Viability of unmanned aerial vehicles in identifying potential breeding sites for mosquito: A scoping review

Zulfadli Mahfodz, MSc[1,2], Nazri Che Dom, PhD[1], Samsuri Abdullah, PhD[3], Nopadol Precha, PhD[4]

[1]Faculty of Health Sciences, Universiti Teknologi MARA, Selangor Branch, Puncak Alam Campus, 42300 Selangor, Malaysia, [2]Faculty of Applied Sciences, Universiti Teknologi MARA, Perak Branch, Tapah Campus, Tapah Road, 35400 Perak, Malaysia, [3]Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, Malaysia, [4]School of Public Health, Walailak University, Nakhon Si Thammarat, Thailand

ABSTRACT

Introduction: Surveillance of mosquito breeding sites is essential because it provides the information needed to assess risks and thus respond to dengue outbreaks. This article aims to review existing research on the viability of using unmanned aerial vehicles (drones) to identify potential breeding sites for *Aedes* mosquitoes and highlight the issues related to their implementation.

Materials and Methods: The authors conducted a literature search in four databases (Scopus, Web of Science, Science Direct, and IEEE Xplore) and completed it in December 2022. Articles that do not directly address the application of drones for surveillance and control of mosquito breeding sites were excluded.

Results: The initial search using the keywords yielded 623 documents. After screening abstracts and reviewing the full text, only 17 articles met the inclusion criteria. Most of the studies were in the proof-of-concept stage. Many studies have also incorporated drone technologies and machine learning techniques into surveillance efforts. The authors have highlighted seven key issues related to the operational aspects of using drones. Those are hardware, software, law and regulation, operating time, expertise, geography, and community involvement.

Conclusion: With rapid developments in drone technologies and machine learning techniques, the viability of drones as surveillance tools can be enhanced, thus effectively responding to global public health concerns.

KEYWORDS:
Mosquito, breeding site, unmanned aerial vehicle, vector control, machine learning

INTRODUCTION

The dengue virus infects humans via a female mosquito bite. Dengue fever is now deemed endemic in over 100 countries, with Asia bearing more than two-thirds of the burden.[1] The principal vector of dengue, yellow fever, and chikungunya is *Aedes aegypti*.[2] The spread of *Ae. aegypti* is a severe public health issue. This relationship is further increased by the mosquito's ability to disperse and adapt to new surroundings and poor sanitation.[3] Targeted environmental and ecosystem management remains critical in controlling dengue due to the lack of effective vaccines or antiviral treatment.[1] Dengue can thrive in either artificial containers or naturally occurring environments.[4] Stagnant and unpolluted water is ideal for the reproduction of *Aedes* mosquitoes.[5] They have adapted to human environments and can now be seen breeding in various small containers.[1]

The prevention of mosquito-borne diseases will continue to pose a difficulty in the forthcoming years because of rapid urbanization and globalization, coupled with the dynamic change of mosquito populations.[6] Various strategies available to control mosquitoes can be tailored to suit individual, community, and regional environments. By mitigating mosquito proliferation can lessen the future effects of diseases transmitted by mosquitoes.[7] Such efforts could result in costly, time-consuming, ineffective monitoring and control without efficient mosquito management strategy.[2,8] Field technicians have encountered a new occupational risk when performing dengue surveillance and control due to the COVID-19 pandemic.[9] Health inspectors must visit residences to find and eliminate potential mosquito breeding sites. This technique presents a considerable challenge for officials and has various drawbacks, including time limits, safety concerns, and cost.[2,5]

Drones are rotary or fixed-wing aircraft operated remotely. When equipped with suitable sensors, drones have been used in a wide range of public health studies, agriculture, forestry and ecological monitoring.[2,10] Drones are viable alternatives to manual assessment because they can be maneuvered to overcome obstacles that impede human access. It can be used as a suitable remote photographing, mapping, and data collection platform.[3] Drones can capture images or recordings with a higher spatial or temporal resolution from various angles and altitudes.[11] Using a programmable drone enhances the auditors' safety by reducing their exposure to potentially hazardous situations or locations.[12-14]

This study aims to review existing research on the viability of using drones to identify potential breeding sites for *Aedes* mosquitoes. The advancement of drone technology and its integration with machine learning have made drones promising tools to complement the current methods of dengue prevention strategies. This review highlighted the recent research's issues, challenges, and limitations in using drones as a guideline for future studies before field implementation.

This article was accepted: 30 January 2024
Corresponding Author: Zulfadli Mahfodz
Email: zulfa2015@uitm.edu.my

MATERIALS AND METHODS

This research adhered to a framework by Arksey et al.[15] to conduct a scoping review, which provides a comprehensive perspective of a complex topic by mapping the available data from different sources.[16] The five stages of this approach include identifying the research question, identifying relevant studies, selecting studies, charting the data, and collating, summarizing, and reporting the results.[15] This review also follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations (Figure 3).

Data Sources and Search Criteria

A literature search was completed in December 2022 using the four online databases: Scopus, Web of Science, Science Direct, and IEEE Xplore. There were no time constraints imposed on the literature search strategy. To maximize the scope of the initial literature search, a two-block search strategy was used and modified from Hiebert et al.[17] Block one contained drone-related nomenclature, whereas block two contained mosquito-related nomenclature (Table I).

The search was constructed in three steps: (1) the Boolean operator "OR" was used to connect all terms in block 1; (2) the Boolean operator "OR" was used to connect all terms in block (2); and (3) the Boolean operator "AND" was used to connect all terms in block 1 with all terms in block 2 to ensure all documents retrieved included both drone- and mosquito-related nomenclatures (Figure 1).[17] The same search string was used for all online databases selected (Figure 2).

Study Identification and Selection

Following the article search strategy (Figure 2), the significance and relevance of the selected literature were evaluated based on its subject matter and publication format. During title and abstract screening (Figure 3), documents were maintained for full-text review if they fulfilled the following inclusion criteria:

i. The title or abstract emphasizes the application of drones for surveillance and control of mosquitoes breeding sites;
ii. The studies conducted for any species of mosquito regardless of any stage of the life cycle; and
iii. The document must be a full research paper and written in English.

At this stage, documents were omitted from analysis if any of the subsequent conditions were met:

i. The document was not related to the application of drones for surveillance of mosquitoes breeding sites;
ii. The document was a review article, operational note, newsletter, book chapter, commentary, editorial note, unpublished manuscript, or conference abstract;
iii. The document was authored in a language other than English; and
iv. The document was duplicate or non-availability of the full text articles.

Following the identification of articles in the aforementioned databases, the articles were imported into the EndNote Version 20.4.1 (Clarivate, Philadelphia, Pennsylvania, United States), where any duplicates were deleted. Only those documents that appeared to be relevant to the topic at hand and fulfilled inclusion criteria, were kept for a more in-depth read. The full texts of articles were then retrieved to identify which were eligible for inclusion in the review as shown in the PRISMA flowchart (Figure 3).

A data extraction form (Table II) was used to extract study details such as the paper ID, the author(s), the year of publication, the study objectives, the study sites, the mosquito species, and disease studied (if specified), the methodological approaches and the application of drone.

RESULTS

The initial search using the keywords yielded 623 documents from four databases: Scopus (N=192), Web of Science (N=119), Science Direct (N=273), and IEEE Xplore (N=39). A total of 342 articles were excluded due to title, abstract, and duplicate removal screening. The remaining 51 articles were assessed for eligibility on an individual basis. Finally, only 17 full-text articles met the inclusion criteria. The comprehensive review process for the study collection is depicted in Figure 3.

General Characteristics of the Articles Included in the Review

Table III summarizes the articles included in the scoping review. The included publications were published between 2016 and 2022. There were two studies in 2016, three in 2017, one each in 2018 and 2019, two in 2020, five in 2021, and three in 2022, with 71% published within the last five years. Most of the articles reviewed were from Brazil. Sri Lanka was second with three articles, followed by Tanzania and Malawi with two articles each. United States, Ecuador, India, Mexico, and Peru each contributed one article. Dengue fever treatment has a significant economic impact in several countries, particularly Brazil. A study conducted in 17 Latin and Central American countries estimated that the annual cost of dengue outbreaks in these countries is more than US $3 billion, with Brazil alone accounting for US $1.4 billion annually.[18] There has also been considerable international collaboration; some authors studied regions outside their own. As mosquito populations continue to expand, greater international collaboration is expected.[7]

The objectives of the selected studies can be summarized under four main headings. First, nine documents (50%) focused on identifying and mapping potential mosquito breeding sites using high-resolution drone imagery. Seven documents (38.9%) addressed computer-based approaches, including machine learning and remote sensing, to map mosquito breeding sites using aerial drone imagery. One paper (5.6%) examined the effectiveness of the two technologies for surveying a study area which are drones and global positioning system-based receivers. One document (5.6%) examined the relationship between socioeconomic status and mosquito breeding sites.

Dengue fever is endemic in many of the regions studied. The most studied species is *Aedes* mosquitoes (*Ae. aegypti* and *Ae. albopictus*). *Aedes sp.* accounted for 64.7% of the mosquito species analyzed; *Anopheles sp.* accounted for 29.4%, and one study did not report any of the mosquito species involved (5.9%). Dengue was the most frequently discussed disease (41.7%), followed by Zika (25%), malaria (20.8%), and chikungunya (12.5%). A single mosquito species can serve as

Table I: Terms used in the initial document search

Block 1: Drone-related Nomenclature	Block 2: Mosquito-related Nomenclature
Unmanned aerial vehicle	Mosquito
Unmanned aircraft system	Vector control
Drone	Breeding site

a vector for multiple mosquito-borne diseases; therefore, some studies addressed multiple diseases. In general, most of the studies were conducted in urban areas or a combination of suburban and rural areas. 52% of the study focused on urban areas, 33% on most suburban areas and 14% on rural areas.

Integrating machine learning techniques into surveillance activities has gained interest in many studies. 70.6% of the selected articles used machine learning in their research. Another 29.4% analyzed high-resolution imagery from drone technology. Most of the study was conducted using a DJI drone from Shenzhen, China. The DJI Phantom 4 was the most widely used, accounting for 47.1%, followed by the DJI Phantom 3 (23.5%), and only one study used the DJI Phantom 2 (5.9%). Another type of drone from the French company Parrot AR was also used in one study (5.9%). In the remaining three studies (17.6 %), the type of drone used was not specified. All studies conducted (100%) were at the same implementation level, which is proof of concept and descriptive study design. However, the application of drones in the study was either for surveillance purposes (82.4%) or larval control (17.6%).

DISCUSSION

The Application of Drone Technology as Surveillance Tools

The applications of drones are essentially governed by variables such as size, power, and operating conditions, which vary widely depending on the type of drone.[19] The application of drone technology has already led to numerous remarkable results. The images of water bodies are examined to identify potential mosquito breeding sites.[14] Drone surveying approaches for artificial containers are becoming more accurate by combining global positioning system receivers with machine learning techniques and imaging technologies such as multispectral imaging.[24] In other research they merged internet of medical things and geographic information systems.[25] They contain and manage dengue virus outbreaks by analyzing call records. Hardy et al.[26] analyze drone data using a mix of mapping methods: supervised image classification with machine learning and technology-enabled digitizing mapping accessible to those without a technical background.

Machine learning can detect patterns in data at or above human levels, which is useful for classification, prediction, and clustering.[7] Artificial intelligence can accurately estimate the number of larvae and pupae in a sample by automating repetitive learning processes.[12] Many studies used orthomosaic maps that are constructed by stitching together 2D aerial photographs with at least 70% picture overlap as reference points.[20] Drones were used to collect many aerial photo configurations for a database.[21] The proposed system was tested and trained using the collected photos and the annotated database. This technology allows the detection of tiny objects that existing remote sensing methods cannot detect.[22] In an example of architectural innovation that combining and applying two established technologies to a new market and context.[23] Results showed that drone deployment and insecticides could reduce mosquito populations in an irrigated rice agroecosystem. Improving the precision of the technology requires extensive engagement and data from many images representing a wide range of situations.

The Issues, Challenges, and Limitations of Using Drone

This review has highlighted and grouped the operational issues of using drones under seven themes, including hardware, software, law and regulation, operating time, expertise, geography, and community involvement (Table III). The ability of drones to fly in inaccessible areas is their most important advantage. Drones are available in different sizes and configurations; therefore, specific criteria must be taken into consideration to determine which model is best suited for searching breeding habitats.[3]

The most highlighted issue by many authors is software (22%) (Figure 4), which includes drone control software, formatting, data processing, and image classification. The study by Prasad et al.[27] highlighted the failure of SVM-based approaches and optical flow, after which a combined method called horizon mask, was developed to address this issue. Identifying waters in the resulting orthomosaic can be challenging, especially when waters with significant suspended sediment are the same color as bare ground.[13] There needs to be more techniques for rapid data processing and solutions for accelerated image processing.[14] Obtaining unbiased, ethical, comprehensive, and global datasets is challenging but needed for practical machine learning applications in mosquito control.[7,28] Creating orthomosaics from drone imagery is a time-consuming process that requires a powerful computer, a large data storage capacity, and specific software.[10]

Regarding hardware (20%), some aspects such as specification, flight duration, maximum altitude, signal strength, spare parts supply, data management, and cost efficiency are among the highlighted issues. A drone can only stay in the air for up to 20 minutes before its battery runs out.[4] Therefore, numerous flights over the area are required to create a single map; this may result in some temporal variation between scenes on the single map and affect the spectral signature, although this effect is likely minimal.[14] Drone signals are lost when there is a large body of water or telecommunications towers between the drone pilot and the drone, as these areas absorb drone signals.[4] Although purchasing commercially available drones in the country is possible, obtaining replacement parts or repairs becomes difficult and expensive when technical problems occur.[10]

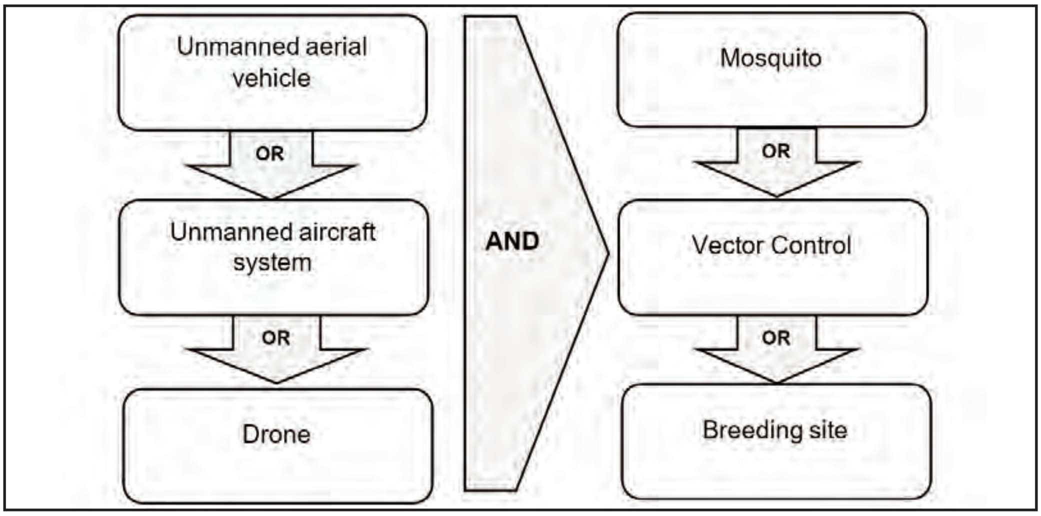

Fig. 1: Boolean operators used to connect the term search

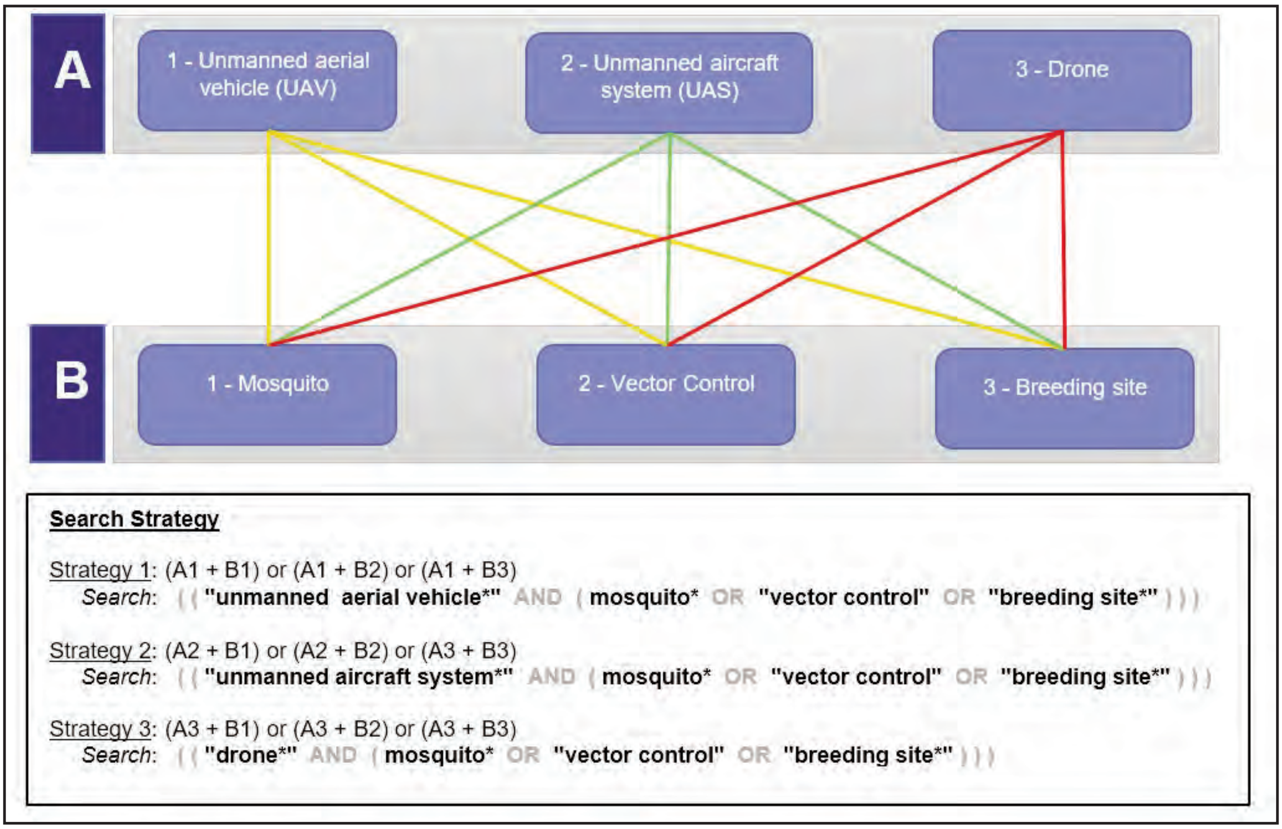

Fig. 2: Article search strategy. A: Block one contained drone-related nomenclatures. B: Block two contained mosquito-related nomenclatures

Expertise issues (20%) include incompetence, training hours for drone pilots, and insufficient previous research data. The aerial inspection is manually controlled, which depends on the drone pilot's ability to fly the drone.[4] Drone flight requires a certain level of skill.[14] In searching for water bodies in a rural setting, drone image capture inevitably presents technical and skill-based challenges.[10,29] The lack of comprehensive research on this topic in the past and the small sample size in the training phase of deep learning presented a significant challenge for researchers.[5,30]

Regarding geographic limitations (12%), drones cannot be used in very difficult-to-access locations, such as areas with high plant density or tree canopies. Due to the dynamic nature of water bodies, conducting large-scale surveys from the ground has not been possible.[13] Other obstacles such as power lines and telecommunication towers, auto-fly mode cannot be used in urban areas.[4] This limits the application of the drone. The operating time (10%) for the drone's flight was another factor that need to be considered. Since drone could not be flown in wet or windy conditions, the flight experience

Table II: Summary finding of eligible articles

ID	Author (Year)	Main Objective	Methodology					Application of drone	
			Study Site	Species of Mosquito Studied	Disease concerned	Study Design / Area	Integrate Machine Learning Techniques (YES/NO)	Type of Drone	Type of Activity
1	Mehra et al., (2016) [5]	To identify the presence of stagnant water bodies in images taken from UAVs	Brazil	Aedes	Zika	Descriptive / Urban	YES	Not specified	Surveillance
2	Prasad et al., (2016) [27]	To inspect and identify stagnant water patches in hard-to-access areas using a quadcopter	India	Not specified	Dengue	Descriptive / Urban	YES	Parrot's AR drone	Surveillance
3	Amarasinghe et al., (2017) [4]	To capture the images of the water retention areas via a drone	Sri Lanka	Aedes	Dengue	Descriptive / Urban & Suburban	YES	DJI Phantom 4	Surveillance
4	Suduwella et al., (2017) [31]	To identify the possible water retention inaccessible areas via drone images	Sri Lanka	Aedes	Dengue & Zika	Descriptive / Urban	NO	DJI Phantom 4	Surveillance
5	Hardy et al., (2017) [13]	To map water bodies as targets for larval source management by using low-cost drones	Tanzania	Anopheles	Malaria	Descriptive / Suburban	NO	DJI Phantom 3	Control (Larva)
6	Dias et al., (2018) [21]	To determine mosquito-breeding habitats' location by employing computer vision tools on aerial images using UAVs	Brazil	Aedes	Dengue, Chikungunya, Zika	Descriptive / Suburban	YES	DJI Phantom 2	Surveillance
7	Carrasco-Escobar et al., (2019) [14]	To identify mosquito breeding sites with high-resolution imagery from drone	Peru	Anopheles	Malaria	Descriptive / Suburban	YES	DJI Phantom 4	Control (Larva)
8	Schenkel et al., (2020) [24]	To investigate the effectiveness between the two technologies of interest in surveying a study area: drones and global position system-based receivers	USA	Aedes	Zika	Descriptive / Urban	NO	DJI Phantom 3	Surveillance
9	Amarasinghe et al., (2020) [34]	To identify possible mosquito breeding grounds using drone images and propose two algorithms to identify small-scale standing water bodies.	Sri Lanka	Aedes	Dengue, Zika, Chikungunya	Descriptive / Urban	YES	DJI Phantom 4	Surveillance
10	Bravo et al., (2021) [22]	To propose computational approaches for the automatic identification of mosquito breeding sites by using aerial images from drones	Brazil	Aedes	Dengue	Descriptive/ Urban & Suburban	YES	DJI Phantom 3	Surveillance
11	Stanton et al., (2021) [10]	To identify larval habitat by using high-resolution images from drone	Malawi	Anopheles	Malaria	Descriptive / Suburban	YES	DJI Phantom 4	Control (Larva)
12	Valdez-Delgado et al., (2021) [9]	To evaluate the effectiveness of low-cost drone images in identifying mosquito breeding sites	Mexico	Aedes	Dengue	Descriptive / Urban	NO	DJI Phantom 4	Surveillance
13	Cunha et al., (2021) [30]	To detect possible mosquito breeding sites using remote sensing and deep learning; to investigate the area's socioeconomic level	Brazil	Aedes	Dengue, Zika, Chikungunya	Descriptive / Urban & Suburban	YES	DJI Phantom 3	Surveillance

cont..... pg 153

cont from..... pg 152

Table II: Summary finding of eligible articles

ID	Author (Year)	Main Objective	Methodology					Application of drone	
			Study Site	Species of Mosquito Studied	Disease concerned	Study Design / Area	Integrate Machine Learning Techniques (YES/NO)	Type of Drone	Type of Activity
14	Lee et al., (2021) [32]	To explore the use of UAV mapping as a tool to identify spatial risk factors for symptomatic dengue	Ecuador	Aedes	Dengue	Descriptive / Urban & Rural	NO	Not specified	Surveillance
15	Passos et al., (2022) [2]	To have a comprehensive dataset of aerial videos, from a drone, containing possible mosquito breeding sites.	Brazil	Aedes	Dengue	Descriptive / Urban	YES	DJI Phantom 4	Surveillance
16	Hardy et al., (2022) [26]	To compare the results of two mapping approaches, supervised image classification using machine learning and Technology-Assisted Digitising (TAD) mapping	Tanzania	Anopheles	Malaria	Descriptive / Rural	YES	DJI Phantom 4	Control (Larva)
17	Stanton et al., (2022) [35]	To detect larval habitats using high-resolution images by drones	Malawi	Anopheles	Malaria	Descriptive / Rural	YES	Not specified	Surveillance

Table III: General characteristics of articles included in the scoping review

Characteristic	Number of articles, n (%)
Publication Year	
• < 2018	5 (29.4)
• 2018 – 2022	12 (70.5)
Study Objective (can be more than 1 objective per article)	
• Identify and map the potential breeding sites of mosquitoes using a drone	9 (50)
• Study computational approaches including machine learning and remote sensing for the automatic identification of objects and mapping mosquito breeding sites by using aerial images from drones	7 (38.9)
• Investigate the effectiveness of drones and global positioning systems (GPS) in identifying potential mosquito breeding sites.	1 (5.6)
• Investigate the area's socioeconomic level associated with identified breeding sites of mosquitoes.	1 (5.6)
Study sites	
• Brazil	5 (29.4)
• Sri Lanka	3 (17.6)
• Tanzania	2 (11.8)
• Malawi	2 (11.8)
• USA	1 (5.9)
• Ecuador	1 (5.9)
• India	1 (5.9)
• Mexico	1 (5.9)
• Peru	1 (5.9)
Species of mosquito studied	
• Aedes sp.	11 (64.7)
• Anopheles sp.	5 (29.4)
• Not specified (general)	1 (5.9)
Type of disease concerned (can be more than 1 disease per article)	
• Dengue	10 (41.7)
• Zika	6 (20.8)
• Malaria	5 (25.0)
• Chikungunya	3 (12.5)
Integrate Machine Learning Techniques	
• Yes	12 (70.6)
• No	5 (29.4)
Type of Study Area (can be more than 1 type of study area per article)	
• Urban	11 (52)
• Suburban	7 (33)
• Rural	3 (14)
Type of drone	
• DJI Phantom 4	8 (47.1)
• DJI Phantom 3	4 (23.5)
• DJI Phantom 2	1 (5.9)
• Parrot's AR	1 (5.9)
• Not specified	3 (17.6)
Level of implementation	
• Proof of concept	17 (100)
Type of drone activity (can be more than 1 activity per article)	
• Surveillance	14 (82.4)
• Control (larva)	3 (17.6)

is critical in determining optimal flight times.[10] The tilt angle of the drone camera should be 90 degrees, and the drone should fly around midday to reduce the shadow effect.[31] Shadows cast by large trees and structures can obscure potential water sources.[13] Therefore, avoid conducting drone surveys when the sun is low in the early morning or evening to mitigate this effect.

For law and regulation (8%), the authors emphasized the licensing process, no-fly zone areas, and military deployment control. Before utilizing drones for any activities, national civil aviation authorities require drone pilots to get approved qualifications and secure relevant authorization, even though rules differ by country.[10] The importance of community involvement (8%) was also addressed in several studies. Researchers are experimenting with community-based monitoring systems that integrate technology into communities. Partnering with communities to collect surveillance data was also an effective data-collecting technique for public health practitioners and epidemiologists.[32] Concerns have been raised about how local communities will respond to the use of drones, the number of drones required, the area of coverage, when these drones will be used, and how human privacy will be protected. Therefore, community members must be involved to help address all these potential future issues.[33]

With recent advancement in drone technology, particularly the internet of things, smaller drones can take high-resolution photos and upload them to the cloud in real-time for rapid data processing. These drones are energy efficient and can cover large areas without losing connectivity to their

Table IV: Issues, challenges, and limitations of using drone

Issues & Challenges	Paper ID 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Hardware (specification, flight duration, height, signal strength, spare parts replacement, managing in-house data, cost-effectiveness)		√	√	√	√		√	√	√	√	√	√	√	√	√	√	√
2. Software (piloting drone, formatting, data & image processing/classification)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
3. Law & Regulation (licensing, no-fly zone, military deployment)								√	√			√		√		√	√
4. Operating time (weather, shadows effect, time-consuming)			√	√	√		√				√		√	√	√		
5. Expertise (skill/training hours / previous research & data)		√	√	√	√	√	√	√	√	√	√	√	√	√		√	√
6. Geographical (hard-to-reach locations, tree canopies, area covered)			√				√	√	√	√			√	√	√	√	
7. Community involvement	√										√	√	√	√		√	

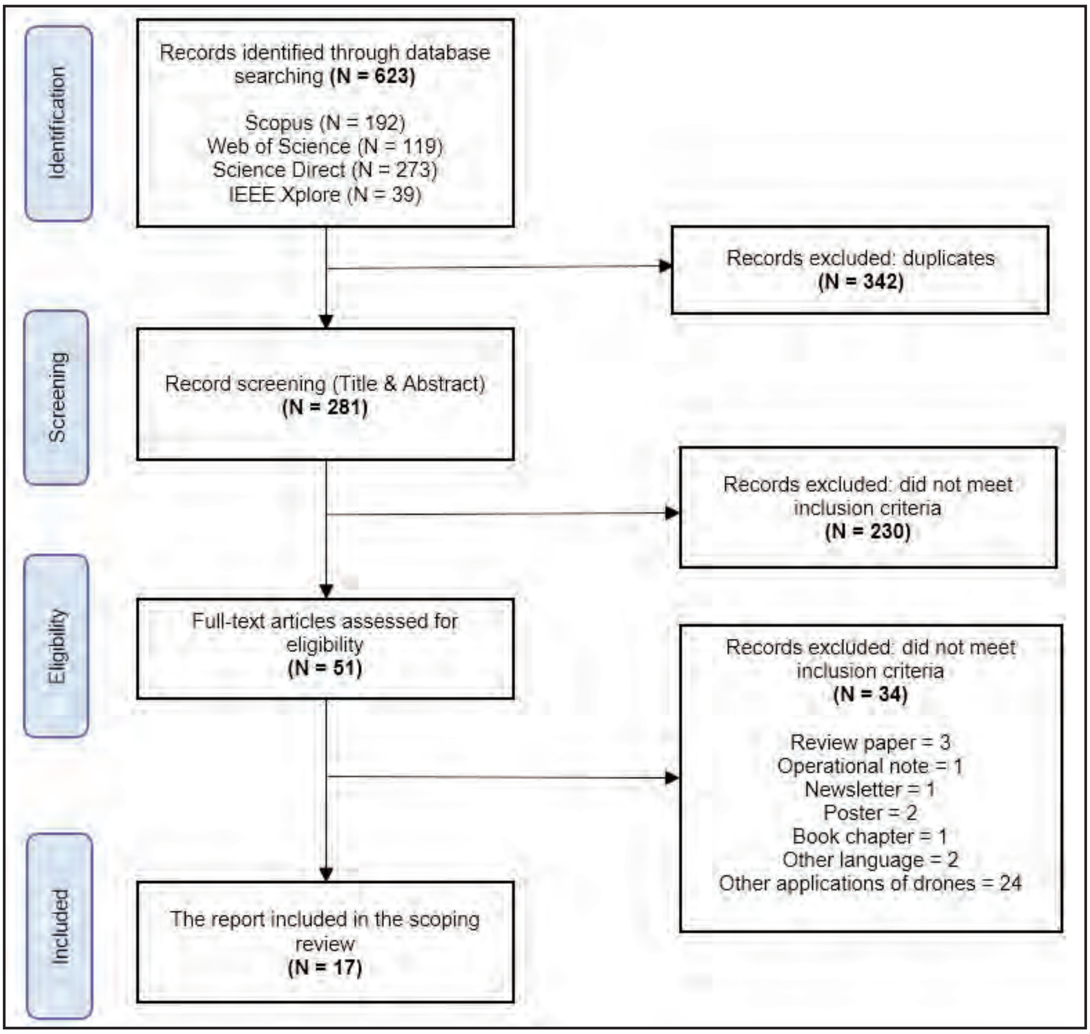

Fig. 3: PRISMA flowchart of the study collection

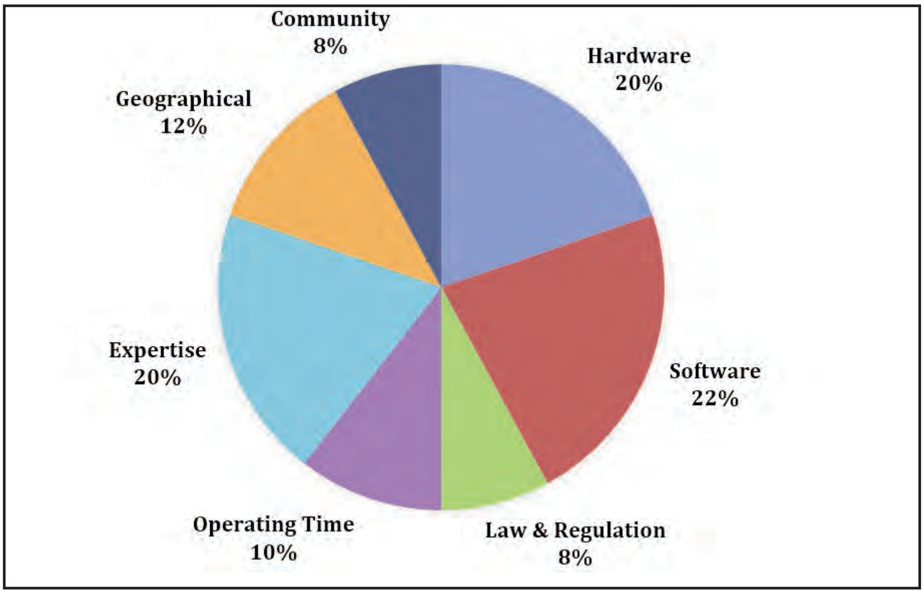

Fig. 4: Issues, challenges and limitations of using drone

base station.[33] However, there is a need for additional consultations between experts and stakeholders in the fields of drones, image analysis, and vector control to develop more specific recommendations for how this technology can be utilized most effectively.[10]

CONCLUSION

The feasibility of drone technology being used in mosquito breeding control programs should be further explored, as it could complement the conventional method of larval habitat inspection, which is a more labor-intensive approach. Even though the current data is scarce and lacks evidence, the literature search shows growing interest. The advancement in drone technology and collaboration with government agencies and the community will give strong evidence for a new dimension to dengue prevention and control programs in Malaysia and other endemic regions.

ACKNOWLEDGEMENT

This research is supported by the Malaysian Ministry of Higher Education and Universiti Teknologi MARA (UiTM) under the Academic Training Scheme for Bumiputera (SLAB).

REFERENCES

1. Haddawy P, Wettayakorn P, Nonthaleerak B, Su Yin M, Wiratsudakul A, Schöning J, et al. Large scale detailed mapping of dengue vector breeding sites using street view images. PLoS Negl Trop Dis 2019; 13(7): 1-27.
2. Passos WL, Araujo GM, de Lima AA, Netto SL and da Silva EAB. Automatic detection of Aedes aegypti breeding grounds based on deep networks with spatiotemporal consistency. Comput Environ Urban Syst 2022; 93: 101754.
3. Aragão FV, Zola FC, Marinho LHN, Chiroli DM de G, Junior AB, and Colmenero JC. Choice of unmanned aerial vehicles for identification of mosquito breeding sites. Geospat Health 2020; 15(1): 92-100.
4. Amarasinghe A, Suduwella C, Niroshan L, Elvitigala C, De Zoysa K and Keppetiyagama C. Suppressing dengue via a drone system. In 17th International Conference on Advances in ICT for Emerging Regions. IEEE. 2017; Sep: 1-7.
5. Mehra M, Bagri A, Jiang X and Ortiz J. Image Analysis for Identifying Mosquito Breeding Grounds. In International Conference on Sensing, Communication and Networking (SECON Workshops). IEEE. 2016; Jun: 1-6.
6. Messina JP, Brady OJ, Golding N, Kraemer MU, Wint GW, Ray SE, et al. The current and future global distribution and population at risk of dengue. Nat Microbiol 2019; 4(9): 1508-15.
7. Joshi A and Miller C. Review of machine learning techniques for mosquito control in urban environments. Ecol Inform 2021; 61: 101241.
8. Fernandes JN, Moise IK, Maranto GL and Beier JC. Revamping mosquito-borne disease control to tackle future threats. Trends Parasitol 2018; 34(5): 359-68.
9. Valdez-Delgado KM, Moo-Llanes DA, Danis-Lozano R, Cisneros-Vázquez LA, Flores-Suarez AE, Ponce-García G, et al. Field effectiveness of drones to identify potential Aedes aegypti breeding sites in household environments from Tapachula, a dengue-endemic city in southern Mexico. Insects 2021; 12(8): 663.
10. Stanton MC, Kalonde P, Zembere K, Hoek Spaans R and Jones CM. The application of drones for mosquito larval habitat identification in rural environments: a practical approach for malaria control? Malar J 2021; 20(1): 1-7.
11. Grubesic TH, Wallace D, Chamberlain AW and Nelson JR. Using unmanned aerial systems (UAS) for remotely sensing physical disorder in neighborhoods. Landsc Urban Plan 2018; 169: 148-59.
12. Haas-Stapleton EJ, Barretto MC, Castillo EB, Clausnitzer RJ and Ferdan RL. Assessing mosquito breeding sites and abundance using an unmanned aircraft. J Am Mosq Control Assoc 2019; 35(3): 228-32.
13. Hardy A, Makame M, Cross D, Majambere S and Msellem M. Using low-cost drones to map malaria vector habitats. Parasit Vectors 2017; 10(1): 1-3.
14. Carrasco-Escobar G, Manrique E, Ruiz-Cabrejos J, Saavedra M, Alava F, Bickersmith S, et al. High-accuracy detection of malaria vector larval habitats using drone-based multispectral imagery. PLoS Negl Trop Dis 2019; 13(1): e0007105.

15. Arksey H and O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol 2005; 8(1): 19-32.
16. JBI. The Joanna Briggs Institute Reviewers' Manual 2015: Methodology for JBI scoping reviews. Joanne Briggs Institute 2015; 1-24.
17. Hiebert B, Nouvet E, Jeyabalan V and Donelle L. The application of drones in healthcare and health-related services in north america: A scoping review. Drones 2020; 4(3): 30.
18. Laserna A, Barahona-Correa J, Baquero L, Castañeda-Cardona C and Rosselli D. Economic impact of dengue fever in Latin America and the Caribbean: a systematic review. Rev Panam de Salud Publica 2018; 42: e111.
19. Daud SM, Yusof MY, Heo CC, Khoo LS, Singh MK, Mahmood MS and Nawawi H. Applications of drone in disaster management: A scoping review. Sci Justice 2022; 62(1): 30-42.
20. Truong HM and Clavel M. Identifying temporary water bodies from drone images at real-time using deep-learning techniques. In International Conference on Advanced Computing and Analytics. IEEE 2022; Nov: 12-19.
21. Dias TM, Alves VC, Alves HM, Pinheiro LF, Pontes RS, Araujo GM, et al. Autonomous detection of mosquito-breeding habitats using an unmanned aerial vehicle. In 2018 Latin American Robotic Symposium, 2018 Brazilian Symposium on Robotics (SBR) and 2018 Workshop on Robotics in Education (WRE). IEEE. 2018; Nov: 351-6.
22. Bravo DT, Lima GA, Alves WA, Colombo VP, Djogbenou L, Pamboukian SV, et al. Automatic detection of potential mosquito breeding sites from aerial images acquired by unmanned aerial vehicles. Comput Environ Urban Syst 2021; 90: 101692.
23. Mukabana WR, Welter G, Ohr P, Tingitana L, Makame MH, Ali AS, et al. Drones for area-wide larval source management of malaria mosquitoes. Drones 2022; 6(7): 180.
24. Schenkel J, Taele P, Goldberg D, Horney J and Hammond T. Identifying potential mosquito breeding grounds: Assessing the efficiency of UAV technology in public health. Robot 2020; 9(4): 91.
25. Ali A, Nisar S, Khan MA, Mohsan SA, Noor F, Mostafa H, et al. A Privacy-Preserved Internet-of-Medical-Things Scheme for Eradication and Control of Dengue Using UAV. Micromachines 2022; 13(10): 1702.
26. Hardy A, Oakes G, Hassan J and Yussuf Y. Improved use of drone imagery for malaria vector control through Technology-Assisted Digitizing (TAD). Remote Sens 2022; 14(2): 317.
27. Prasad MG, Chakraborty A, Chalasani R and Chandran S. Quadcopter-based stagnant water identification. In Fifth National Conference on Computer Vision, Pattern Recognition, Image Processing and Graphics. IEEE. 2015; Dec: 1-4.
28. Rund SS, Moise IK, Beier JC and Martinez ME. Rescuing troves of hidden ecological data to tackle emerging mosquito-borne diseases. J Am Mosq Control Assoc 2019; 35(1): 75-83.
29. Wyngaard J, Rund SS, Madey GR, Vierhauser M and Cleland-Huang J. Swarming remote piloted aircraft systems for mosquito-borne disease research and control. In 40th International Conference on Software Engineering: Companion Proceedings. IEEE. 2018; May: 226-7.
30. Cunha HS, Sclauser BS, Wildemberg PF, Fernandes EA, Dos Santos JA, Lage MD, et al. Water tank and swimming pool detection based on remote sensing and deep learning: Relationship with socioeconomic level and applications in dengue control. PloS One 2021; 16(12): e0258681.
31. Suduwella C, Amarasinghe A, Niroshan L, Elvitigala C, De Zoysa K and Keppetiyagama C. Identifying mosquito breeding sites via drone images. In 3rd Workshop on Micro Aerial Vehicle Networks, Systems, And Applications. ACM. 2017; Jun: 27-30.
32. Lee GO, Vasco L, Márquez S, Zuniga-Moya JC, Van Engen A, Uruchima J, et al. A dengue outbreak in a rural community in Northern Coastal Ecuador: An analysis using unmanned aerial vehicle mapping. PLoS Negl Trop Dis 2021; 15(9): e0009679.
33. Annan E, Guo J, Angulo-Molina A, Yaacob WF, Aghamohammadi N, Guetterman TC, et al. Community acceptability of dengue fever surveillance using unmanned aerial vehicles: A cross-sectional study in Malaysia, Mexico, and Turkey. Travel Med Infec Dis 2022; 49: 102360.
34. Amarasinghe A and Wijesuriya VB. Drones vs Dengue: A Drone-Based Mosquito Control System for Preventing Dengue. In RIVF International Conference on Computing and Communication Technologies. IEEE. 2020; Oct: 1-6.
35. Stanton M, Kalonde P, Zembere K, Spaans RH, Jones C and Ghalayini R. Combining Drone-Based Ultra-High-Resolution Earth Observation Data with AI for Mosquito Larval Habitat Identification: A Scalable Method in Malaria Vector Control. In International Geoscience and Remote Sensing Symposium. IEEE. 2022; Jul: 4483-5.