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The Application of Drone Technology in Micro-Watershed Evaluation

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Abstract

The application of drone technology in micro-watershed evaluation in Sub-Saharan Africa may potentially attract sustainable management of watersheds and limit practices that encourage pollution, erosion, flooding, deforestation and afforestation, among others. This paper employs data from literature sources to establish the significance of adopting drone application technology in the evaluation of micro-watersheds in Kenya to discourage the alteration of the specified ecosystems and enhance their general functioning. Of the reviewed literature, 80% sources were from developed nations; and 20% were from developing countries. The results suggest that the application of drones in micro-watershed evaluation has a wide range of benefits; including the provision of real time assessment, offering comprehensive visual information, enhancing agricultural productivity, enhancing decision-making capabilities; promoting optimal and sustainable utilization of resources; promoting improved food security and socio-economic wellbeing; attracting cost effectiveness; fostering innovation; promoting efficient data collection; reducing crop and environmental damages; ensuring controlled utilization of agricultural inputs; and the provision of accurate data, large amount of data, and real-time data. Moreover, the application of drones in micro-watersheds ensures unlimited coverage, high accuracy and speed; endurance and controlled range; and replicability and availability. The results conclude that drones are useful, reliable and effective in the evaluation of micro-watersheds, and may thus protect watersheds from being altered.

Keywords: *drones, unnamed aerial vehicles, watershed, micro-watershed and evaluation*

1. Introduction

The application of drone technology in the evaluation of micro-watersheds is highly encouraged because watersheds serve as homes for natural and human resources on the earth's surface. In most cases, available natural resources within watersheds are exploited without cognizance of their existence in the future (George et al., 2015). Even though some human activities like afforestation and agroforestry, among others, can boost the resource base,

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watershed services and functions may be threatened by deforestation, uncontrolled timber harvesting, changes in farming systems, overgrazing, roads and road construction, pollution, and the invasion of alien species (Wagner & Wolter, 2017). Further, overexploitation of existing resources can lead to depletion. This poses a challenge to watershed management, livelihood security, economic development, and environmental sustenance. Addressing these challenges demands effective management and intervention in catchments, which necessarily involves gaining further knowledge of hydrological systems, and filling current information gaps (Vélez-Nicolás et al., 2021). In this regard, watersheds require regular assessment globally to promote their sustainable utilization to achieve social, economic and environmental sustainability.

Initially, watershed supervisors manually surveyed slopes and relevant areas using basic dumpy levels and hydro markers (IdeaForge, 2020) during watershed assessment. Due to technological advancements, satellite imagery has been used for watershed assessment globally. Satellite imagery is appropriate for the assessment of both macro- and micro-watersheds, but have bottlenecks in terms of real-time quality data (DeBell et al., 2015). There is a growing need for fine-scale responsive data in Water Resources Management (WRM), which cannot be delivered from satellites or aircraft in a cost-effective way (DeBell et al., 2015). Drones have recently emerged as new allies in environmental monitoring and management (Vélez-Nicolás et al., 2021). Photo 1 shows an example of a drone: a type of aircraft also known as unmanned aerial vehicle (UAV), or unnamed aerial system (UAS), because it does not need a pilot on board to fly it (Hossain, 2022, Daud et al., 2022; & Ahirwar et al., 2019).

Photo 1: Image of a Drone
Source: Ahirwar et al. (2019)

Drones have not only made a bird's eye observation a reality, but also offer a vast range of applications that are continually growing as technology advances (Vélez-Nicolás et al., 2021). Researchers and regulators are increasingly using drones to fill the gaps in both spatial and temporal data resolution (Acharya et al., 2021).

Drones have come up as key catalysts and efficiency-enablers within the integrated or participatory watershed management approaches (IdeaForge, 2020). These UAVs are often more cost-effective than traditional remote sensing or in situ data collection methodologies; and the availability of new advancements in UAV design, power supply, payload capacity, and sensors has been driving rapid innovations in their use in the hydrological sciences (Acharya et al., 2021). The use of UAVs and connected analytics have great potentials to support and address some of the most pressing problems faced by agriculture in terms of access to actionable real-time quality data (Kolhe & Munde, 2019). Through crop health imaging, integrated GIS mapping and minimizing the need to physically go through the field, drones can play key roles in decision-making and management processes that can contribute to increased yields and reduced costs (Ayamga et al., 2021). In addition, drones can be used in monitoring rugged areas, tracking down illegal activities, and observing forest fires and other natural disasters (ibid.). Currently, drones have been adopted by central and local authorities in developed countries for watershed management (IdeaForge, 2020). This has in turn increased efficiency and effectiveness of some management actions (Ayamga et al., 2021).

Although in developing regions—e.g., in Africa—the drone (UAV) industry is taking off and evolving into a massive enterprise (Digital Observer 4 Africa, 2023), it cannot yet match its use in the developed world in data capture. As explained by Whitehurst et al. (2021), accurate cadastre information, or datasets that define property boundaries and ownership, are frequently lacking in the developing world. While several African companies—for example, Drone Africa Service (Niger), Drones Service Limited (Zambia), Zipline (Rwanda), ATLAN Space (Morocco), FasoDrone (Burkina Faso), Map Action (Mali) and Zenvus (Nigeria)—are currently using GIS drones to collect aerial photos that are clearer than satellite photos (Digital Observer 4 Africa, 2023)—this has been comparatively on a small scale manner.

Drones have been used in the health, agriculture and natural resources management sectors in Africa (Digital Observer 4 Africa, 2023). In the area of agriculture, UAVs can help enhance and optimize crop yields via aerial monitoring of fields and early stress detection in plants (Shearwater Aerospace, 2022). Furthermore, drones are nowadays being used to solve some socio-economic or environmental problems—e.g., in spotting poor infrastructure and inaccessible health care, detecting drought and pests, fighting malaria, and in mapping wetlands (Digital Observer 4 Africa, 2023). Drones can now hover over fields of vegetables and grain, such as maize, sweet potato and rice, with special infra-red sensors that can collect aerial data that farmers and governments can use to better understand and predict crop yield, assess crop health, and keep weed cover at bay (Shearwater Aerospace, 2022; Digital Observer 4 Africa, 2023).

In some developing countries—for example, Rwanda, Tanzania, Kenya and Botswana, among others—drones are allowed to fly with the permission of the respective civil aviation authority of the respective country; while in other countries (e.g., Liberia) there is no legal framework for the use of drones (ibid.). Franckiewicz (2023) states that drone technology is being explored in Kenya for its potential to transform agriculture and wildlife conservation. He further contends that drones offer a promising solution to the challenges of vast savannahs, dense forests and arid deserts (ibid.). Wetlands, mines and urban centres, among others, require reliable topographic data for planning and management of resources. Drones have the potential of being a reliable source for detailed scale, if controlled with accurate Ground Control Points (GCPs) (Hanafi & Iryanthony, 2019). Also, drones can carry out representative GCPs, good quality photos and low altitudes as topographic data sources in micro-watersheds. Drone data has the flexibility on the spatial resolution and all the characteristics needed for micro drone management system (DSM), morphometric and hydrological analysis (Hanafi & Iryanthony, 2019).

Therefore, drones are suitable and are required urgently for monitoring and evaluation of micro-watersheds in developing nations for planning and effective management of the watersheds. Whitehurst et al. (2021) stated that accessible, low-cost technologies and tools are needed in the developing world to support community planning, disaster risk assessment, and land tenure. This is because manual assessment and application of satellite images may pose challenges manifested in delays in access to information, financial strain, minor variations that may exist between images acquired by different sensors in different seasons (for instance, between rainy and dry seasons), inaccurate data and change detection which can be binary, multiclass and in longtime series of images. In addition, the utilization of available resources within watersheds may pose challenges manifested in the invasion of alien species, erosion, spread of pests and diseases, resource use conflicts, and depletion of resources, among others. As such, all this requires frequent monitoring and evaluation of watersheds to gather accurate first-hand information that can be shared timely with users and agencies manning watersheds for proper management of available resources to achieve social, economic and environmental sustainability. In the end, the use of drones will promote monitoring and control of human activities, natural occurrences and hazardous events to curb overexploitation, destruction, and depletion of resources within a given watershed for sustainable livelihoods. This will, in turn, contribute to the achievement of sustainable development goals (SDGs), whose one major goal is to protect the planet and promote sustainable consumption (UNDP, 2018).

As mentioned above, regular watershed evaluation offers a solution in the effective management of watersheds. Among watershed monitoring systems, drone technology has been used in developed and newly industrializing nations for the detection, identification and monitoring of watershed activities and hazards. Developing nations are still struggling to adopt new watershed monitoring systems like satellites and drones. They have depended on the analysis of already existing images downloaded from websites. However, these satellite images are time-bound, and hence limit access to current information about watersheds. It is only the application of drones in watershed evaluation that gives first-hand and timely information that is appropriate for sustainable management of the watersheds. Hence, achieving sustainability among developing nations requires urgent adoption and application of drone technology.

This paper presents a literature review of the application of drone technology in micro-watershed evaluation with the aim of informing policy on its benefits and qualities to enhance its adoption in developing nations. The review provides useful information that will be used in the planning and management of watersheds to achieve social, economic and environmental sustainability.

2. Context and Methods

This paper draws input from a study that employed a systematic literature review as its main source of data. A systematic review can be explained as a research method and process for identifying and critically appraising relevant research, as well as for collecting and analysing data from the said research (Liberati et al., 2009; & Mustafa et al., 2021). Its aim is to identify all empirical evidence that fits a pre-specified inclusion criteria to answer a particular research question or hypothesis (Snyder, 2019). It minimizes bias and provides reliable findings from which conclusions can be drawn and decisions be made (Mustafa et al., 2021; & Moher et al., 2009). Published journals were reviewed. The inclusion and exclusion criteria were peer reviewed journals, year of publication, and language. In this regard, English-language publications from 2019 to date were reviewed, while those published earlier were excluded. In addition, article had to be research articles on the application of drone technology in watershed evaluation; and ones that discussed the application of drones with a particular focus on surveying, mapping, ecological, social and economic investigation, and narrowing down on benefits (endurance, coverage, accuracy, speed, replicability and availability). Therefore, the study covered the application of drones in micro-watershed assessment; extent and relevance of drones in micro-watershed evaluation; and the accuracy and relevance of data acquired by drones for watershed planning.

The literature review was done following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework guidelines for the reporting of article selection criteria and results of systematic reviews. Database searches for article titles and article abstracts; the application of inclusion criteria and rating of relevancy, article classification and rating; and data extraction was done to gather information on the application of drone technology. The electronic databases of SCOPUS and Google Scholar were searched by a desktop research method. The literature search returned a total of 104 results. Sourced article titles and abstracts were screened for relevance to the aims and scope of the review, and duplicates were rejected. Full texts of chosen articles (10) were downloaded in PDF and analysed for inclusion in the final review (Figure 1).

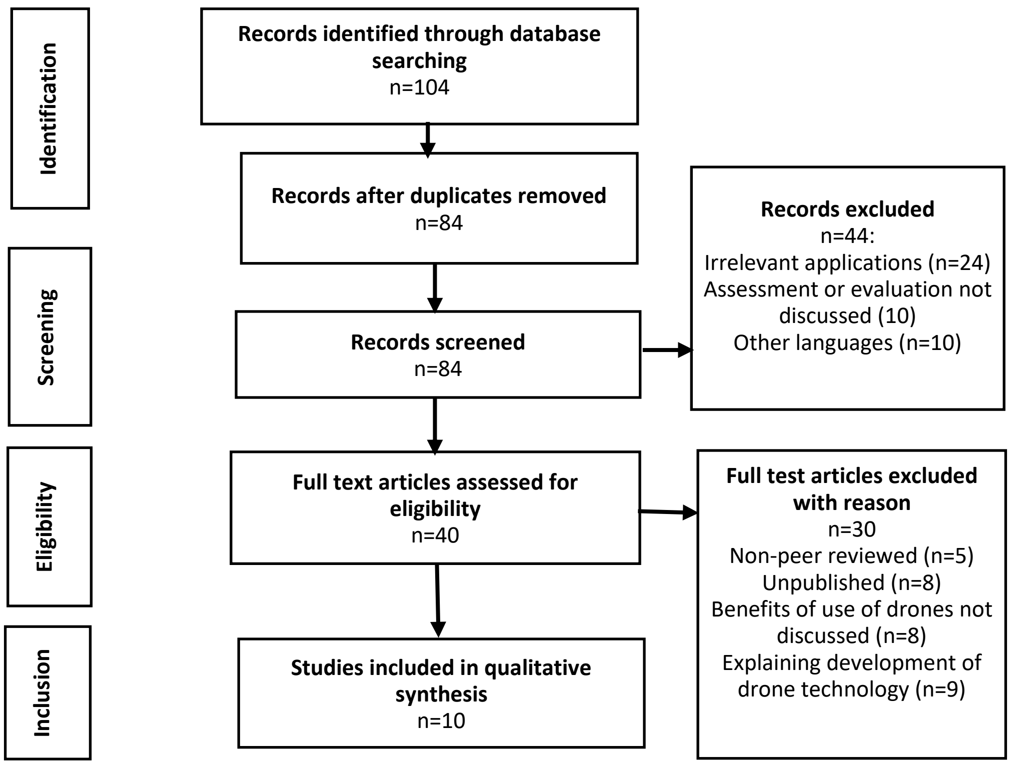

Figure 1: PRISMA Flow Chart for Systematic Review

Source: Modified from Alla et al. (2018)

In areas that are not restricted to randomized controlled trials, a major challenge lies in assessing the quality of research findings using a meta-analysis approach. In such areas, a strict systematic review process is used to collect articles, and then a qualitative approach is used to assess them (Snyder, 2019). Therefore, the study used relational content analysis to assess the application of drones in the evaluation of micro-watershed. The goal in relational content analysis is to explore the relationships between variables, while also testing theoretical assumptions (Delve & Limpaecher, 2023). It combines the flexibility of inductive analysis with the rigor of deductive analysis to gain deeper understanding of complex relationships between different concepts in data (Delve & Limpaecher, 2023).

3. Results

In micro-watershed evaluation, the application of drones cover numerous areas with a lot of benefits. The uniqueness of geographical locations, different human activities and unpredictable natural and human-induced occurrences: all these require the use of different types of drones in micro-watershed assessment or evaluation for accurate data capture and valid results. Shahmoradi et al. (2020) did a comprehensive review of the current state of drone technology in the mining industry. The paper aimed at providing a comprehensive review of the current state of drone technology and its applications in the mining industry. The applications included 3D mapping of mine environments, ore control, rock discontinuities mapping, post blast rock fragmentation measurements, and tailing stability monitoring, among others. The study found that drones equipped with different types of sensors can conduct a quick inspection of an area, either in an emergency situation or hazard identification. In addition, inspection and unblocking of blocked box-holes and ore-passes can be done using drones. Drones can also be used for blockage inspection, and explosive and package delivery. The study stated that the adoption of drones in the mining industry can ease automation by providing visual and various types of sensing data. Considering their excellent manoeuvrability, low-costs, and maintenance, drones can make huge benefits to mine by surveying large areas in a short period of time compared to traditional methods that used the human workforce. The study also found that drones can provide required data where there are health and safety hazards like in slopes or unstable cavities, hence making mines safer workplaces. Table 1 (Shahmoradi et al., 2020) shows the application of drones in surface, underground and abandoned mine.

Gokool et al. (2023) conducted a scoping review and bibliometric analysis to evaluate the state-of-the-art regarding actual applications of UAV technologies to guide precision agriculture practices within smallholder farms. The study revealed that UAVs have emerged as one of the most promising tools to monitor crops and guide precision agriculture practices to improve agricultural

Table 1: Applications of Drones in Mining

Surface Mine	Underground Mine	Abandoned Mine
Mine operation	Geotechnical characterization	Subsidence monitoring
3D mapping	Rock size distribution	Recultivation
Slope stability	Gas detection	Landscape mapping
Mine safety	Mine rescue mission	Gas storage detection
Construction monitoring		Acid drainage monitoring
Facility management		

productivity and promote a sustainable and optimal use of critical resources. The results of the investigations revealed that UAVs have largely been used for monitoring crop growth and development (Figure 3) (Gayathri Devi et al., 2020), guiding fertilizer management, and crop mapping; but also have the potential of facilitating other precision agriculture practices. The study concluded that precision agricultural applications that are facilitated through the use of UAVs have the potential to transform the fortunes of smallholder farmers, as the adoption of these technologies to guide decision-making can enhance agricultural productivity whilst promoting optimal and sustainable utilization of critical resources. This, in turn, promotes improved food security and socio-economic well-being, and equips farmers and communities to adapt and build resilience to the impacts of climate change. The study recommended future applications of UAVs and associated technologies to inform policy, planning, and operational decision-making.

Gayathri Devi et al. (2020) reviewed the implementation of UAVs for crop monitoring (Photo 2) and pesticide spraying. The results showed that agricultural drones are one of the important innovations for increasing productivity of crops in Indian agriculture. They stated that the monitoring of crops and the need for spraying pesticides and fertilizers at the correct moment, and at the exact location of plants, is an important parameter to increase the productivity of crops for sustainable livelihoods. The study revealed that the application of drones in agricultural sectors will reduce the time and the hazardous effects that can arise due to the spraying of pesticides and fertilizers in micro-watersheds. The study concluded that the overall performance of UAVs will increase by using quadcopter, which will spray pesticides and monitor crops. This method will reduce the amount of pesticides and fertilizer used in agricultural fields, and also increase crop yield.

Choi et al. (2023) presented a comprehensive overview of the applications of drones in the construction industry, focusing on their utilization in the design, construction, and maintenance phases. The utilization of drones in the construction industry represents a transformative leap towards achieving higher levels of efficiency, safety, and sustainability. By harnessing their data acquisition, monitoring, and inspection capabilities, construction professionals can make informed decisions, improve project outcomes, and optimize resource utilization.

Photo 2: Crop Spraying Using UAV
Source: Gayathri Devi et al. (2020)

As the drone technology continues to evolve, it is expected to play an increasingly pivotal role in reshaping the construction industry, fostering innovation, and driving the adoption of smart and resilient construction practices. In addition, the utilization of drones in surveying and mapping offers significant benefits, including efficient data collection, high accuracy, comprehensive visual information, and enhanced decision-making capabilities. The combination of surveying and mapping with drones provides valuable insights for design, engineering, and asset management processes; ultimately improving the efficiency and quality of construction projects within watersheds. The study showed that drones are used during the construction phase for earthwork and grading monitoring, quality control and progress monitoring, safety monitoring, material tracking and delivery. They were also useful at the maintenance phase in improving safety, enhancing efficiency, reducing costs and providing real-time data on the condition of structures; hence enabling maintenance teams to make informed decisions and adjust maintenance schedules accordingly. In conclusion, drones enabled construction professionals to gather precise data, generate accurate 3D models, and assess topography. This, in turn, facilitated informed decision-making and enhanced the overall design process.

Tan et al (2021) studied public acceptance of drone applications in a highly urbanized environment. The study revealed that new and emerging applications of drone technologies were ubiquitous: be it for routine building inspection, constant security surveillance, or last mile commercial delivery, drone technologies were found as cost-effective solutions. The study further revealed that with the rapid advancement in drone technologies, there was a growing interest among business leaders, policymakers, regulators, and the general public to apply the technology in a myriad of areas such as aerial photography, infrastructure inspection, search and rescue, commercial delivery, and surveillance for law enforcement. The study showed that drone applications with higher levels of support include such spheres as search and rescue, disaster management, and monitoring or preserving environments. Drone applications with the lowest levels of support were transporting people and photography. The authors further advanced that, without doubt, this technology will increasingly find its way into more areas of application for state, industrial, commercial, and recreational purposes in the foreseeable future. The study concluded that the public is ready for extensive drone use, although more work must be done to educate it on its potential benefits; and at the same time allay their fears and concerns especially regarding drone applications in residential areas.

On their part, Stanton et al. (2021) studied the application of drones for mosquito larval habitat identification in rural environments. The paper explored the use of drones as a method for collecting very high resolution (< 10 cm) and contemporary imagery of an area for the purposes of identifying larval habitat (Figure 2). An imagery covering an area of 8.9km^2 across eight sites was captured. Larval habitat characteristics were successfully identified using GeoOBIA on images captured by a standard camera (median accuracy = 98%), with no notable improvement being observed after incorporating data from a near-infrared sensor. Larval samples captured from 326 sites confirmed that drone-captured characteristics, including aquatic vegetation presence and type, were significantly associated with larval presence. In conclusion, the study stated that drone mapping is being touted as at least equivalent (if not superior) to, and more cost-effective than, mapping larval habitat manually or using remotely sensed satellite imagery. The study demonstrates the potential for drone imagery to be used as a tool to support the identification of mosquito larval habitat in rural areas where malaria is endemic.

Ahirwar et al. (2019) assessed the application of drone in agriculture, stating that the use of advanced technologies such as drone in agriculture offer potential solutions for several major or minor challenges facing agriculture. The study focused on the major applications of drone in the agricultural fields of irrigation, crop monitoring, soil and field analysis, and bird control. The study also identified and discussed the main applications of drones, including military, delivery services, security and law enforcement, search and rescue, film and television industries, wildlife monitoring, disaster management, soil and field analysis, crop spraying, crop monitoring, irrigation and health assessment.

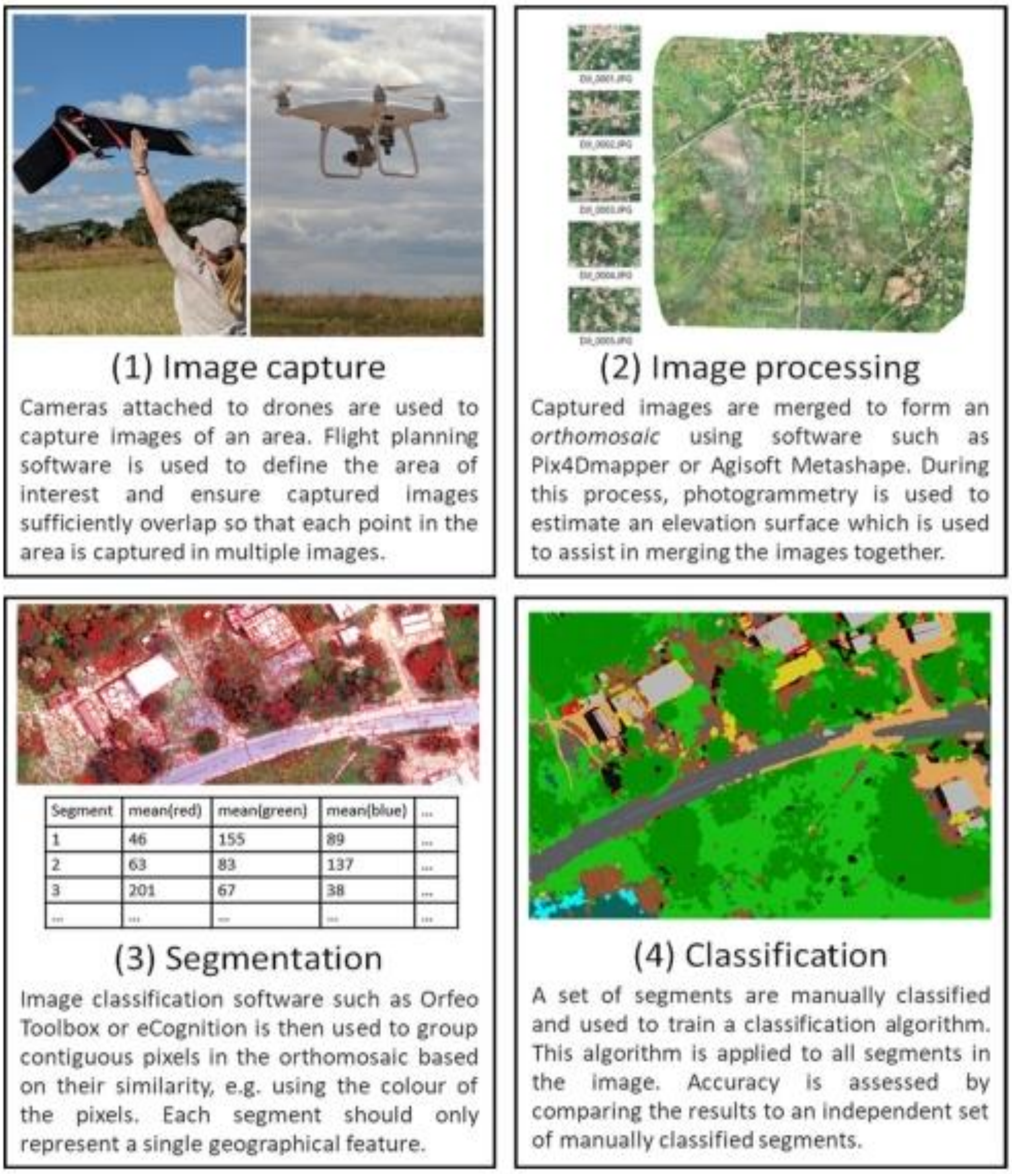

Figure 2: Process Undertaken to Identify Larval Habitat From Drone Imagery
Source: Stanton et al. (2021)

The study concluded that agricultural drone is an amazing advance technology, which is becoming a tool like any agricultural equipment as it gives specific data to a farmer. By using this data, a farmer can increase yields and reduce crop and environmental damages. The study added that farming is an input-output problem. Therefore, the application of drones can help a farmer reduce inputs—e.g., water and pesticides—and maintain the same output. Agricultural drones change farmer's ability to monitor and manage key aspects of farm business that are impossible to sustain in remote places.

Daud et al. (2022) assessed the application of drones in disaster management. The article aimed to evaluate current drone feasibility projects and to discuss a number of challenges related to the deployment of drones in mass disasters in the hopes of empowering and inspiring possible future work. The study results showed that potential application of drones in disasters are broad and are classified into four categories: (i) mapping or disaster management, which shows the highest contribution; (ii) search and rescue; (iii) transportation; and (iv) training. In this context, it became more evident that drone applications need to be further explored to focus more on the assistance of drones, especially in victim identification. The study envisaged that, with sufficient developments, the application of drones appears to be promising and will improve effectiveness, especially in disaster management.

Burgues and Marco (2022) studied environmental chemical sensing using small drones. They found that the application of small drones can be divided into the spheres of atmospheric chemistry research, industrial emission monitoring, law enforcement, safety and security, and precision agriculture. The study explained that instrumented drones can provide experimental measurements of many atmospheric constituents (e.g., CH_4, CO_2, NO_x and O_3), and thermodynamic variables (temperature, humidity, pressure, wind, etc.) in the lower troposphere. The use of drones to acquire such measurements costs less than employing manned aircraft, blimps or balloons; and can be applied over a wider spatial region than fixed monitoring stations or towers; and also at higher spatial resolution than satellite-based measurements. Further, characterizing and monitoring the environmental impact of an industrial plant is key for preventing and reducing industrial pollution, and minimizing negative impacts to the surrounding population. In addition, drones can provide measurements with much better spatial resolution than fixed detectors, and with less risk than walkover surveys. Drones are also a useful measurement platform for environmental agencies and police departments to ensure compliance with air emission regulations. Thanks to their rapid deployment, drones are promising tools for safety and security applications, such as early fire detection, or search and rescue. Drones equipped with chemical sensors can overcome some of the limitations of camera-based drones currently used by fire departments to detect uncontrolled fires. The study added that drones equipped with environmental sensors have been proposed as an option to automate certain agricultural tasks, such as monitoring climate variables in greenhouses, or assessing fruit maturity.

Whitehurst et al. (2021) studied drone-based community assessment, planning, and disaster risk management for sustainable development. The study stated that enterprise-scale geographic information system (GIS) software and high-resolution aerial or satellite imagery are tools which are typically not available, or affordable, to resource-limited communities. The paper presents a concept of aerial data collection, 3D cadastre modelling, and disaster risk assessment using low-cost drones and adapted open-source software. Computer vision/ machine learning methods were used to create a classified 3D cadastre that contextualizes and quantifies potential natural disaster risks to existing or planned infrastructure. Building type and integrity were determined from aerial imagery. Potential flood damage risk to a building was evaluated as a function of three mechanisms: undermining (erosion) of the foundation, hydraulic pressure damage, and building collapse due to water load. The use of soil and water assessment tool (SWAT) provided water runoff estimates that were improved using classified land features (urban ecology and erosion marks) to improve flow direction estimates. The study used a convolutional neural network (CNN), which was trained to find flood-induced erosion marks from the high-resolution drone imagery. A flood damage potential metric scaled by property value estimates resulted in individual and community property risk assessments. The study concluded that a combination of a comprehensive flood model and building type analysis, using drone imagery, produces great risk modelling potential, particularly for data-scarce communities.

Further, the nations where the researches (reviewed publications) were done were categorized into developed and developing nations (Table 2) to allow a deductive content analysis. Results show that a majority (80%) of the researches were done in developed nations, while minority (20%) are linked to developing nations (Figure 3).

Table 2: Author, Research Title and Nation Type

Author	Research Title	Nation Type
Shalmoradi et al. (2020)	A comprehensive review of applications of drone technology in the mining industry	Developed
Gakool et al. (2023)	Crop monitoring in smallholder farms using unmanned aerial vehicles to facilitate precision agriculture practices: A scoping review and bibliometric analysis.	Developed

Gayathri Devi et al. (2020)	Review on application of drones for crop health monitoring and spraying pesticides and fertilizer.	Developing
Choi et al. (2023)	An Overview of Drone Applications in the Construction Industry	Developed
Tan et al. (2021)	Public acceptance of drone applications in a highly urbanized environment.	Developed
Stanton et al. (2021)	Larval habitat identification in rural environments: a practical approach for malaria control?	Developing
Ahirwa et al. (2019)	Application of Drone in Agriculture	Developed
Daud et al. (2022)	Applications of drone in disaster management: A scoping review	Developed
Burgués & Macos (2022)	Environmental chemical sensing using small drones: A review.	Developed
Whitehurst et al. (2021)	Drone-Based Community Assessment, Planning, and Disaster Risk Management for Sustainable Development	Developed

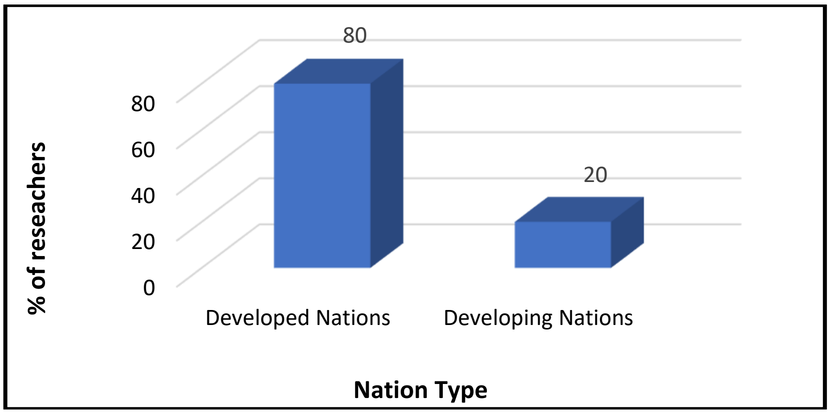

Figure 3: Comparison of Research Among the Developed and Developing Nations
Source: Author, 2023

4. Discussion

This study has established that drone technology can be used to accurately evaluate micro-watershed in areas that include—but are not limited to—mines, farms, construction sites, urbanized environments, mosquito larval habitats, game reserves, disaster management, wildlife monitoring, environmental chemical sensing, and community assessment and planning. The application of drone technology at both macro and micro-watershed scales has demonstrated the collection of accurate and precise data, thereon providing timely and valuable information to users and planners to act swiftly when situations arise. This may make planning and management a success at micro-watershed level in developing nations. From the review, it is evident that drone application at micro-watershed scale can offer the following benefits:

(a) Providing real time assessment;
(b) Easing automation by providing visual and various types of data (comprehensive visual information);
(c) Enhancing agricultural productivity;
(d) Enhancing decision-making capabilities, or guide decision-making
(e) Promoting optimal and sustainable utilization of resources;
(f) Promote improved food security and socio-economic wellbeing;
(g) Being cost effective;
(h) Fostering innovation;
(i) Promoting efficient data collection;
(j) Providing accurate data (high accuracy);
(k) Providing real time data;
(l) Reducing crop and environmental damages;
(m) Ensuring controlled utilization of agricultural inputs (reduce inputs like water and pesticides); and
(n) Providing large amount of data.

This list may not be exhaustive since drones can offer more benefits; and this is why developed nations have been seriously engaged in research activities to explore more on the benefits of the drone technology. The higher percentage of involvement in research may also explain why the application of drone technology in micro-watershed evaluation is more advanced in developed nations than in developing nations. On the other hand, the insubstantial involvement in research by developing nations on drones explains the struggle to adopt the technology. This requires urgent paradigm shift to adopt the technology.

The primary objective for conducting this study was to explore the feasibility of the drone technology being used as part of micro-watershed management toolkit in developing countries. Therefore, the following qualities of drone technology in watershed evaluation can inform policy for its adoption in developing countries.

4.1 Unlimited Coverage

The study results have shown that drones cover a wider area within a shorter period of time, and can cover areas which are inaccessible by humans. Watersheds are unique; and some face challenges of insecurity like some parts of the Rift Valley and North Eastern regions in Kenya, where it is insecure to carry out manual data capture. It is in such regions that drones can provide immediate solutions in studying them. Apart from the volatile nature of some micro-watersheds, disaster-prone areas like the Kano plains in Kenya that is affected by annual floodings; and Ol Doinyo Lengai (volcanic eruptions) in

Tanzania: these also require drones for safe, timely and accurate information gathering for use to mitigate hazards. These findings corroborate those of Vélez-Nicolás et al. (2021): that UAVs have revolutionized the field of hydrology, bridging the gap between traditional satellite observations and ground-based measurements; and allowing the limitations of manned aircraft to be overcome. They also corroborate the study by Ayamga et al. (2021): that drones are typically used to obtain real-time imagery and sensor data from farm fields that cannot be quickly or easily accessed on foot or by a vehicle.

Moreover the wider coverage by drones results in the collection of large volumes of data even in hazardous locations and larger water bodies like Lake Victoria in East Africa. This finding is similar to that of Vélez-Nicolás et al. (2021): that with unparalleled spatial and temporal resolutions and product-tailoring possibilities, UAVs are contributing to the acquisition of large volumes of data on water bodies and submerged parameters; and their interactions in different hydrological contexts that were inaccessible in previous eras.

4.2 High Accuracy and Speed

Drones ease automation by providing visual and various types of sensing data. The study has shown that drones have high accuracy levels of data capture because they are equipped with sophisticated sensors, cameras, and GPS technology. In addition, drones offer unparalleled capabilities to capture real-time data, generate accurate 3D models, and conduct remote inspections. This finding corroborate those of Munde and Kolhe (2019): that drone survey resulted in an accurate estimation of an irrigated area (500,000ha); and further accurate identification of crops for crop-wise area and preparation of statement of water charges. The finding is also corroborated by Friedman (2021), whose drone imagery has a very high spatial resolution (3.5cm), enabling it to provide a lot of details, including marks that show an increase of flooding in certain areas, together with an elevation information.

4.3 Endurance and Controllable Range

Total time taken during the flight or capacity of the battery and the amount of current the motor produces to keep a drone in the air during a flight is very important. Securing a hybrid-electric UAV, which provides high flight endurance capability together with low visual, heat or acoustic signatures, is key for proper drone application in data capture. Such drones lengthens the period of flight operation; hence providing wider coverage. Conversely, securing small UAVs limits flight endurance even though they have the advantages of low visual, heat and acoustic signatures. There is room for deciding on the type of drones to secure as study results have shown the availability of different types of drones for different environments or geographical locations; and drones equipped with different sensors, cameras, and GPS.

The range (how far a drone can travel) is dependent on the amount of electric current the aircraft is producing, endurance, flight speed and aerodynamic performance. These are factors of concern for drone security because at times drones may be attacked. Fortunately, these elements should be checked by the buyer during purchase to ensure the best UAV is secured. Some of the elements can be set by the user to avoid insecurity threats.

4.4 Replicability and Availability

Based on the study results, drones generate accurate large amounts of data, and produce comprehensive visual information. In addition, they enhance efficient data collection. This may be due their replicability and availability. This replicability is advantageous because it promotes the verification of drone images for accuracy purposes. Also, the application of drone technology in micro-watershed evaluation has transparency benefits as drone images are preserved and can be verified during processing. These findings corroborate those of Friedman (2021) who, in exploring the use of aerial imagery taken by a drone to make-up for the lack of historical data at the Dzaleka Refugee Camp located in Dowa, Malawi, found that drones can very easily collect high-resolution images that can then be processed to create a digital terrain model (DTM) and orthomosaic, both of which are useful inputs for hydrological-hydraulic models and the geological-geomorphological flood model presented in the study.

5. Conclusions

Drones, or UAVs, provide a quick and reliable mode of micro-watershed data collection. They are cost effective and give real time information. Thus, they can assess watershed activities in real time for planning and effective management. In this regard, drones are applied in gathering information on agricultural and health activities, industrialization, urbanization, natural occurrences and hazardous events, among others. In addition, the application of drone technology can improve watershed management and promote effective decision-making on the exploitation, restoration and conservation of natural resources. Data collected by drones can also be used by relevant authorities in improving decision-making at micro-watershed levels through information dissemination and watershed user support.

However, even though the application of drones is taking a centre stage worldwide, its application in developing countries is still limited due to government restrictions and procurement logistics. Therefore, there is a need for studies on government policies on the application of drones in developing countries. Studies should also be carried on drone information modelling (DIM), and the use of drone information at micro-watershed level for sustainable development.

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