International Journal on Advanced Science Engineering Information Technology

Vol.11 (2021) No. 1
ISSN: 2088-5334

A Review on Spatial Technologies for Enhancing Malaria Control: Concepts, Tools, and Challenges

Rayner Alfred[a,1], Joe Henry Obit[b,2]

[a]*Knowledge Technology Research Unit, Faculty of Computing and Informatics, Universiti Malaysia Sabah, Sabah, 88400, Malaysia*
[b]*Faculty of Computing and Informatics, Universiti Malaysia Sabah, Sabah, 88400, Malaysia*
Corresponding author: [1]ralfred@ums.edu.my, [2]joehenry@ums.edu.my

Abstract*— This paper presents a review of numerous studies conducted on spatial technologies, tools, and applications for controlling malaria epidemiology. This paper mainly focuses on using statistical or machine learning-based models and geographic information science (GIS) and remote sensing (RS) technology for monitoring malaria disease outbreaks. The literature review includes all articles obtained from journals and conference proceedings published from 2000 through 2020 in Scopus indexed databases (e.g., Elsevier, Springer, IEEE eXplore, ACM, Wiley, and PubMed). We completed this systematic literature review using "Enhancing Malaria Control," "GIS and Malaria Control" and "Spatial Technologies for Monitoring Malaria Disease Outbreaks" search terms. We found a total of 188 articles published in peer-reviewed journals listed in the Scopus indexed databases. After a detailed review, 152 articles were excluded because they did not meet our inclusion criteria; 36 articles were selected for the final evaluation. Several concepts and tools related to GIS applications in monitoring the malaria outbreak's spread is discussed. The discussion is categorized into four categories: a) Application of Spatial Technologies, b) Applications of Machine Learning Algorithms, c) Applying Multiple Sources of Data, and d) Applications of Smartphone Technologies. A spatial technologies framework for enhancing malaria monitoring is also proposed where it identifies the role of spatial technologies and applications in monitoring malaria disease outbreaks. The paper is concluded by providing some of the main challenges related to the issues in controlling the spread of malaria disease outbreaks.

***Keywords*— Geographic Information System; malaria; disease outbreaks; remote sensing; machine learning.**

Manuscript received 6 May. 2020; revised 12 Oct. 2020; accepted 2 Dec. 2020. Date of publication 28 Feb. 2021.

I. INTRODUCTION

Malaria is a perilous disease that is spreaded by the mosquito. People infected with Malaria disease show several symptoms that include high fevers, shaking chills, and flu-like illness. Malaysia has successfully put-up programs that scaled up its national malaria program and WHO has declared Malaysia is still in the pre-elimination phase [1]. It has been estimated that Plasmodium vivax causes 58% of the country's malaria cases, 23% of the total malaria cases caused Plasmodium falciparum, and 5% of the total malaria cases caused by *Plasmodium knowlesi* [1],[2]. Less than 20% of total malaria cases occur in Peninsular Malaysia, in which most occurrences of malaria infections are in the southern and northern coastal and central regions [3], [4]. *Anopheles maculatus, Anopheles sundaicus, Anopheles letifer, Anopheles campestris*, and *Anopheles dirus* are some of the mosquito vectors in peninsular Malaysia [5],[6]. Approximately 80% of nationwide malaria cases are recorded in Borneo, Malaysia, with 58% of the malaria incidences reported in Sabah in which Anopheles *balabacencis, Anopheles sundaicus*, and *Anopheles flavirostris* were the primary mosquito vectors found in Sabah.

The actual number of imported cases is difficult to be quantified because of fear of deportation, undocumented workers living in remote and inaccessible areas, poor knowledge of the disease, and lack of information on the health system [7]–[9].

Many isolated indigenous tribal groups are found in the Borneo island, Malaysia. These indigenous tribal groups usually do not have good access to health services compared to the people in Peninsular Malaysia. Many of these indigenous people turn to local traditional remedies before seeking care in a health facility [10]. As a result, lack of knowledge and information about the malaria disease, the local health system, and the efficient monitoring system for malaria disease outbreak at ungazetted remote areas has hindered the efforts to successfully and efficiently reduce or eliminate malaria Borneo. These constraints can be tackled by implementing an integrated and centralized database that is linked to a web portal, a Geographic Information System (GIS) and a data modeling System. For instance, with the development of the integrated centralized database coupled with Web portal, GIS and data modeling systems, knowledge sharing can be achieved, remote sites can be plotted and stored in the GIS system, environmental parameters and tropical disease forecasting can be performed to assist the efforts to successfully and efficiently reduce or eliminate Malaria in Borneo.

Thus, this paper aims to provide a comprehensive review of spatial technologies for monitoring malaria disease outbreaks. In other words, this paper reviews all the last researches conducted recently that are related to the development of several spatial technologies, tools, and applications such as GIS, expert systems, and knowledge discovery systems for improving the malaria disease information flow management.

The remainder of the paper is organized as follows. Section II presents and discusses the methodology used to perform the Systematic Literature Review (SLR), Section III presents the results or the reports of the review. Section IV proposes the spatial technologies framework for enhancing malaria monitoring. Finally, Section V concludes this paper by outlining several recommendations to enhance the malaria disease outbreak monitoring.

II. Material and Method

This systematic literature review (SLR) aims to identify, evaluate, and interpret all available research relevant to ICT application in limiting the spread of Malaria disease outbreaks. This SLR is based on the quality reporting guidelines proposed by Kitchenham [11]. There are five primary stages are identified to be included in this SLR. They are called Identification of Preliminary Requirement (IPR), Contents Retrieval (CR), Contents Evaluation (CE), Contents Summarization (CS) and Review Findings Reporting (RFR). IPR stage involves identifying the requirements for a systematic review and eliminating the possibility of researcher bias by identifying the appropriate review protocol. The contents retrieval stage consists of formulating research questions that focus on the spatial technologies leveraged to limit the spread of Malaria disease outbreaks and finally establish the appropriate search process to conduct the search activities.

The contents evaluation stage involves the following steps: formulating the predefined selection criteria to select relevantly and assess these studies' quality based on the predefined quality assessment procedure outlined in this work. The contents summarization stage was then extracted from the studies in which data synthesis was performed, and the results were summarized. The final reporting of the review findings stage presents the findings and concludes this review with some future works derived from this review. All these processes are illustrated in Fig. 1, in which new information can be integrated into the report in the future.

A. *Preliminary Requirement Identification*

In this stage, we determine an SLR's requirements by determining the appropriate review protocol that eliminates the researchers' possibility of biases when reviewing these papers. The objective of the review protocol is to ensure that the process of reviewing can be conducted unbiasedly.

The most critical elements of the proposed review protocol in this work include all the outlined research questions, the process of searching, assessing, and determining relevant studies is discussed in the next section.

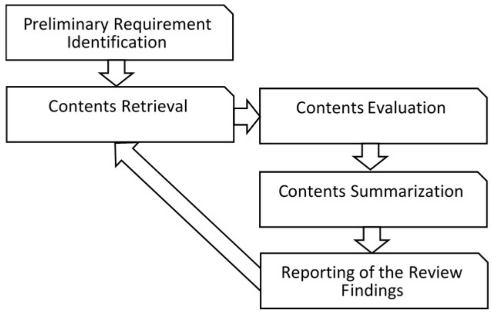

Fig. 1 The framework of systematic literature review.

B. *Contents Retrieval*

1) Formulating research questions: The research questions (RQs) were formulated to define the scopes of the research according to three viewpoints; population (e.g., prediction, detection, or monitoring), intervention (e.g., roles of spatial technologies) and outcomes (e.g., the efficiency of the proposed tools in monitoring malaria disease outbreak) [10]. This SLR aims to collect and analyze appropriate evidence to answer the outlined research question (RQ). Our motivation in this paper is to answer the outlined RQ that enhance our knowledge of spatial technologies' roles in limiting the spread of Malaria disease outbreak. The RQ of this research is as follow:

RQ: What are the roles of spatial technologies, tools and applications in limiting the spread of Malaria disease outbreak?

2) Search Process: The search process is conducted, and it must ensure that the predefined research questions can be taken into consideration and thus, this search process involves identifying the appropriate digital libraries, defining the period in term of the year for the article's publications and identifying keywords that were used to search for relevant articles. In this work, we retrieved all articles from the Scopus indexed databases (e.g., Elsevier, Springer, IEEE eXplore, ACM, Wiley, and PubMed). Furthermore, several independent relevant journals and conference proceedings in the GIS and machine learning fields were explored. In this work, only articles publication that were made in the interval from 2000 to 2020 were included and we used “Enhancing Malaria Control”, “GIS and Malaria Control” and “Spatial technologies for Monitoring Malaria Disease Outbreaks” search terms in order to list out all the candidates of the study that were selected for further assessment.

C. *Contents Evaluation*

In the content evaluation phase, several criteria were carefully formulated to ensure that appropriate studies are selected. Table 1 shows the assessment criteria outlined in this work. Then, all retrieved studies were examined carefully. This quality assessment was performed according to the quality checklist proposed by Kitchenham [11]. The assessment's main objective is to evaluate and select relevant studies that address the predefined research question.

TABLE I
QUALITY ASSESSMENT QUESTION

No	Quality Assessment Question
1	Does the study state the primary objective related to limiting the spread of Malaria diseases outbreak?
2	Does the study describe any ICT related tools or models used to limit the spread of Malaria diseases outbreak
3	Does the study discuss any findings obtained from using ICT-related tools or models to limit the spread of malaria outbreaks?
4	Does the study discuss any limitations faced by using ICT-related tools or models to limit the spread of malaria outbreaks?

D. Contents Summarization

In this stage, we extracted both the quantitative and qualitative data from the selected studies that address the four main issues related to the quality assessment questions outlined in Table 1.

E. Reporting of Review Findings

The summary was obtained from the selected primary studies based on outlined research questions in the reporting of review findings.

III. RESULT AND DISCUSSION

We completed this systematic literature review using “Enhancing Malaria Control,” “GIS and Malaria Control” and “ICT for Monitoring Malaria Disease Outbreaks” search terms and found a total of 188 articles published in peer-reviewed journals listed in Scopus indexed databases (e.g., Elsevier, Springer, IEEE eXplore, ACM, Wiley, and PubMed). After performing the screening process, we have excluded 152 articles as they did not fulfil the criteria specified in Table 1. Based on the assessment conducted, only 39 articles were selected to be reviewed and included in the SLR. Table II summarizes the number of studies reviewed and the technologies and concepts discussed in each of the papers reviewed based on publication year.

Based on Table II, more researches are conducted to investigate the feasibility of integrating multiple sources of data (e.g., remote sensing data, GPS data, and data captured using drones) and coupling GIS with other web-based applications and machine learning algorithms in order to produce a more efficient and effective tool for monitoring malaria disease outbreak.

In this paper, based on the reviews that have conducted for 39 studies listed in Table II, the discussion is categorized into four categories: a) Application of Spatial Technologies, b) Applications of Machine Learning Algorithms, c) Applying Multiple Sources of Data and d) Applications of Smartphone Technologies.

TABLE II
STUDIES AND TECHNOLOGIES REVIEWED ACCORDING TO YEAR

Year	Qty	Studies & Technologies
2020	3	GIS and Remote Sensing [51], [53], [54];
2019	9	GIS, GPS, and Machine Learning [12]; Machine Learning [13],[14],[15],[16]; GPS [17]; Surveillance System [18]; GIS and Remote Sensing [19]; Remote Sensing and Drone [20];
2018	7	GIS and Software Development [21][22]; GIS and Remote Sensing [23], [52]; Machine Learning [24],[25],[26]; Smartphones [27];
2017	4	GIS and Remote Sensing [28]; Smartphones [29]; GPS [30]; Remote Sensing and Drone [31];
2016	3	Web-Based GIS [32]; GIS and Smartphones [33]; Smartphones and Image Processing [34];
2015	4	GIS and Machine Learning [35]; Machine Learning [36],[37],[38];
2014	2	GIS [39]; GIS and Remote Sensing [40];
2012	2	GIS and DSS [41]; Mobile Phone [42];
2011	1	GIS and DSS [43];
2010	1	GIS and Machine Learning [44];
2009	1	GIS, GPS, and Remote Sensing [45];
2000	2	Remote Sensing [46]; GIS [47];

A. Applications of Spatial Technologies

Global Positioning System (GPS), Remote Sensing (RS), and Geographic Information System (GIS) are considered as part of the spatial technologies [45]. Spatial technology can be defined as a field of information technology that captures, stores, analyses, and models, interprets and visualizes datasets. Spatial technology deals with datasets that focus on the geographic, temporal, and spatial reference.

GIS technology can provide the ultimate mechanism to perform continuous surveillance. It can be used as an efficient platform to integrate parasitemia survey and surveillance data. There is an exponential increase in GIS usage, integrated GIS, or modified GIS in facilitating the monitoring of malaria disease outbreak. This is very important in understanding health problems in different locations or parts of the world. Recently, the various usages of integrated machine learning algorithms and GIS technologies has led health professionals to work more efficiently and effectively [39].

Based on the data extracted from satellite images, maps and aerial photos, GIS can be used to facilitate the monitor malaria transmission. Given the complexity of the spatial data obtained from the GIS, the heterogeneity of malaria vectors distribution and the varieties of inherent malaria risks, GIS is shown to have the capacity to assist us in monitoring the malaria diseases [41].

Matching the malaria control measures or program activities to the specific areas affected by endemic malaria has provided us with better plans and opportunities for more efficient malaria control. For instance, GIS was fully utilized to display data related to malaria cases in very town and district, which is very useful in stratifying malaria risk [47]. GIS also can be customized and integrated with expert systems (e.g., Spatial Decision Support System (SDSS)) to assist any activities, such as indoor residual spraying (IRS) operation, to reduce the number of malaria cases [43]. The obtained raw data from the project indicate that high user acceptance regarding the use of this SDSS as the proposed SDSS is very useful to be used as a tool for planning, implementing, monitoring, and evaluating the IRS operations.

GIS and RS are found to be very effective for surveillance and monitoring of malaria disease outbreaks. Besides that, it can also be applied for disease management and resource allocations. For instance, a GIS and (RS) can be combined to implement a very effective and efficient tool to monitor malaria disease outbreak [28]. Coupling GIS with machine learning algorithms and sound knowledge of mosquito vector populations' ecology is very effective and efficient in controlling malaria disease outbreaks. GIS and RS can also be used to identify and map the related landscape elements to the malaria cases and its vectors [44]. Based on the satellite imagery, several relevant data or features can be extracted to facilitate the efforts to map the high-risk areas and identify significant factors that contribute to the high receptivity to formulate the control strategy. These data are extracted to monitor the temporal changes in adult mosquito densities, larval, vegetation, and water bodies.

In Ethiopia, RS and GIS are integrated GIS to perform the malaria risk mapping [40]. Several types of malaria data that includes climatic, social and topographic aspects (flow distance to stream, elevation and slope) from secondary data were integrated for the decision support system that applies GIS and remote sensing tool. In this study, coupling GIS and remote sensing is crucial in creating operational maps that could help identify hazard and risk areas for malaria disease control.

Tokarz and Novak utilized GIS spatial autocorrelation models and RS techniques to identify and rank the most *prolific Anopheline larval's* habitats to monitor malaria disease outbreak in Uganda's rural communities [23]. In their study, a mosquito surveillance program that was designed and conducted by the local community in which they collected data related to the location of the larval habitats of Anopheles mosquitoes and plotted them spatially daily.

In Solomon Islands, RS and GIS technologies were also exploited and used to map a Plasmodium transmission's spatial suitability index [19]. Jeanne et al. suggested that remote sensing images can translate environmental preferences (e.g., availability of water sources, elevation, and distance to coastline) of *Anopheles farauti* into geolocated information. This is done to provide the basis for the computation of the Transmission Suitability Index (TSI). Then, RS image processing and GIS are used to develop the TSI model to predict the likely malaria transmission larval sources.

GPS can also be utilized to track devices and any ICT applications tools used to develop human activities model relative to land use and cover to assess the community's exposure to zoonotic malaria [12]. Based on the data obtained, communities located nearer to secondary forest have a higher probability of being infected with malaria. Besides collecting data related to malaria occurrence, finding the relationship between the human movement and space use is also important in determining the interactions between pathogens, insect vector and the community around the malaria habitats.

In a high-transmission area, GPS data loggers have also been used to assess the relations between the spatio-temporal movement patterns and malaria incidence [17]. In this study, 84 participants were interviewed and requested to undergo malaria testing and treatment. Then, their daily activities and movements were tracked and monitored using a GPS data logger. After 1 month, all participants were asked to have medical examinations again in which polymerase chain reaction was used to detect and identify the incidence of malaria infections. Based on the findings obtained, the data analysis's movement patterns show no significant association with the number of incidences of the parasitemia in this population. This is probably because the size of the sample was not enough to have significant statistical comparisons. Similar study found in which Searle et al. characterized and quantified the movement patterns of a human using GPS data loggers in rural southern Zambia [30].

A web-based GIS can also be used to detect malaria disease patterns based on the specific area using spatial parameters to support managers in making informed decisions [32]. For instance, a web-based GIS was developed to improve health-related services [32]. With the emergence of spatial statistics coupled with web-based GIS, more analysis can be made to predict or detect the malaria diseases outbreak.

A web based android software has also been developed and fully utilized in malaria surveillance program for aiding control of malaria in Mangaluru [22]. This GIS based software technology is designed and implemented to instantaneous transfer information such as number of cases reported, number of houses visited, and the number of cases closed with parasite clearance, numbers of malaria's sources eliminated [22]. Based on the findings obtained, the web based android software can facilitate an efficient execution of malaria control activities or program to eliminate the transmission cycle in that area.

Carrasco-Escobar et al. explored drones' application in their efforts to map the water bodies by extracting and using the normalized difference vegetation index (NDVI) from the multi-spectral imaging data [20]. It this work, they have demonstrated the efficiency of applying the extracted NDVI map the mosquito habitats. Previously, similar research has been done by Hardy et al. in which the malaria vector habitats were mapped using images captured by a low-cost drone [31].

B. Applications of Machine Learning Algorithms

Several studies have been found that focus on modeling or forecasting the malaria occurrence based on several types of data. In most studies, deep learning algorithms have a better predictive capability for predicting malaria disease outbreaks.

In order to predict the morbidity incidence of malaria disease, multiple Data Sources were integrated to predict malaria diseases in China using multiple machine learning models that include deep learning model (recurrent neural network, RNN), time series analysis model, boosting tree model and linear model were designed and implemented [14]. The RNN algorithm was found to have better predictive capability for malaria disease. The trends of Baidu search engine keywords and its volume were integrated with the maximum, minimum, and average morbidity incidence of malaria over the past 3 months were included in the proposed models.

Deep learning algorithms, such as LSTM and stacking algorithms (ensemble) are shown to be more superior in predicting Malaria outbreak with RMSE of 0.072 and 0.068 using meteorological data [15]. The findings also indicate that the ensemble stacking architecture produced promising results in predicting malaria disease prediction as different architecture produces different prediction results.

A deep learning algorithm, LSTM was also applied to predict malaria disease in Korea based on multiple sources of data that include meteorological data, social media data and keyword search trends [24]. Based on the findings obtained, the deep learning algorithms' performances are better than ARIMA when predicting malaria for the short term.

A machine learning LASSO algorithm was also assessed in term of its capability to provide useful forecast for malaria pathogen in countries with different climates [25]. Based on the results of the predictions obtained, long term predictions where predictions made beyond 4 weeks sahead were increasingly discrepant from the actual scenario. The LASSO algorithm is more accurate in capturing the outbreak but less sensitive to predicting the outbreak size.

Ren at al. studied the prediction of malaria vector distribution in China under different climate change scenarios, land use changes and urbanization simultaneously [38]. One of the outputs of this study is a map that indicates the potential current (suitable and unsuitable) and the predicted environmentally suitable area (ESA) for the four dominant malaria vectors (e.g*., An. dirus, An. minimus, An. lesteri and An. sinensis*) in China under different representative. However, one of the limitations is that the association between malaria vector presence and predictor variables based on current or historic data holds true under different climate projection scenarios.

Machine learning and image analysis have also been proposed for detecting malaria [26]. For instance, in this study, machine learning algorithms were used to analyze the different human malaria Plasmodium species in thin blood film to detect malaria disease. Some of the image processing methods include removing impulse noise and preserving edges, closing, and opening, filtering unwanted objects, hole filling, edge detection, enhancing image resolution, contrast enhancement, removing nonuniform illumination effects, illumination correction and normalization of image color profile. Given the fact that more and more studies apply the deep learning algorithms for features extraction and construction [48],[49] and classification, a large amount of annotated image repositories is highly required for training to improve the classification accuracy. Mwanga *et al.* proposed an approach that applies mid-infrared spectroscopy and logistic regression analysis to detect malaria parasites in dried human blood spots [16].

C. Applying Multiple Sources of Data

Several environmental factors have also been identified that are responsible for the malaria disease outbreak [28]. In malaria epidemiological studies, the malaria disease outbreaks can be linked with certain environmental features or factors which include rainfall, land cover and use, land surface temperature (LST), elevation and vegetation [46]. Several studies also indicated that the environmental [13], climatic [35], and socio-economic [14] risk factors are important for monitoring of malaria disease outbreak. For instance, deforestation affects the number of malaria occurrence. Communities located near to secondary forest have higher probability to be infected with the malaria diseases. Investigating the spatial and temporal data related to certain environmental features or factors that include land use and land cover, land surface temperature (LST), rainfall, vegetation and elevation can also improve the spread of the malaria disease outbreak [13].

An ecological study of mapping and modelling malaria risk can also be performed using GIS spatial and temporal models [13]. The findings show that there is a high positive relationship between the increase rate of deforestation and the increase number of malaria incidence in Rondonia. In other words, the number of malaria incidence decreases as the rate of deforestation decreases. The time-series dynamic regression results showed that the malaria incidence increases as the accumulated deforestation increases, whereas the human activity and development index does not affect the number of malaria incidence in Acre's westernmost areas.

Integrating case data with other information, strengthening modelling, visualization and use of data and improving coverage of surveillance are some of the areas that can be improved to strengthen the surveillance systems to reduce and eliminate the incidence of malaria disease outbreak [18].

D. Applications of Smartphone Technologies

Several studies combine several existing technologies to support malaria elimination campaigns to create more effective and efficient tools. For instance, Scherr et al. have combined mobile phone imaging and cloud-based analysis for standardized malaria detection and reporting [34]. In this study, Scherr et al. captured the Rapid diagnostic tests (RDT) and uploaded them into a globally accessible database (REDCap). These images are then analyzed by using three types of methods, namely image processing program, manual visual inspection, and finally, using a commercial lateral flow reader.

The widespread use of mobile phone SMS in rural areas, in which the health systems are weak and the infrastructure is poor due to the widespread of poverty, offers a solution for controlling the spread of malaria disease outbreak. The integration of m-Health and GIS with existing health systems helped model the spatial and temporal pattern of malaria and responded accordingly [36]. For instance, the utilization of smartphone technologies in rural populations has been proposed in Uganda in which this technology is called m-Health [33]. In this study, m-Health protocol based on the mobile network showed high efficiency as part of anti-malaria strategies. The m-Health approach has a high impact as it could outreach the vastest portion of the remote population. In a separate study, text messaging interventions have been proposed to support disease management in Africa [42].

The mobile phone-based technology has also been commonly used to collect and transfer health information and services in different settings for areas where the health systems are weak, and the infrastructure is poor due to widespread poverty [29]. In monitoring the malaria disease outbreak, mobile-application software has been developed for generating graphical and textual reports in real-time and cumulatively. This mobile phone-based technology's applicability in real-time reporting of fever cases was assessed by village health workers (VHWs) in north-eastern Tanzania. Based on the findings obtained in this study, mobile phone-based technology can be successfully used for improved malaria case management and drug resistance surveillance. A Smartphone-based app monitoring system was also developed and tested to identify and detect any infections in real-time among travelers [27].

E. *Framework for Spatial and ICT Tools and Applications*

This section deals with framework for spatial and ICT tools and applications as in Figure 2 below.

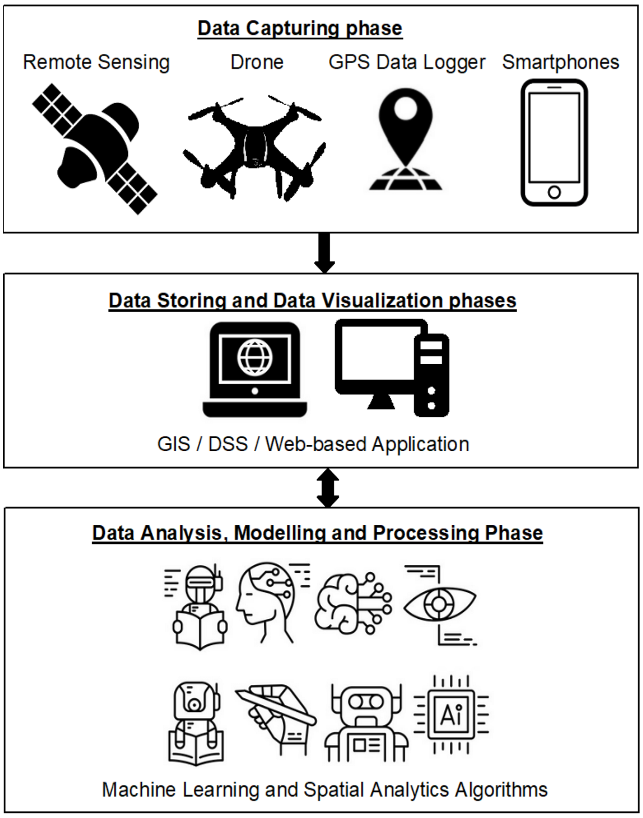

Fig. 2 Spatial technologies, tools, and applications framework for monitoring malaria disease outbreak

The review findings indicate that spatial technologies, machine learning algorithm have a vast potential for surveillance applications in monitoring malaria disease outbreak. Data captured from remote sensing, GPS data loggers, smartphones and drones can be used and coupled with other data stored on the GIS platform. These data are then preprocessed and analyzed using any of the machine learning algorithms by performing spatial analysis, data analysis, and image classification. We use the findings from the literature to develop spatial technology, tools, and applications framework that the practitioners can use to enhance the efforts of monitoring malaria disease outbreaks. The proposed framework shown in Fig. 2 has four main components: (a) Data Capturing phase; (b) Data Storing phases; (c) Data Analysis, Modelling, and Processing phase; (d) Data Visualization phase.

1) Data Capturing Phase: The data generated from different sources in the proposed framework was used for making predictions and classification using different machine learning algorithms. Remote sensing [18], [19], [23], [28], [40], [45] and drone [20], [31] are the most used technologies to capture imageries related to malaria habitats. GPS data logger is another spatial device that is used to track the movement of travelers in order to detect [12], [17], [30], [45], [38]. Other devices include mobile phones [36] and smartphones [29], [33].

2) Data Storing Phase: All the captured data was stored in the database. All data related to spatial were stored in the GIS database, and the others were stored in a traditional relational database [34]. A web-based platform or mobile-apps platform can be designed and implemented in order to access these data [22],[32].

3) Data Analysis, Modelling and Processing Phase: In the data modeling and visualization phase, data were analyzed or modeled in order to predict and detect the occurrence of the malaria disease outbreak. Machine learning algorithms can be used to analyzed non-spatial and temporal data [14],[15],[24],[25],[38], and the mapping and modeling of malaria risk can also be performed by using GIS spatial and temporal models [13]. Image processing can be used to process the imageries captured using remote sensing devices [26]. In addition to that, image classification is also applied in classifying blood for humans infected by malaria disease [16].

4) Data Visualization Phase: GIS can be used to visualize the exact location of the malaria disease outbreak [36]. There are also some efforts initiated to the development of smartphone-based applications to assist the efforts in monitoring, detecting, and visualizing malaria disease outbreaks system in real-time among travelers [27].

IV. Conclusion

The application of geographical information systems in monitoring the program activities to limit the spread of malaria disease outbreaks was enormously valuable [47]. A customized geographical information system (GIS) can be implemented to improve or enhance malaria monitoring [32], [41], [43]. Some challenges require attention in the future. These challenges are as follows; (a) Integration of multiple sources of data: Features extraction and selection, noise removal and reduction and integration of multiple types and sources of sources that includes structured and unstructured data to train better models and produce better prediction and detection capabilities; (b) Data Dependency: Determining the correlation of data using current or historical data under different climate projection scenario between malaria vector presence and predictor variables; (c) Better Models with Robust Predictive Capacity: Designing effective and efficient deep learning architecture to produce better accuracy in predicting and detecting the spread of malaria disease outbreak; Designing ensemble classifiers with a robust predictive capacity [50] (d) Quality of Data: Expanding the coverage of surveillance, integrating case data with other relevant information, and producing more robust models, improving the visualization and use of data. Based on the reviews in this paper, it can be concluded that the future development of hybrid approaches of GIS with the utilization of geostatistical and spatial analysis tools combined with high-quality data extracted from multiple types and sources of data can provide new and better insight into malaria epidemiology and understanding the complexity of malaria transmission potential in high-risk areas.

Acknowledgment

This work was supported by the Universiti Malaysia Sabah internal grant no. SBK0302-TK-2016 and SDN0076-2019.

References

[1] WHO. (2019) "World Malaria Report 2019", *Geneva: World Health Organization.* [Online]. Available: https://www.who.int/malaria/publications/world_malaria_report/en/

[2] Singh, B., and Daneshvar, C., "Plasmodium knowlesi Malaria in Malaysia", *Med J Malaysia*, vol.65, no.3, pp. 223–30. 2010.

[3] Rundi, C., (2011) Malaria Elimination in Malaysia. *Third annual meeting of the Asia Pacific Malaria Elimination Network (APMEN)*, Kota Kinabalu, Sabah, Malaysia.

[4] Kheong, C., (2020) Country Updates: Malaysia. Asian Collaborative Training Network for Malaria (ACTMalaria): Executive Board Meeting, Luang Prabang, Lao PDR.

[5] Sinka, M.e., Bangs, M.L., Manguin, S., Chareonviriyaphap, T., Patil, A.p., Temperley, W.H., "The dominant Anopheles vectors of human malaria in the Asia-Pacific region: occurrence data, distribution maps and bionomic precis," *Parasit Vectors*. 2011; 4: 89.

[6] Rahman, H., (2009) "Updates on Malaria Control Activities in Malaysia," *First annual meeting of the Asia Pacific Malaria Elimination Network* (APMEN); Brisbane, Australia.

[7] (2020) "Asian Collaborative Training Network for Malaria," *Malaysia-Country Profile: 2020.* [Online]. Available: https://www.actmalaria.net/home/

[8] (2018) "Malaysia Health at a Glance," *Malaysian Healthcare Performance Unit.* [Online]. Available: http://www.moh.gov.my/moh/penerbitan/MYHAAG2018.pdf

[9] (2010) "Country Health Plan, 10th Malaysia Plan 2011-2015," *Malaysian Healthcare Performance Unit.* [Online]. Available: http://www.moh.gov.my/moh/images/gallery/Report/Country_health.pdf

[10] Al-Adhroey, A., Zurainee, M.N., Hesham, A.M., Mahmud, R., "Opportunities and obstacles to the elimination of malaria from Peninsular Malaysia: knowledge, attitudes and practices on malaria among aboriginal and rural communities," *Malaria Journal*, vol.9, no.137, pp. 1–6, 2010.

[11] Kitchenham, B., "Procedures for performing systematic reviews," Keele, UK, Keele Univ. vol.33, pp. 1-26, 2004.

[12] Fornace, K.M., Alexander, N., Abidin, T.R., "Local human movement patterns and land use impact exposure to zoonotic malaria in Malaysian Borneo," *Elife*. 2019;8: e47602. doi:10.7554/eLife.47602, 2019.

[13] de Oliveira Padilha, M.A., de Oliveira, G. Romano, M.J., *et al.*, "Comparison of malaria incidence rates and socioeconomic-environmental factors between the states of Acre and Rondônia: a spatio-temporal modelling study," *Malar J* 18, 306 (2019). https://doi.org/10.1186/s12936-019-2938-0

[14] Jia, W., Wan, Y., Li, Y., *et al.*, "Integrating Multiple Data Sources and Learning Models to Predict Infectious Diseases in China," *AMIA Jt Summits Transl Sci Proc*. Vol.2019, no.2019, pp. 680–685. 2019.

[15] Wang, M., Wang, H., Wang, J., Liu, H., Lu, R., Duan, T., Gong, X., Feng, S., Liu, Y., Cui, C., Li, C., Ma, J., (2019) "A novel model for malaria prediction based on ensemble algorithms," *PLoS ONE* 14(12): e0226910. https://doi.org/10.1371/journal.pone.0226910

[16] Mwanga, E.P, Minja, E.G., *et al.*, "Detection of malaria parasites in dried human blood spots using mid-infrared spectroscopy and logistic regression analysis," *Malar J*, vol.18, no.341 (2019). https://doi.org/10.1186/s12936-019-2982-9

[17] Hast, M., Searle, K.M., *et al.*, "The use of GPS data loggers to describe the impact of spatio-temporal movement patterns on malaria control in a high-transmission area of northern Zambia," *Int J Health Geogr*, vol.18, no.19, 2019. https://doi.org/10.1186/s12942-019-0183-y

[18] Lourenço, C., Tatem, A.J., Atkinson, P.M., Cohen, J.M., Pindolia, D., Bhavnani, D. and Menach, A.L., "Strengthening surveillance systems for malaria elimination: a global landscaping of system performance, 2015–2017," *Malar J* vol.18, no.315, 2019. https://doi.org/10.1186/s12936-019-2960-2

[19] Jeanne, I., Chambers, L.E., Kazazic, A., Russell, T.L., Bobogare, A., Bugoro, H., Otto, F., Fafale, G., and Amjadali, A., "Mapping a Plasmodium transmission spatial suitability index in Solomon Islands: a malaria monitoring and control tool," *Malar J* vol.17, no.381, 2018. https://doi.org/10.1186/s12936-018-2521-0

[20] Carrasco-Escobar, G., Manrique, E., Ruiz-Cabrejos, J., Saavedra, M., Alava, F., Bickersmith, S., Prussing, C., Vinetz, J.M., Conn, J.E., Moreno, M., Gamboa, D., "High-accuracy detection of malaria vector larval habitats using drone-based multispectral imagery," *PLoS Negl Trop Dis* vol.13, no.1., e0007105, 2019. https://doi.org/10.1371/journal.pntd.0007105

[21] Mohammed, M.A., "Malaria prone area analysis and mapping using geospatial tools: The case of Amibara and Gewane Woreda, afar region, Ethiopia," *Journal of Geography and Regional Planning* vol. 11, no.6, pp. 80-94, 2018.

[22] Baliga, S., Koduvattat, N., Kumar, M.,Rathi, P., Jain, A., "GIS based software technology assistance for effective control of malaria in Mangaluru, India," *International Journal of Infectious Diseases*. Vol.73, no.222, 2018. 10.1016/j.ijid.2018.04.3919.

[23] Tokarz, R., Novak, R.J., "Spatial–temporal distribution of Anopheles larval habitats in Uganda using GIS/remote sensing technologies," *Malar J*, vol.17, no.420, 2018. https://doi.org/10.1186/s12936-018-2567-z

[24] Chae, S., Kwon, S., Lee, D., "Predicting Infectious Disease Using Deep Learning and Big Data," *Int J Environ Res Public Health.* vol.15, no.8, pp.1596, 2018. doi:10.3390/ijerph15081596

[25] Chen, Y., Chu, C.W., Chen, M.I.C., Cook, A.R., "The utility of LASSO-based models for real time forecasts of endemic infectious diseases: A cross country comparison," *J Biomed Inform*. No. pp. 16–30, 2018. doi: 10.1016/j.jbi.2018.02.014

[26] Poostchi, M., Silamut, K., Maude, R.J., Jaeger, S., Thoma, G., "Image analysis and machine learning for detecting malaria," *Translational Research*, vol.194, pp. 36-55, 2018, ISSN 1931-5244, https://doi.org/10.1016/j.trsl.2017.12.004.

[27] Rodriguez-Valero, N., Ledesma Carbayo, M.J., *et al.*, "Real-time incidence of travel-related symptoms through a smartphone-based app remote monitoring system: a pilot study," *Journal of Travel Medicine*, vol.25, no.1, 2018, tay034, https://doi.org/10.1093/jtm/tay034

[28] Dung, P., Omalu, I.C.J., Akintola, A., Dan, Y., Kalesanwo, A.O., Babagana, M., Muhammad, S.A., Ocha, I.M., Kamoru, A., "The Role of GIS And Remote Sensing in the Control of Malaria," *Online Journal of Health and Allied Sciences*. vol.16, no.7, 2017.

[29] Francis, F., Ishengoma, D.S., Mmbando, B.P., *et al.*, "Deployment and use of mobile phone technology for real-time reporting of fever cases and malaria treatment failure in areas of declining malaria transmission in Muheza district north-eastern Tanzania," *Malar J*, vol.16, no.308, 2017. https://doi.org/10.1186/s12936-017-1956-z

[30] Searle, K.M., Lubinda, J., Hamapumbu, H., Shields, T.M., Curriero, F.C., Smith, D.L., Thuma, P.E., Moss, W.J., "Characterizing and quantifying human movement patterns using GPS data loggers in an area approaching malaria elimination in rural southern Zambia," *Royal Society Open Science*. vol.4, no.5, pp. 170046, 2017. DOI: 10.1098/rsos.170046.

[31] Hardy, A., Makame, M.O., Cross, D.E., Majambere, S., and Msellem, M.I., "Using low-cost drones to map malaria vector habitats," *Parasites & Vectors*, vol.10, 2017.

[32] Bui, T.Q., Pham, H.M., "Web-based GIS for spatial pattern detection: application to malaria incidence in Vietnam," *SpringerPlus* 5, 1014, 2016. https://doi.org/10.1186/s40064-016-2518-5

[33] Larocca, A., Visconti, A.M., Marconi, M., "Malaria diagnosis and mapping with m-Health and geographic information systems (GIS): evidence from Uganda," *Malaria journal*, vol.15, no.1, pp. 520, 2016, https://doi.org/10.1186/s12936-016-1546-5

[34] Scherr, T.F., Gupta, S., Wright, D.W., and Haselton, F.R., "Mobile phone imaging and cloud-based analysis for standardized malaria

detection and reporting," *Sci Rep*, vol.6, 28645, 2016. https://doi.org/10.1038/srep28645

[35] Qayum, A., Arya, R., Kumar, P., Lynn, A.M., "Socio-economic, epidemiological and geographic features based on GIS-integrated mapping to identify malarial hotspots," *Malar J*. vol.2015, no.14, pp. 192. doi: 10.1186/s12936-015-0685-4.

[36] Xia, J., Cai, S., Zhang, H., Lin, W., Fan, Y., Qiu, J., *et al.*, "Spatial, temporal, and spatiotemporal analysis of malaria in Hubei Province, China from 2004–2011," *Malar J*., vol.2015, no.14, pp. 145. doi: 10.1186/s12936-015-0650-2.

[37] Gwitira, I., Murwira, A., Zengeya, F.M., Masocha, M., "Modelled habitat suitability of a malaria causing vector (Anopheles arabiensis) relates well with human malaria incidences in Zimbabwe," *Appl Geogr*. vol.2015, no.60, pp. 130–138. doi: 10.1016/j.apgeog.2015.03.010.

[38] Ren, Z., Wang, D., Ma, A., *et al.*, "Predicting malaria vector distribution under climate change scenarios in China: Challenges for malaria elimination," *Sci Rep,* vol.6, 20604, 2016. https://doi.org/10.1038/srep20604

[39] Fradelos, E.C., Papathanasiou, I.V., Mitsi, D., Tsaras, K., Kleisiaris, C.F., and Kourkouta, L., "Health Based Geographic Information Systems (GIS) and their Applications," *Acta informatica medica: AIM: journal of the Society for Medical Informatics of Bosnia & Herzegovin*a: casopis Drustva za medicinsku informatiku BiH, vol.22, no.6, pp. 402–405, 2014. https://doi.org/10.5455/aim.2014.22.402-405

[40] Ahmed, A., "GIS and Remote Sensing for Malaria Risk Mapping, Ethiopia. ISPRS - International Archives of the Photogrammetry," *Remote Sensing and Spatial Information Sciences*. vol. XL-8. pp. 155-161, 2014, https://doi.org/10.5194/isprsarchives-XL-8-155-2014.

[41] Chanda, E. Mukonka, V.M., Mthembu, D., Kamuliwo, M., Coetzer, S., Shinondo, C.J., "Using a geographical-information-system-based decision support to enhance malaria vector control in zambia," *J Trop Med*. vol.2012, 363520, 2012 doi:10.1155/2012/363520. PMID: 22548086; PMCID: PMC3323906.

[42] Zurovac, D., Talisuna, A.O., Snow, R.W., "Mobile phone text messaging: tool for malaria control in Africa," *PLoS medicine*, vol.9, no.2, 2012, e1001176. https://doi.org/10.1371/journal.pmed.1001176

[43] Kelly, G.C., Seng, C.M., Donald, W., *et al.*, "A spatial decision support system for guiding focal indoor residual interventions in a malaria elimination zone," *Geospat Health*, vol.6, no.1, pp. 21–31, 2011. doi:10.4081/gh.2011.154

[44] Geospatial World. (2010) "Application of GIS to predict distribution of malaria vectors in India," [Online]. Available: https://www.geospatialworld.net/article/application-of-gis-to-predict-distribution-of-malaria-vectors-in-india/

[45] Saxena, R., Nagpal, B., Srivastava, A., Gupta, S., Dash, A., "Application of spatial technology in malaria research & control: Some new insights," *The Indian journal of medical research*. vol.130, pp. 125-32, 2009.

[46] Curran, P.J., Atkinson, P.M., Foody, G.M., Milton, E.J., "Linking remote sensing, land cover and disease," *Adv Parasitol*, vol.47, pp. 37–80, 2000. doi:10.1016/s0065-308x(00)47006-5

[47] Booman, M., Durrheim, D.N., La Grange, K., *et al.*," Using a geographical information system to plan a malaria control programme in South Africa," *Bull World Health Organ*. vol.78, no.12, pp. 1438–1444, 2000.

[48] Alfred, R., "Feature Transformation: A Genetic-Based Feature Construction Method for Data Summarization," *Computational Intelligence*, vol.27, no.3, pp. 315-335, 2011, Published by John Wiley & Sons, Ltd.

[49] Alfred, R "The Study of Dynamic Aggregation of Relational Attributes on Relational Data Mining," In: Alhajj R., Gao H., Li J., Li X., Zaïane O.R. (eds) *Advanced Data Mining and Applications. ADMA 2007. Lecture Notes in Computer Science*, vol.4632. Springer, Berlin, Heidelberg, 2007

[50] Alfred, R., Shin, K.K., Chin, K.O., Lau, H.K., and Hijazi, M.H.A, "k-NN Ensemble DARA Approach to Learning Relational," *Proceedings of the International Conference on Data Engineering 2015 (DaEng-2015)*, pp. 203-212., 2019, 10.1007/978-981-13-1799-6_22.

[51] Odhiambo, J.N., Kalinda, C., Macharia, P.M., et al., Spatial, and spatio-temporal methods for mapping malaria risk: a systematic review, BMJ Global Health, vol.2020, no.5, pp. e002919, 2020.

[52] Pahrol, M.A., Noraishah, M.S., Nasir, R.A. "Spatial Distribution of Malaria Incidence in Sabah from 2012 to 2016. Geoinfor Geostat: An Overview", vol.6, no.3. doi: 10.4172/2327-4581.1000184, 2018.

[53] Khashoggi, B.F.; Murad, A. Issues of Healthcare Planning and GIS: A Review. ISPRS Int. J. Geo-Inf., vol.9, no.6, pp. 352, 2020.

[54] Murad, A.; Khashoggi, B.F. Using GIS for Disease Mapping and Clustering in Jeddah, Saudi Arabia. ISPRS Int. J. Geo-Inf. 2020, vol.9, no.5, pp. 328.