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A CONCEPTUAL FRAMEWORK FOR ASSESSING THE FIELD EFFICIENCY OF DRONES IN IDENTIFYING POTENTIAL BREEDING SITES OF THE *Aedes* MOSQUITO

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ABSTRACT

The identification of breeding sites is key to dengue prevention strategies. Community involvement and breeding site surveillance play a vital role in controlling the Aedes population. Drones have emerged as a promising tool to be used in surveillance activities. Therefore, the aim of this paper is to develop a conceptual framework and present comprehensive intervention methods to control dengue cases. This study explores the concepts of community engagement, habitat profiling and mapping, and technology integration that will be implemented in the three main phases. Phase I: Community engagement, in which to understand the implementation characteristics of the proposed system using the Consolidated Framework for Implementation Research (CFIR) and Human-Centred Design (HCD); Phase II: Profiling and mapping potential breeding sites, in order to compare and characterise vector breeding sites of the Aedes mosquito in selected urban and rural areas using innovative drone technologies; Phase III: Technology integration by developing automated linkage of information on the mapping of mosquito breeding sites for dengue risk to an application platform. This conceptual framework can assess the efficiency of drones as an alternative tool for dengue surveillance and the use of technology to locate breeding sites effortlessly, which can later be applied in dengue-endemic regions.

1. INTRODUCTION

Aedes aegypti is the main vector of dengue, yellow fever, and chikungunya (Passos et al., 2022). There are no vaccines or antiviral treatments available to treat mosquito-borne diseases. Therefore, the most appropriate method currently available for combating these diseases is to remove any potential mosquito breeding sites (Rahman et al., 2021). In general, the breeding sites can be categorized as either artificial or natural containers (Amarasinghe et al., 2017). Aedes mosquitoes reproduce in stagnant and clean water (Mehra et al., 2016). Subsequently, all water-holding containers have the potential to serve as breeding grounds. Mosquito control and monitoring efforts can become costly, time-wasting, and ineffective without sufficient technical support (Passos et al., 2022). Contributing to the failure of control programmes are human social factors, improper garbage collection, and a lack of hygienic awareness (Hasnan et al., 2017; Madzlan et al., 2017). The strategies employed to control mosquitoes differ according to the individual, community, and regional environments (Joshi & Miller, 2021). The COVID-19 pandemic has affected dengue monitoring and control field technicians dynamically as they confront a new occupational hazard (Valdez-Delgado et al., 2021). Currently, health inspectors are required to visit residences to identify and destroy mosquito breeding grounds. This practice is difficult for officials to carry out and presents a number of disadvantages, including time limits, safety hazards, and high expenses (Mehra et al., 2016; Passos et al., 2022). Drones were originally envisioned as simple devices, but their complexity has developed in tandem with the intricacy of their designated duties. According to Hardy et al. (2022) and Mohd Daud et al. (2022), the type, size, power, and application conditions of drones are the main factors that determine their operational capabilities.

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Drones are used in public health research for a wide range of purposes, including tracing survivors after natural disasters, shipping medical supplies to isolated areas, and providing initial treatment in emergency locations (Carrillo-Larco et al., 2018; Fornace et al., 2014; Hiebert et al., 2020; Passos et al., 2022). Drones are also put into operation in various other fields, including agriculture, forestry, ecology, and environmental monitoring (Stanton et al., 2021). The evidence on the efficiency of drones in finding mosquito breeding sites is insufficient and limited (Valdez-Delgado et al., 2021). Satellite imaging is considered unfeasible due to its long repeat times, cloud contamination, limited geographical and temporal resolutions, and high costs (Fornace et al., 2014; Hardy et al., 2022). Rapid technological advancements, encouraged by commercial demand and open market competition, have changed drones from mere hobbies into potentially useful tools that can shorten surveillance activities and enrich mosquito control programmes (Faraji et al., 2021).

In this study, aerial photography of water retention from drones used to produce a map. It supplies data based on the shadow effect and the tilt angle of the drone camera with adequate precision to detect water retention. This is related to the studies in Carrasco-Escobar et al. (2019) and Haas-Stapleton et al. (2019), which examine the properties of water bodies to identify potential mosquito breeding places. In the study conducted by Dias et al. (2018), drones were operated to attain many aerial image configurations for a database. Using the collected photos and the annotated database, the proposed system was tested and trained. This technology allows the detection of tiny objects that cannot be observed by existing remote sensing methods (Bravo et al., 2021). In the study, Mukabana et al. (2022) provided an example of architectural innovation by combining two established technologies and executing them in a new market and context. The results revealed that a combination of drone application and insecticides can effectively reduce mosquito populations in an irrigated rice agroecosystem. Most of the research emphasizes that developments in computer and software engineering and computer science are the primary drivers of drone technological growth (Mohd Daud et al., 2022). Numerous significant outcomes have been yielded by the application of technology to drones. Drone surveying attempts for man-made containers, for instance, are made more precise by pairing Global Positioning System (GPS) receivers with machine learning techniques and image technologies like multispectral imaging (Schenkel et al., 2020). In the following investigation was reported in Ali et al. (2022), they merged the Internet of Medical Things (IoMT) and Geographic Information System (GIS) maps. The authors provide a way to mitigate and manage dengue virus outbreaks through call data record analysis. Once the patient's specific location has been confirmed, a spray unit will be alerted to send out drones to treat the affected area. In another scenario, Hardy et al. (2022) analyse drone data using a hybrid of mapping methods: supervised image classification using machine learning and technology-assisted digitising mapping that is accessible even to those with no technical background. As stated in Valdez-Delgado et al. (2021), the advancement of machine learning must be further investigated, and further research is required to spread out the usage of neural networks in mosquito surveillance. Improving the precision of technology requires a comprehensive commitment and data from many images representing a vast array of situations.

As preliminary data, we conducted a SWOT analysis (Figure 1) on the viability of using drones for surveillance based on information from related articles. Each article described a new and better way to use drone images to find possible mosquito breeding grounds. The ability of drones to fly in difficult-to-access areas is their greatest advantage. According to Hardy et al. (2022), drones can not only capture images or videos with greater spatial or temporal resolution but also from a variety of angles and heights. In addition, deploying programmable drones increases health inspectors' safety by decreasing their contact with potentially hazardous incidents or sets. The initial cost of drone hardware is considerable, but it is feasible since a small team can cover a vast area from the air with minimal operating costs (Chiroli et al., 2017). Drone implementation for mosquito breeding site surveillance may face numerous challenges. For example, the laws and guidelines for flying drones in each region are different. There is no standard set of guidelines for operating or regulating drones; there are restricted zones where drones cannot be used; there are topographic and climate differences; there are privacy concerns; and community attitudes towards and acceptance of drones vary across cultures (Annan et al., 2022; Mohd Daud et al., 2022; Poljak & Šterbenc, 2020). The scalability of the proposed method may be limited due to limitations in the geographical area that a single drone can cover (Bravo et al., 2021). However, Hardy et al. (2017) demonstrated that a low-cost drone can be used to map water bodies in various settings, including natural water bodies, rice paddies, and urban areas, with the goal of identifying and mapping aquatic mosquito habitats. A well-organized database for identifying and categorizing objects in aerial videos is also an essential element. Among the features highlighted by Passos et al. (2022), a database should have a significant number of samples for each target group, an absence of image distortions, and precise object annotation.

Detecting water bodies in remote areas using drone-captured images requires several technological and competence hurdles. Creating orthomosaics from drone imagery is a time-consuming process that calls for a powerful computer, a huge space for records of information, and specialised software (Stanton et al., 2021; Wyngaard et al., 2018). In addition to hardware and software concerns, misconfigured drones can pose risks and vulnerabilities (Wyngaard et al., 2018). Flight experience was essential for calculating the ideal flight hours, as the drone could not be piloted in rainy weather and the influence of adverse weather on the equipment could cause it to overheat on hot days. More engagements between stakeholders and specialists across disciplines are required to provide more specific recommendations on how this technology can be used most efficiently (Stanton et al., 2021).

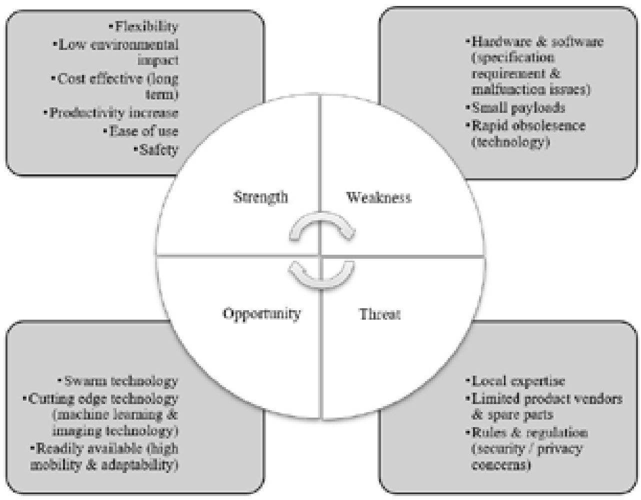

Figure 1: SWOT analysis on the viability of using drones for surveillance activities

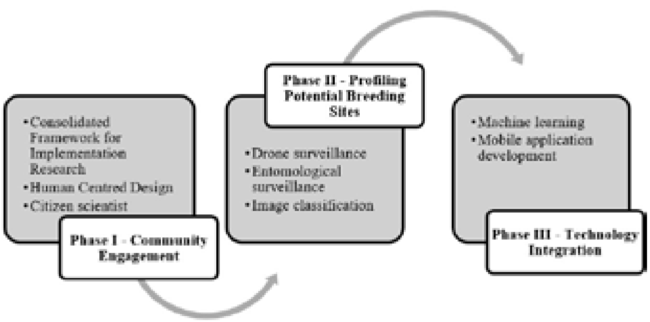

Figure 2: Main phases and elements in the conceptual framework

Therefore, from the literature search and SWOT analysis, the objective of this paper is to develop a conceptual framework and discuss the intervention methods that will be executed in three main phases are summarized in Figure 2. These phases revolve around three main interventions whereby community engagement, profiling potential habitat, and technology integration are fully taken into consideration in developing sustainable dengue preventive measures. In the end, a unique mobile application will be developed based on drone image data to enhance early dengue outbreak identification and control efforts, with an emphasis on health equality. The application will be customised and tested for two distinct end-users: household members and national vector control personnel.

2. PHASE I: COMMUNITY ENGAGEMENT

Many studies related to the prevention and control of the Aedes mosquito indicate that household intervention can aid in larval reduction programmes; however, empowering and sustaining such practises over time and outside of research projects can be challenging (Rahman et al., 2021)we aimed to map the spatial distribution of female adult Ae. aegypti and predict its abundance in northeastern Thailand based on socioeconomic, climate change, and dengue knowledge, attitude and practices (KAP. The integration of household involvement into routine dengue programmes, including the most effective strategies, types of educational materials needed, programme regularity, and participation models, is still the subject of ongoing research. As discussed by Kleinman (2010), interventions are dynamic, can result in unforeseen effects, and are socially established. A review of dengue programmes in four countries by Horstick et al. (2010)questionnaires indicated several factors that contributed to the failure of the programmes. It includes a shortage of manpower, funds, and knowledge; an overdependence on chemicals; a low level of household participation; and a nearly non-existent comprehensive assessment system. Therefore, any interventions must be tailored according to the local landscape and engage specific communities at risk (Carrasco-Escobar et al., 2022)global health security has been threatened by the geographical expansion of vector-borne infectious diseases such as malaria, dengue, yellow fever, Zika and chikungunya. For a range of these vector-borne diseases, an increase in residual (exophagic.

2.1 Consolidated Framework for Implementation Research (CFIR)

This study employs qualitative grounded theory research in compliance with the Consolidated Framework for Implementation Research (CFIR) to evaluate the strengths and weaknesses of the current dengue management system and use the discoveries to enhance the proposed dengue alert system. The CFIR is a well-established framework designed to completely review and evaluate the implementation of health technology. It comprises five domains, namely: characteristics of the individuals involved, intervention characteristics, outer setting, inner setting, and the process of implementation (Damschroder et al., 2009), which have been widely used in the design and evaluation of health programmes. This study will combine the CFIR implementation framework with the anthropological framework developed by Bardosh (2018) to well value the implementation of neglected tropical disease strategies by analysing the geography, public interference, incentives and strategies, technology, and governance, connecting the gap between research and practise, and interpreting evidence-based practise and research into real-world settings.

2.2 Human-Centered Design (HCD)

Implementing new technologies is most convenient when linked with participatory processes that strengthen household engagement, civil society, and system accountability. Methods such as Human-Centred Design (HCD) and Participatory Design (PD) can be applied to establish feasible strategies for a particular group of people. HCD is a participatory action research framework that is used to reframe human-centered challenges and rapidly test multiple strategies tailored to specific geographic locations (Duque et al., 2019). To enable the effective implementation of health data systems, human-centred techniques are specifically designed for healthcare domains. Thus, enhance the performance and effectiveness of the system, facilitate learning and user experience, minimize medical faults, design time, funding, and training costs (Zhang, 2005). In each targeted household, the study will establish a community council, involve end-users via a team of citizen scientists, and perform a few participatory workshops. The purpose of each workshop will be different. In addition to user experience and design specifications, the workshop will also emphasize the performance efficiency, security and privacy, usability, and portability of the proposed project. This process will ensure that the technology products adopted for the project are prototyped, examined, and fine-tuned to improve their performance and acceptance by end-users.

2.3 Citizen Scientist

Citizen scientists will be selected from local community councils and trained in household outreach and fundamental research techniques during a training course. To guide their operations, a manual book will be prepared. Citizen scientists will work with the project team in person or virtually during the longitudinal cohort's home visits, particularly during the prototyping and reviewing phase of the mobile application. Thus, ensuring the long-term sustainability of the proposed platform (in Phase III). In the first phase, the study will perform a modified grounded theory analysis based on the constant comparative technique, which produces categories and concepts iteratively and tests them with evidence. The framework will be developed through open coding, followed by axial and selective coding (Strauss & Corbin, 1990). Initial transcripts will be coded independently; discrepancies in coding will be identified and reviewed until a codebook consensus is achieved. The research team will have frequent meetings and encourage the involvement of citizen scientists in the development of categories and themes. In addition, this study will also do a focused analysis to learn about execution, including how the platform is perceived.

The data from semi-structured interviews will be analysed using QDA Miner, a programme for managing, assessing, and presenting qualitative and mixed-methods research data. Over the course of the project, researchers will examine the data to ensure that specific topics reach saturation, the time at which supplementary data collection no longer adds complexity to the final conclusions. Citizen scientists will undergo training in human subject research prior to collecting any data; the selection of participants will be based on equity and diversity. Finally, the acquired quantitative data on application usage will be used to conduct a mixed-methods study that includes the qualitative findings. By combining application usage data with qualitative categories or themes, we can obtain a greater knowledge of the factors that explain application usage variation.

3. PHASE II: PROFILING POTENTIAL BREEDING SITES OF Aedes MOSQUITO

In several regions worldwide, Aedes mosquitoes primarily inhabit artificial containers (Carrasco-Escobar et al., 2022; Madzlan et al., 2017). The physical landscape characteristics and availability of containers that can retain water have been discovered to be critical elements in the reproduction of mosquitoes in Malaysia and other countries (Muñiz-sánchez et al., 2022). Knowing the habitat characteristics and other elements like vegetation indices, land use, canopy cover, and elevation can provide comprehensive knowledge about mosquito abundance and distribution (Carrasco-Escobar et al., 2022). Health inspectors are currently conducting larval surveys and destroying dengue breeding grounds in dengue hotspot areas as part of the Ministry of Health Malaysia's preventative measures. Due to broad coverage areas and a limited number of health inspectors in each district, this task is time-consuming and cannot be completed properly. Consequently, drone-based monitoring of breeding sites will have a wider scope, be more prospective, and require less human work.

3.1 Drone Surveillance

Aerial surveillance permits the identification of potential breeding sites in areas that are inaccessible to traditional ground surveillance. Thus, it assists health inspectors in accurately identifying and mapping the breeding sites using drone images (Muñiz-sánchez et al., 2022). The size of mosquito breeding sites can be smaller than 1 meter; therefore, the ability of drones to capture high-precision images is critical for analysis (Hardy et al., 2022). The drone surveillance will be conducted using the method explained in Carrasco-Escobar et al. (2019). In selected study areas, weekly aerial surveys will be conducted using a drone to identify suitable outdoor breeding places such as pails, vessels, bins, and bowls. Any man-made structures outside the buildings that can serve as breeding grounds directly or indirectly will also be inspected. The drone will fly to an altitude of approximately 100 meters in the area of interest, resulting in a sample distance of about 0.1 meters per pixel on the ground. To construct an orthomosaic, 100 waypoints will be automatically determined in each grid to give a 70% overlap between neighbouring images.

3.2 Entomological Surveillance

Entomological surveillance is crucial to effectively monitor and assess interventions, identify regions that require further surveillance, and assess the possibility of vector-borne transmission (Carrasco-Escobar et al., 2022)global health security has been threatened by the geographical expansion of vector-borne infectious diseases such as malaria, dengue, yellow fever, Zika and chikungunya. For a range of these vector-borne diseases, an increase in residual (exophagic. The Aedes larval surveillance data will be derived from weekly inspections of selected areas for both natural and artificial containers. A breeding site will be georeferenced if a positive Aedes mosquito is identified or suspected. A breeding site will be considered positive if the sample contains at least one Ae. aegypti or Ae. albopictus larva. Expert taxonomists will identify the Aedes larvae by using morphological criteria. Due to the varying sizes and forms of the research area, this study will superimpose a 200-meter grid system on the map of the study area and use these fixed grid cells as study units to minimise the amount of normalisation required. Additionally, surveillance will be conducted within a 200-meter radius of the gravid oviposition traps. After five days of placement, the traps will be returned to the laboratory. Concurrently, larval surveys will be done at prospective breeding sites identified by the drone survey. The larvae of mosquitoes will be identified to the species level using the criteria given by the Malaysian Ministry of Health. Three larval indices, namely the Aedes Index, Container Index, and Breteau Index, will also be measured in accordance with World Health Organization (WHO) standards.

3.3 Data Analysis and Image Classification

The images captured by the drone will be used for visual inspection to find any water bodies that may serve as potential breeding sites. Subsequently, a comprehensive map of the mosquito breeding grounds and the surrounding landscape can be generated (Carrasco-Escobar et al., 2022)global health security has been threatened by the geographical expansion of vector-borne infectious diseases such as malaria, dengue, yellow fever, Zika and chikungunya. For a range of these vector-borne diseases, an increase in residual (exophagic. Drones can generate various maps, including two-dimensional maps, elevation maps, thermal maps, and three-dimensional maps or models. It can also gather precise information about the landscape with a ground resolution that is significantly higher than that of any current satellite imaging (Budiharto et al., 2021)developing 3D models using photogrammetric and situation mapping uses geographic information systems. The drone used has advantages in a wider range of areas with adequate power support. The drone is also supported by a high-quality camera with dreadlocks for image stability, so it is suitable for use in mapping activities. Conclusions: Using Google earth data at two separate locations as a benchmark for the accuracy of measurement of the area at three variations of flying height in taking pictures, the results obtained were 98.53% (98.68%. AgiSoft Photoscan Pro will be utilized for photogrammetric analysis, which requires photographically based surface measurements (Hardy et al., 2017). The generated drone photography will be imported into Photoscan and used to construct orthomosaics, which are geo-referenced mosaics of overlapping images with topographic distortion correction for each study site. The photogrammetric method can be utilized to create a three-dimensional landscape that contains both natural and man-made parts of the environment. Then, it can be fed straight into Geographic Information System (GIS) software for visualisation (Carrasco-Escobar et al., 2022)global health security has been threatened by the geographical expansion of vector-borne infectious diseases such as malaria, dengue, yellow fever, Zika and chikungunya. For a range of these vector-borne diseases, an increase in residual (exophagic.

4. PHASE III: TECHNOLOGY INTEGRATION

Integration of available technologies like drones, machine learning, deep learning, big data, and citizen science can be used to have dependable evidence about mosquito population dynamics and administering areas at risk (Muñiz-sánchez et al., 2022). The technology of mobile applications permits users to send and receive notifications. Current smartphone applications are restricted to notifying users about dengue cases and hotspots. This project will develop a new interactive application to alert the public about dengue risk and outbreaks, as well as the measures they have taken to eradicate or lessen mosquito breeding sites, based on a newly developed algorithm using mosquito breeding site mapping by drone images.

4.1 Machine Learning

Google Earth Engine and selected machine learning software, RapidMiner, will be used to classify photoscan images of breeding sites. The 10-fold cross-validation will be executed to partition the images into a training and validation set 10 times and predict the breeding sites using machine learning algorithms such as Support Vector Machine (SVM), random forest, XGboost93, LightGBM94, and artificial neural networks, including deep learning. SVM is a classification technique for machine learning that uses the separation hyperplane to distinguish between classes of the target variable based on whether it is above or below the separation line. XGBoost and LightGBM are gradient-boosting decision tree ensemble tree-based models. A gradient boosting model is a strategy in which a new model is developed to iteratively modify an old tree model by fixing its mistakes. By fitting the mistake in the difference between the expected and projected values, the developed model based on the boosting method will increase accuracy. Deep learning approaches like convolutional neural networks (CNNs) are effective in image recognition. It is anticipated that the prediction models would reasonably recognise proper images of potential breeding sites with water retention zones. The dengue risk prediction application will be built using a few data points, such as the location of breeding sites, dengue cases, and environmental data. In addition, this study will employ deep neural networks to determine the pattern of breeding site areas, dengue hotspot areas, dengue cases, and mosquito populations. This research will detect the risk of dengue and any outbreaks that may arise throughout the study period. All analyses will be performed with either R or Python.

Machine learning approaches have made a significant contribution, especially in mapping potential breeding sites for mosquitoes. In the study by Hardy et al. (2022), several dominant land cover classes were used, such as open water, open water with sunlight, emergent vegetation, dry, and land cover types, to assist in the classification process. In another example, Rahman et al. (2021)we aimed to map the spatial distribution of female adult Ae. aegypti and predict its abundance in northeastern Thailand based on socioeconomic, climate change, and dengue knowledge, attitude and practices (KAP used five supervised learning models, which are logistic regression, support vector machine, k-nearest neighbour, artificial neural networks, and random forest based on socioeconomic, climate change, and dengue knowledge, attitude, and practices (KAP), to predict the abundance of mosquitoes (high and low). The use of machine learning models for the prediction of mosquito abundance can provide significant information to authorities to design vector surveillance and prevention strategies for outbreaks. By using available data, machine learning can train and test the data, use the model results to predict future outcomes, and improve the prediction from time to time.

4.2 Development of Mobile Applications

The overall architectural concept design of the proposed system is composed of four layers: user, public network, cloud network, and enterprise network. Data collector, drone pilot, programmer, specialist, and service manager are the five primary tasks involved in generating the solutions. Both the data collector and the drone pilot are responsible for data collection. The developer, the service manager, and the specialist are responsible for creating the application, establishing the infrastructure, and validating the data. The photos and their geo-information will be mapped with the data collected from idengue.mysa.gov.my using crawler software and the historical data from the Ministry of Health, Malaysia, to provide a more precise analysis for forecasting and to guarantee the analysis's reliability. The concurrent processes of taking photos and crawling real-time data from idengue.mysa.gov.my allow for rapid data preparation from both resources. Once all the data have been collected and analysed, the prediction engine will perform additional analysis to produce the final output, which is a forecast of future dengue cases. The results will be communicated to the home via a mobile application, along with recommendations for the elimination of breeding grounds and vector management methods. The application platforms will be compatible with both Android and iOS. Additionally, the graphical outputs will be user-friendly. A calendar that displays the projected dengue cases on specific days and a basic notification three weeks before the predicted dengue cases are two primary outputs of the application. Figure 3 shows an overview of the proposed framework.

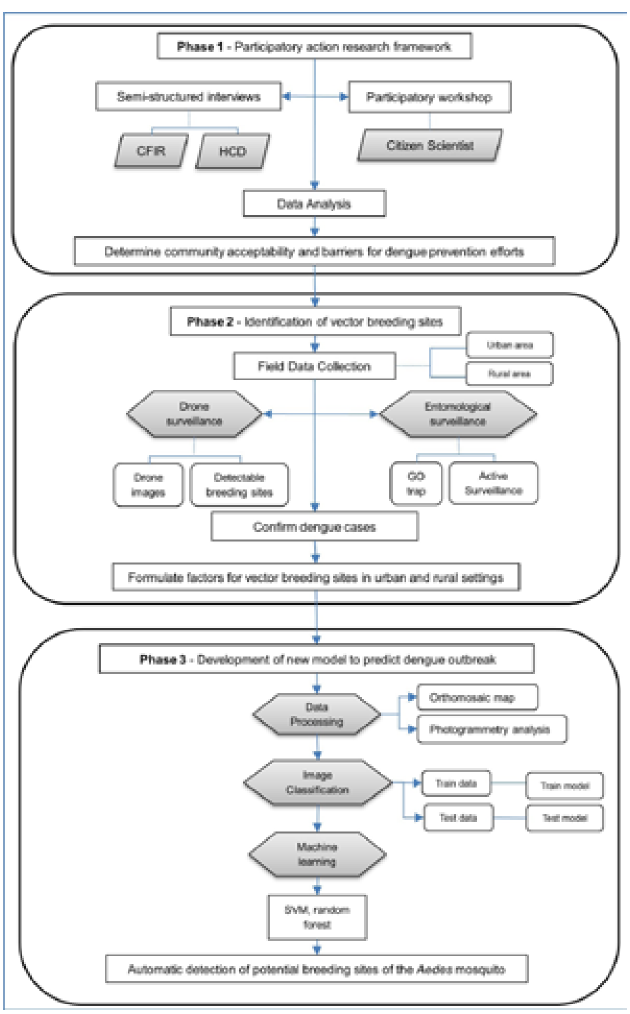

Figure 3: Overview of the proposed framework

5. CONCLUSION

Due to the geographical expansion of dengue in recent years, the information gathered through surveillance is essential for risk evaluation and epidemic management, making it a vital component of dengue prevention. Surveillance activities should ideally involve ecological monitoring and social risk issues in addition to the early detection of human infections and vector control. In Malaysia, rigorous dengue control measures are implemented in certain localities based on the notification of lab-confirmed human cases and the location of dengue hotspots. Currently, house-to-house larval inspections by the health inspector, removing mosquito breeding sites, larvicide activities, and fogging are among the control measures taken by the Ministry of Health, Malaysia. The feasibility of using drone technology in mosquito breeding control programmes should be contemplated as an effective alternative tool, as it could substitute for the time-consuming conventional process of observing larval habitats. This novel method, which integrates drones and technologies, household engagement, and collaboration with government agencies, will add a new dimension to dengue prevention and control programmes in Malaysia and other endemic regions.

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