained to the environmental and social themes and provide comparison to the lower-end models in the other selected studies. The most commonly used software for mission planning and analysis was Agisoft PhotoScan, Pix4D, and DroneDeploy. However, two of studies used manual flight as compared to autonomous missions. While there are many benefits to autonomous missions, the ability to capture useable data via manual flight creates a lower barrier-of-entry and provides more opportunities for utilizing these systems that doesn’t require further hardware and software needs.

Table 4: Use of UAS Theme

Short Citation	Specific Drone Model	Software Used
Afif et al., 2019 (1)	DJI Phantom 4 Pro	Postflight Terra 3D
Ballari et al., 2016	Sensefly eBee	Pix4D, MicMac
Calantropio et al., 2018	DJI Spark, Leica BLK360, Cam2 Faro Focus3d X 330	Not Mentioned
Candiago et al., 2015	ESAFly 2500 WH	PhotoScan
Caprioli et al., 2016	Custom System	Pix4D Mapper
Chaudhary et al., 2018	DJI Phantom 4 Pro	Not Mentioned, Field Observations
Chingombe et al., 2015	Not Mentioned	DroneDeploy
Colloredo-Mansfeld et al., 2020	DJI Phantom 4, DJI Mavic Pro Platinum	Not Mentioned
Cottray, 2018	Sensefly eBee	DroneDeploy
Darmawan et al., 2020	DJI Phantom 4 Pro	Open access Mission Planner v1.25
Doukari et al., 2017	Iris+ w/ Canon 130	Pix4D
Feng et al., 2015	River-Map UAV	Manual Flight
Hardy et al., 2017	DJI Phantom 3	Not Mentioned
Hernina et al., 2021	DJI Phantom 4 Pro	Not Mentioned
Lee et al., 2020	DJI Mavic 2 Pro	Not Mentioned
Lin & Hsueh, 2019	Not mentioned/ “Popular, cheap, convenient"	PhotoScan
Pagán et al., 2019	Not Mentioned	Multiple
Paneque-Gálvez et al., 2017	Multiple	Pix4D
Paudel et al., 2020	DJI Phantom 4 Pro	Not Mentioned
Pucino et al., 2021	Not Mentioned	Manual Flight
Rohman & Prasetya, 2019	DJI Phantom 4	PhotoScan
Schaefer et al., 2020	DJI Phantom 4/DJI Phantom 3	Not Mentioned
Suroso, 2019	Custom	Pix4D
Suroso, 2020	DJI Spark	Pix4D
Widodo et al., 2019	DJI Phantom 3 Advanced	Pix4D
Yalcin, 2018	DJI Matrice 600	Pix4D

The systematic review results of twenty-six studies that pertain to the theme involving the use of UASs and its subcategories

The final and secondary theme of this studies regarded privacy and security when conducting UAS missions for the purposes related to this study. Did community members feel as though their privacy was compromised by surveying? Were there any security concerns related to private or governmental issues as a result of the UAS missions? Table five presents which studies considered the theme of privacy and security in their research. Overall, a very minimal amount of these studies considered this theme. Twenty-four percent of the studies did consider the concern of privacy in relation to community members as well as nineteen percent of the studies considering security in relation to private organizations and government. Most notably, was Doukari et al (2017) that remarked that “the privacy of data and image is also relevant as the community members have little control over the usage of the data collected by the UAV.” While it may meet legal criteria, the ethics of the privacy factor are still evident.

Table 5: Privacy and Security Theme

Short Citation	Involvement of Privacy Concerns	Involvement of Security Concerns
Afif et al., 2019 (1)	No	No
Ballari et al., 2016	No	No
Calantropio et al., 2018	No	No
Candiago et al., 2015	No	No
Caprioli et al., 2016	Yes	Yes
Chaudhary et al., 2018	No	No
Chingombe et al., 2015	No	No
Colloredo-Mansfeld et al., 2020	No	No
Cottray, 2018	No	No
Darmawan et al., 2020	Yes	Yes
Doukari et al., 2017	Yes	No
Feng et al., 2015	No	No
Hardy et al., 2017	No	No
Hernina et al., 2021	No	No
Lee et al., 2020	No	No
Lin & Hsueh, 2019	No	No
Pagán et al., 2019	Yes	Yes
Paneque-Gálvez et al., 2017	Yes	Yes
Paudel et al., 2020	No	No
Pucino et al., 2021	No	No
Rohman & Prasetya, 2019	Yes	Yes
Schaefer et al., 2020	No	No
Suroso, 2019	No	No
Suroso, 2020	No	No
Widodo et al., 2019	No	No
Yalcin, 2018	No	No

The systematic review results of twenty-six studies that pertain to the privacy and security theme

Individual personalized emails were sent out to the corresponding author listed on each of the individual studies through Qualtrics. Two of the corresponding emails were undeliverable suggesting the recipient email was no longer active. After a two-week waiting period, only one response was recorded with the participant rejecting the follow-up interview. Individual personalized reminder emails were sent out at this time. Four further responses were recorded for a total of five responses out of the potential forty. All participants rejected the follow-up interview component. Due to the low response rate, the data collected from the survey responses are not suitable as primary data. The purpose of the survey and interview components were to derive data from the participants' original research that was not mentioned in the articles. It was expected that the survey responses would supply additional data pertaining to the original research – however, this was not effective due to the lack of respondents. To address this, a systematic review was conducted to act as the primary data rather than secondary data. Accurate to the original proposal, several articles detail many components that this research sought – however, pertinent data regarding the themes was unable to be derived which resulted in missing data points. Regardless, the results of the systematic review provide unique insight into the entwinement of budgetary UAS, environmental surveying and community health and relationship.

The most notable results of the survey indicated that two of the five studies, the involvement of community stakeholders was "very important." Furthermore, two of the five studies also entailed public participation GIS in which one respondent marked that it was "very important" while the other marked that is "not at all important." However, for the respondent that listed public participation GIS as very important, they included that the use of community members providing qualitative data was "extremely important." Of the five studies, one respondent remarked that privacy and security were considered in their study with an emphasis on community members’ privacy. For all five studies, DJI systems were used with four of them being the Phantom series and one of them being the Mavic series. No respondents were interested in participating in a follow-up interview.

DISCUSSION

It is evident that the usage of consumer drone systems for environmental surveying has the potential to benefit social groups based on the analysis of the literature. However, limitations exist. Due to the low response rate, the original study design was infeasible and what was expected to be the source of the primary data became secondary data. The systematic review, acting as the primary data, derived expected results, most notably that consumer drone systems when used for environmental surveying to address community needs are separate themes that are seldomly considered in these studies, yet the social theme is a valuable contribution to these studies and further studies should include community consideration, be it the use of public participation GIS or community stakeholders.

The results of this study suggest that there is a disconnect between the environmental surveying in a community and the community itself. A number of studies that pertain to environmental surveying within a community utilizing a UAS disregard the social impacts that the unique data brings with it. Social implications are seldomly considered throughout environmental surveying focused articles – even when the surveying itself is directly within a community. An example of this comes from Gevaert et al. (2018) where "the privacy of data and image is also relevant as the community members have little control over the usage of the data collected by the UA[S]." Gevaert et al. (2018) also places an emphasis on these concerns when the data collection takes place in a marginalized community where "the lack of a unified policy framework directing such practices leaves much of the responsibility to industry self-regulation, which may not sufficiently protect these communities." Yet, despite this consideration, privacy and security were seldom considered through these studies. However, the implementation of privacy and security are prevalent in the studies that do consider them. This study sought to discover the impact that budgetary UAS for environmental surveying has on communities with an emphasis on those that are marginalized. While this research did present a unique look into this emerging field – it emphasized the beneficial possibilities of these systems. However, the results of the systematic analysis presented a broader scope of the possibilities in which paramount concerns have arisen. The protection of these communities lies beyond the environmental capacity that these systems bring – rather, it asks, how can we use these systems in this capacity while also considering the invasiveness of these systems? As Gevaert et al. (2018) suggests, a unified policy framework is needed.

The development of such a framework lies beyond the scope of this research. However, one suggestion derived from the privacy and security results of the systematic analysis would be the inclusion of community members in environmental surveying research within community boundaries. While further research is needed to identify methods of reducing this detachment, this research suggests that the inclusion of community members in the theme of Public Participation GIS would have the potential to act as an intermediary between the environmental surveying research and the privacy concerns of the community. By involving community members, not only is the community made aware of the surveying, but they are involved in the surveying. As seen in Chaudhary et al. (2018), the inclusion of community member input can provide supplemental information to environmental surveying, in this case, farmland abandonment. Chaudhary et al. (2018) suggests that "the interdisciplinary of human-environment interactions and of future landscape development that is rooted in the empirical realities of the case study area should be considered." Through the intertwinement of social surveys and remote sensing for environmental surveying, a comprehensive insight into the rise of farmland abandonment was able to be meticulously analyzed. Although, community stakeholders are a promising theme in this study, it is important to note that there are ineffective outcomes even with the involvement of these themes. Paneque-Gálvez et al. (2017) remarks that:

> "Although indigenous peoples have the formal right to free, prior, and informed consent to projects in their territories, in practice this mechanism is frequently ineffective in defending territorial rights because it rarely permits indigenous communities to reject or substantially modify an undesired project, and has been shown to act as a bureaucratic trap in many cases."

In relation to the theme of the use of a budgetary UAS, the comparison between the lowest-tier model (DJI Spark, $499) and the higher-tier model (SenseFly eBee X, $19,800) presented in figure 1, the technical specifics of the drone models, although highly different, the overarching components remain the same. The primary technical differences lie in the sensor and accuracy of the system. Between the two models, the most expensive model has a specialized multiband sensor that is commonly used in agricultural while the cheapest model has a common mass-produced CMOS RGB sensor. At such a vast cost difference, the sensors still collect imagery in the same means and can be analyzed similarly. The industrial application of the commercial system is able to be similarly replicated in the much cheaper consumer system. This research does not suggest that the lower-tier consumer system can or should replace the commercial system, but rather that high-quality data collection can be similarly replicated at a much more affordable price point and ease-of-use, thus, opening the potential of budgetary systems to provide useful data for analysis to communities that may lack access to this type of GIS data.

Not only can these communities' benefit from this type of data, but also have the potential to collect the data themselves. As seen in Paneque-Gálvez et al. (2017), individual community members with limited training have the potential to operate these systems and collect the data themselves. Paneque-Gálvez et al. (2017) analyzed multiple workshops where indigenous community members conducted surveying missions of compromising operations occurring in their community such as an illegal gold mining operation. The training workshop indicated that the members, with very limited training, were able to fly and conduct the mission themselves. Implementing technical operations in communities also must factor in community resources such as access-to-power and access-to-internet.

It was expected that personalized emails related to the author's own works would incentive a response – however, the response rate was thirteen percent. While this response rate would be suitable for a study with a much larger sample size, it was insignificant to use in this study. It should be noted that this study took place during the COVID19 pandemic which may have negatively influenced the response rate. Yet, the lack of responses provided a unique insight into the value of the survey and interview components that this study originally sought as the primary data. Table 2 identifies many variables as "not mentioned" indicating that the article alone did not provide the necessary information to document in the systematic review. This suggests that a centralized framework has yet to be developed for this specific niche. By developing and implementing a framework that integrates the themes in this study, further studies would be able to consider themes that may not have originally been considered.

CONCLUSION

This research suggests that the value of environmental surveying using consumer drone technology does have the potential to benefit social groups but considering the privacy and security of these communities is a theme that should be valued in future studies of a similar nature. Currently, addressing this lies in the responsibility of self-regulation, which is seldom considered.

There is evidence for the use of budgetary UAS for environmental surveying and its application to social groups – but it is a niche still in its infancy. Future studies should consider the use of budgetary UAS for research that is more strictly constrained by budget. This study promotes that by developing and implementing a standardized framework for the use of low-cost UAS for the benefit of social groups through environmental surveying, community members can not only benefit from UAS involved studies but collect and analyze data themselves for the betterment of their community.

APPENDIX A

SURVEY QUESTIONNAIRE

Budgetary Drone Use in Environmental Surveying: A Social Perspective

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Start of Block: Use of Drone Technology

Q1.1 What type of physical drone was utilized in this study?

- ▢ Fixed-Wing (1)
- ▢ Quadcopter (2)
- ▢ Hexacopter (3)
- ▢ Other (4) ____

Q1.2 What specific drone model was used?

____

Q1.3 In what ways were drone technologies utilized in this study?

- ▢ Mission Planning (1)
- ▢ Data Collection (2)
- ▢ Post-Processing (3)

Display This Question:

In what ways were drone technologies utilized in this study? = Mission Planning

Q1.4 What program/method of mission planning was used?

- ▢ Free Flight (Manual Flight) (1)
- ▢ DJI Ground Station Pro (2)
- ▢ Pix4D (3)
- ▢ DroneDeploy (4)
- ▢ ESRI PhotoScan (6)
- ▢ ESRI Drone2Map (7)
- ▢ Other (5) ____

Q1.5 How important was a budget in this study?

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
Importance of Budget (1)	○	○	○	○	○

Q1.6 How important was each drone use component?

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
Use of a physical drone system (1)	○	○	○	○	○
Use of pre-flight mission planning software (2)	○	○	○	○	○
Use of post-processing software (3)	○	○	○	○	○

End of Block: Use of Drone Technology

Start of Block: Environmental Component

Q2.1 Would you say your study has an environmental component?

○ Yes (1)

○ No (2)

Skip To: End of Block If Would you say your study has an environmental component? = No

Display This Question:

Would you say your study has an environmental component? = Yes

Q2.2 Does the study pertain to one of these environmental categories?

- ▢ Disaster Management and Reduction (1)
- ▢ Environmental Monitoring and Surveying (2)
- ▢ Agriculture (3)
- ▢ Other (4) ____

Q2.3 How important was each environmental component?

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
Disaster Management and Risk Reduction (1)	○	○	○	○	○
Environmental Monitoring and Surveying (2)	○	○	○	○	○
Agriculture (3)	○	○	○	○	○

End of Block: Environmental Component

Start of Block: Social Component

Q3.1
Does your study contain a social component? I.e. were individuals or a community influenced by this research or involved in the research (not including the core research team)?

- ○ Yes (1)
- ○ No (2)

Skip To: End of Block If Not including core research team = No

---

Display This Question:

Not including core research team = Yes

Q3.2 Were community members involved in the study (not including the core research team)?

- ○ Yes (1)
- ○ No (2)

Display This Question:

Were community members involved in the study (not including the core research team)? = Yes

Q3.3 In what ways were community members involved in the study?

- ☐ Community members participated in data collection (i.e., drone operations, mission planning, post-processing) (Public Participation GIS) (1)
- ☐ Community members used research data to influence public policy and governance (community stakeholders) (2)
- ☐ Community members provided personal qualitative input such as observations, opinions, and concerns (3)
- ☐ Other (4)

Display This Question:

In what ways were community members involved in the study? = Other

Q3.4 If you selected “other,” please provide further details

____

Q3.5 How important was each social component?

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
Public Participation GIS (1)	○	○	○	○	○
Community Stakeholders (2)	○	○	○	○	○
Providing of Qualitative Data (3)	○	○	○	○	○

End of Block: Social Component

Start of Block: Privacy and Security

Q4.1 Were privacy and security concerns considered in this study?

○ Yes (1)

○ No (2)

Skip To: End of Block If Were privacy and security concerns considered in this study? = No

Display This Question:

Were privacy and security concerns considered in this study? = Yes

Q4.2 In what ways were privacy and security involved in this study?

- ☐ Geofencing (1)
- ☐ Community Members' Privacy (2)
- ☐ Boundary Concerns (I.e. Jurisdictional Borders) (3)
- ☐ Private Property Concerns (5)
- ☐ Other (4)

Q4.3 How important were privacy and security concerns

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
Privacy: Community Members' Privacy (1)	○	○	○	○	○
Privacy: Boundary Concerns (2)	○	○	○	○	○
Security: Geofencing Limitations (3)	○	○	○	○	○
Security: Use of a drone system in private properties (4)	○	○	○	○	○

End of Block: Privacy and Security

Start of Block: Further Information

Q5.1
What position best describes you:

- ○ Principal Investigator (1)
- ○ Lead Author (2)
- ○ Co-Author (3)
- ○ Other (4)

Q5.2
Would you be interested in a follow-up virtual meeting for further discussion?

- ○ Yes (1)
- ○ No (2)

Q5.3 If you answered yes, please provide your email or the best way to reach you.

____

End of Block: Further Information

APPENDIX B

IRB SURVEY EMAIL

Department of Sociology, College of Sciences

4000 Central Florida Blvd.

Orlando, Florida 32816

Hello, [INSERT SUBJECT NAME HERE],

We are contacting you regarding your research, [INSERT RESEARCH TITLE HERE].

Based on the high interest and applicability of your study, we invite you to participate in a short online survey through Qualtrics that you can complete in a location of your choosing and should take 5 to 10 minutes. The survey will help us with analyzing existing studies that use budgetary Unoccupied Aerial Systems (UAS) for environmental surveying. This research seeks to develop an understanding of the evolution of modern UAS technology and how they may or may not benefit more indigent social groups using them for environmental analyses.

Your study was selected from an extensive literature review search on Google Scholar for its relation to three themes: inclusion of a budgetary UAS, its use for environmental analyses, and those analyses having a social impact.

We would greatly appreciate your participation in this survey and believe your input will provide a valuable contribution to the growing field of UAS technology for environmental research and publicly accessible Geographic Information Systems. Furthermore, at the completion of the survey, you will be invited to participate in a virtual interview to further expand upon topics in the survey. If you choose to participate in the interview portion, you will receive an email with further details. This interview will take up to 30 minutes and be conducted on Zoom at a location of your choosing. You have the option to have your camera turned on and the interview will not be recorded. Participants will not be compensated for their time. You may withdraw your consent at any time during or after the study closes.

You are welcome to forward this invitation to another co-author who is suited to complete this survey.

Results and participant identities will be protected and stored locally with password protection and access only via single accounts by the investigator and faculty mentor. Participant identification will be protected through a generated crosswalk table in which the participant identity is protected and replaced with ID numbers assigned to each participant. All data will be stored on university-managed password protected device for 5 years after study closure.

For a further understanding of the research that we are involved in and how it relates to your work, please visit www.citizensciencegis.org/uasreview.

To qualify for participating, you must be an author on the mentioned article and must be 18 years or older to participate in this study.

Thank you for your time.

Sincerely,

Tyler Copeland

Tyler.copeland@ucf.edu

Graduate Research Assistant

Department of Sociology and Citizen Science GIS

University of Central Florida

Timothy L Hawthorne

Timothy.hawthorne@ucf.edu

Associate Professor of GIS

Department of Sociology and College of Sciences GIS Cluster

University of Central Florida

APPENDIX C

IRB EXEMPTION

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

EXEMPTION DETERMINATION

February 4, 2022

Dear Tyler Copeland:

On 2/4/2022, the IRB determined the following submission to be human subjects research that is exempt from regulation:

Type of Review:	Initial Study, Initial Study
Title:	BUDGETARY UNOCCUPIED AERIAL SYSTEMS FOR ENVIRONMENTAL SURVEYING: A SOCIAL PERSPECTIVE
Investigator:	Tyler Copeland
IRB ID:	STUDY00003754
Funding:	Name: SOCIOLOGY
Grant ID:	
Documents Reviewed:	• HRP-251- FORM - Faculty Advisor Scientific-Scholarly Review fillable form_TLH.pdf, Category: Faculty Research Approval; • Interview Recruitment Email, Category: Recruitment Materials; • Interview Template.docx, Category: Interview / Focus Questions; • Recruitment Email, Category: Recruitment Materials; • Study 3754 HRP-254-FORM Explanation of Research_Copeland_020222.pdf, Category: Consent Form; • Study 3754 HRP-255-FORM_02032022.docx, Category: IRB Protocol; • Survey, Category: Survey / Questionnaire;

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made, and there are questions about whether these changes affect the exempt status of the human research, please submit a modification request to the IRB. Guidance on submitting Modifications and Administrative Check-in are detailed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB

Library within the IRB system. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Gillian Bernal
Designated Reviewer

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