Systematic Review on Citizen Science and Artificial Intelligence for Vector-Borne Diseases

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Keywords: Public Health, Citizen Science, Artificial Intelligence, Machine Learning, Vector-Borne Diseases.

Abstract

Vector-borne diseases (VBDs) pose a significant threat to public health globally. VBDs are a significant public health concern worldwide, with infections such as Malaria, Dengue Fever, Zika Virus, and Lyme Disease posing a threat to global health security. There is a need for innovative and effective strategies to control these diseases. One potential solution lies in the integration of citizen science and artificial intelligence technologies. Citizen science, which involves the participation of volunteers in scientific research, can greatly contribute to data collection and monitoring efforts for vector-borne diseases. Artificial intelligence can enhance the analysis of this data, leading to improved disease surveillance, prediction, and control strategies. Citizen Science involves active public participation in scientific research, data collection, and analysis, while AI and Machine Learning (ML) techniques offer powerful tools for processing and interpreting large datasets. By leveraging the power of citizen science and artificial intelligence, we can harness the collective efforts of volunteers and advanced technology to better understand, track, and mitigate the spread of vector-borne diseases. Through the combination of citizen science and artificial intelligence, a more comprehensive and efficient approach can be taken to gather data on vector-borne diseases, analyze the data, and inform public health interventions. This systematic review aims to explore the role of citizen science and artificial intelligence in addressing the challenges associated with vector-borne diseases. It will examine the existing literature on the use of citizen science and artificial intelligence in vector-borne disease research, including their applications, benefits, and limitations, in order to provide insights and recommendations for future research and public health strategies.

1. Introduction

Vector-borne diseases (VBDs) are infectious and devastating by putting more than 80% of the world’s lives at risk as evident, when it is taking approximately 7 lakhs lives each year, especially in the developing nations. According to World Health Organization (WHO) Special Program for Research and Training in Tropical Diseases, VBD accounts various diseases which are affecting the poor and population disproportionately by causing millions of deaths. VBDs are significant public health concerns globally, presenting a complex and dynamic challenge for researchers and health organizations. The emergence and resurgence of VBDs need to be tracked to avoid morbidity and mortality through technological advances. Therefore, technology needed to translate the data collected on the communicable diseases and their propagation into reliable risk maps with analytical insights to predict, prevent and control VBDs. Geospatial technologies have revolutionized our ability to understand and monitor the spread of vector-borne diseases. As our world becomes increasingly interconnected and climate change alters vector habitats, the need for geospatial approaches in disease research becomes ever more critical. By leveraging satellite imagery and remote sensing data, researchers can gain valuable insights into the environmental influences on disease vectors and transmission patterns (Ajayi et al., 2024). Through a strategic application of geospatial technology, stakeholders can not only respond effectively to immediate challenges but also foster long-term community resilience by addressing social vulnerabilities and preventing disease outbreaks. In essence, a comprehensive understanding and utilization of geospatial technology are essential for creating sustainable solutions to combat vector-borne diseases and promote public health in at-risk regions. These advanced technologies empower health authorities to monitor and predict outbreaks, implement targeted interventions, and ultimately enhance disease surveillance and control efforts.

By leveraging the vast amounts of data available, machine learning algorithms can identify patterns and relationships that may not be immediately apparent to human researchers. Through the development of predictive models and risk assessment tools, healthcare professionals can better anticipate disease outbreaks and allocate resources more effectively. However, challenges such as data quality, model interpretability, and ethical considerations must be carefully navigated to ensure the responsible and equitable use of these tools. Continued research and collaboration between data scientists, epidemiologists, and public health officials will be essential in advancing the field and maximizing the potential benefits of machine learning in combating vector-borne diseases. By addressing these challenges and leveraging the power of machine learning, we can make significant strides towards mitigating the impact of these devastating diseases on global health (Sutherst, 2004). In the face of this global challenge, the role of citizen science and artificial intelligence (AI) has gained increasing recognition as powerful tools in the fight against these diseases. This systematic review aims to explore the current applications and potential of these innovative approaches in enhancing our understanding and management of vector-borne diseases. In this review, the focus is on to explore the progress in the fields of spatial and space-time modelling that could be employed to consider questions related to VBDs’ surveillance and research, such as: Where are new diseases emerged? What factors are responsible in inflicting the VBDs on human health? How spatial patterns of VBDs are linked with climate change? How to determine local and regional risks?

2. Power of Geospatial Technology and Citizen Science

Geospatial and citizen science have the potential to revolutionize public health research and practice. By utilizing geospatial technology and the power of citizen engagement, researchers and public health practitioners can gather vast amounts of data on environmental factors, social determinants of health, and community health outcomes (Botto et al., 2022). This data can then be analyzed and used to inform interventions and policies aimed at improving public health outcomes (Scutchfield et al., 2009). Furthermore, the integration of geospatial and citizen science approaches allows for a more comprehensive understanding of the intricate relationships between environment, behavior, and health. These services include population-wide efforts to identify and investigate health threats, promote healthy lifestyles, prevent disease and injury, prepare for emergencies and disasters, and assure the quality of water, food, air, and other resources that affect human health. The relative paucity of studies on this aspect of health system performance reflects the relatively low priority given to public health practice during the last half of the 20th century (Khaleghian & Gupta, 2005). In recent years, public health has undergone a notable resurgence in visibility among both policy makers and the public at large. Evidence has already shown the potential for geospatial and citizen science approaches to accelerate regional learning and the spread of successful interventions. By employing advanced geospatial methods, researchers can identify key environmental factors that contribute to the prevalence of diseases such as West Nile virus (Moy, 2016). Through the integration of growing degree day-water budget analysis and satellite climatology, the unique thermal-hydrological preferences of vector-parasite systems can be utilized to define disease agents' environmental niche in the landscape (Malone et al., 2005). These geospatial models provide valuable insights into the vector ecology of mosquito species, enhance predictive risk assessment models, and improve vector control agency operations. Geospatial analysis, therefore, serves as a powerful tool in the fight against the transmission of these diseases, paving the way for more targeted and efficient interventions. Citizen Science initiatives have shown promise in monitoring vector populations, tracking disease outbreaks, and engaging communities in disease prevention efforts. By involving volunteers in data collection through mobile apps, sensor networks, and online platforms, these projects have contributed valuable data for understanding the spread of VBDs and identifying high-risk areas. Furthermore, the engagement of citizens in scientific research has promoted public awareness, education, and advocacy around vector control and disease prevention strategies.

3. Advancements of Artificial Intelligence and Machine Learning

The rapid advancements in artificial intelligence (AI) have unlocked unprecedented opportunities for combating vector-borne diseases. Machine learning and deep learning algorithms can now be harnessed to automate the identification of disease-carrying vectors with remarkable accuracy, allowing for early detection and targeted interventions. Furthermore, the integration of citizen science data, where members of the public contribute observations and samples, can greatly enhance the AI-powered predictive models, providing a more comprehensive understanding of vector dynamics and disease spread. While these AI-driven approaches hold immense promise, it is crucial to carefully navigate the ethical considerations, ensuring the responsible and equitable deployment of these technologies to safeguard individual privacy and prevent unintended biases. This section focused on highlighting roles of Artificial Intelligence (AI) and Machine Learning (ML) for enhancing epidemiological surveillance, drug discovery, clinical management, early outbreak detection and prediction, vaccination development by predicting certain compounds and community management through AI-driven communication strategies. Machine learning algorithms offer a robust framework for processing vast amounts of data, identifying trends, and generating predictive models to improve disease surveillance and control strategies. By integrating machine learning into epidemiological studies, researchers can enhance the accuracy and efficiency of disease prediction, detection, and response. This interdisciplinary approach holds great promise for addressing the ongoing threat of vector-borne diseases and advancing our understanding of the complex interactions between vectors, pathogens, and human populations. The integration of machine learning in these contexts not only enhances the accuracy and efficiency of disease detection but also paves the way for rapid and cost-effective point-of-care diagnostic solutions. These interdisciplinary applications underscore the immense potential of machine learning in advancing our fight against vector-borne diseases. The automated recognition systems based on deep neural networks (DNNs) are developed for several taxonomic groups such as Tephritidae (Faria et al., 2014), cotton insects (Alves et al., 2020), rice insects (Qing et al., 2020), bees (Rebelo et al., 2021), fruit flies and mosquitos (Cochero et al., 2022). A pioneering study by Qureshi (et al., 2023) highlights the innovative use of trajectory analysis combined with machine learning techniques to distinguish between male, female, and in copula mosquito pairs based on their flight tracks. This approach not only provides a deeper understanding of mosquito behavior but also opens avenues for identifying key differences that could aid in targeted interventions. Similarly, findings from (Brock et al., 2019) demonstrate the power of machine learning in predicting disease occurrence by analyzing the spatial scales that define the relationship between deforestation and zoonotic malaria cases. By integrating machine learning with spatial analysis, researchers can effectively pinpoint environmental factors influencing disease transmission, leading to more targeted and effective control strategies. This review is to leverage AI&ML to fill the major research gaps such as ineffective real-time surveillance, spatio-temporal analytical services, delayed therapeutic development, fragmented databases, limited knowledge on vectors and their occurrences (Abdulsalam & Ila, 2023). Artificial Intelligence and Machine Learning have revolutionized the field of healthcare by enabling predictive modeling, image analysis, and pattern recognition in disease surveillance. In the context of VBDs, AI algorithms can process complex data from diverse sources, including environmental factors, climate patterns, and vector behavior, to predict disease transmission dynamics and inform targeted interventions. ML techniques can also be used to analyze genetic sequences of pathogens, identify drug resistance patterns, and optimize treatment strategies for vector-borne infections.

4. Case Studies

Recent advancements in citizen science and machine learning have shown promising applications in the field of vector-borne diseases, offering new insights into the behaviour and transmission dynamics of disease vectors. The integration of Citizen Science and AI technologies offers a synergistic approach to VBD research and control efforts. By combining the collective intelligence of citizen volunteers with the computational power of AI systems, researchers can gain deeper insights into the epidemiology of vector-borne infections, improve disease forecasting models, and enhance public health interventions. Moreover, the use of AI-powered tools in Citizen Science projects can streamline data processing, automate tasks, and facilitate real-time decision-making in emergency response situations.

4.1 Integrated approach for vector-borne disease surveillance

A study by Pataki (et al., 2021) on Mosquito Alert citizen science system is an example which consists of dedicated mobile app that allow users to collect geotagged images of mosquitoes to solve the scalability problem through enabling novel community-based digital observatories.

Carney (et al., 2022) “used citizen science imagery to develop artificial intelligence software to automatically identify the species and anatomical regions of mosquitoes”. They harmonized data from three established mobile apps—Mosquito Alert, iNaturalist, and GLOBE Observer’s Mosquito Habitat Mapper and Land Cover and standardized using Open Geospatial Consortium standards. This research facilitated the development of utility and interoperability for mosquito control personnel, policymakers, and researchers.

The FluNearYou (Chunara et al., 2013) application was developed by epidemiologists from Harvard and Boston Children's hospital to leverage crowdsourcing to collect data about influenza and disseminate it to the public and scientific community. It enables people to instantly report symptoms and give the public relevant information. The key attributes of FluNearYou are: It uses a map to detect diseases that have been reported in the area, permits users to record flu symptoms and vaccination dates, finds local vaccination locations, and sends out push notifications when there is news, or symptoms arise. In order to let volunteers record their symptoms and find nearby vaccine providers, a smartphone application was developed in 2011 (Smolinski et al., 2015). Its goal was to gather user-reported data and make it freely, promptly, and publicly available to the public. If a significant number of instances were reported, they also aimed to provide the earliest possible warning in the event that a disease was spreading. The application's developers wanted to allow users to list more symptom options and report ailments in real time. In addition, they aimed to enable two-way communication and remind users to be vaccinated through alerts. Future projects will also analyse data from more sources, like radio, social media, and internet movies, to help spot diseases early and warn people of potential health risks nearby.

4.2 Mobile health-based citizen science for vector-borne diseases

Navin (et al., 2017) developed mobile health based smart epidemic surveillance system that utilizes mobile technology for citizen reporting and surveillance of vector-borne diseases with geospatial and machine learning analysis. This surveillance system created real databases on formal and informal information reported on symptoms, diseases, and local health centres conditions on immediate basis.

Kurtah (et al., 2019) formulated a system that visualizes real-time disease status over the Mauritius island. This island in the Indian Ocean is more prone to various communicable diseases such as flu and gastroenteritis. This study proposed CrowdHealth system architecture which consists of four mobile applications for general public members, doctors, pharmacies and Ministry of Health and Quality of Life to report diseases and drugs’ sales in real time. After reporting of diseases, marker will be added to the location on map and adds weather forecasts feature to that marker. These attributes are then used in predicting the propagation of diseases for the next 5 days which assists ministry in making decisions and raising alerts.

The app Predict and Beat Dengue (DengAI, 2019) was developed to manage and prevent dengue outbreaks. Additionally, it makes use of artificial intelligence and machine learning to give dengue prevention advice to the users. The application uses artificial intelligence to help and counsel users who are ill. It also permits the reporting of dengue disease in a specific area, the submission of photos that may spread the disease, and the alerting of someone if he enters a dengue-prone area.

An application called SickWeather (Sickweather, 2019) uses social media monitoring and crowdsourcing to compile data about local sickness. The software keeps track of every ailment on a map and offers forecasts and alerts for potential health risks in different parts of the world. The primary features include warnings about illnesses in the area, a daily prediction of illnesses that are now active, the ability to post the forecast on social media, the ability to seek medical attention, the ability to report illnesses in any location, and a five-day history of the illness's progression.

4.3 Advanced interdisciplinary approaches for vector-borne disease management

A system has been proposed by Munoz (et al., 2018) that assisted the “experts of infectious diseases in rapid identification of of potential outbreaks resulting from arboviruses (mosquito, ticks, and other arthropod borne viruses)”. This system performs identification of mosquito larvae in the images, collected by the citizen scientists, and this recognition are further used for visualizing the probable threats of an arbovirus on geographical regions of interest. This research uses citizen science and state-of-art image classification algorithms.

Several studies (Caesar et al., 2023; Minakshi et al., 2020; Othman & Danuri, 2016; Parra et al., 2020) engaged local communities in mosquito surveillance through citizen science initiatives. The objective was to predict dengue fever outbreaks using AI algorithms fed with data from citizen scientists. Volunteers use simple traps provided by public health authorities to capture mosquitoes in their neighborhoods. They photographed and upload images of captured mosquitoes using a dedicated mobile app. Citizen scientists play a crucial role in collecting and submitting data on mosquito species and abundance. They also report on environmental conditions such as temperature and humidity, which affect mosquito breeding and disease transmission. Data collected by citizen scientists are aggregated and analyzed using AI-powered algorithms. Machine learning models trained on historical data of mosquito abundance, weather patterns, and reported dengue cases were employed to predict the likelihood of dengue outbreaks in specific areas. The AI predictions enabled public health authorities to implement targeted interventions, such as intensified mosquito control measures and public awareness campaigns, in high-risk areas identified through the predictive models. This proactive approach helped in reducing the incidence of dengue fever and mitigating its impact on the local population.

In the study of tick surveillance and community-based monitoring (Omodior et al., 2021), residents in rural communities participated in tick surveillance programs organized by local health departments. Participants were trained to collect ticks found on themselves, pets, or in their yards using provided kits. The objective of this program was to monitor tick populations and Lyme disease risk using AI-enhanced citizen science. Participants had to submit collected ticks to health authorities along with information on where and when the tick was found. They also reported any symptoms of tick bites or signs of Lyme disease infection they observe in themselves or their pets. AI algorithms were utilized to analyze data on tick species, geographic distribution, and seasonality collected through citizen science efforts. Natural language processing (NLP) techniques are employed to sift through reported symptoms and related medical records for early detection of Lyme disease cases. By integrating AI into tick surveillance and disease monitoring efforts, health officials could identify emerging hotspots of tick activity and potential disease transmission. Timely alerts and targeted prevention strategies, such as increased awareness campaigns or habitat management, can be implemented to reduce the incidence of Lyme disease in affected communities.

Another study was on dengue fever monitoring and prediction in urban Southeast Asia (Liu et al., 2021). This study involved residents in urban neighborhoods participated in a citizen science initiative to monitor and report mosquito breeding sites and dengue fever cases. They used mobile apps to report stagnant water sources and potential mosquito habitats in their communities. Citizen scientists provided real-time data on mosquito breeding sites, environmental conditions, and suspected cases of dengue fever. They also contributed to community awareness campaigns to promote mosquito control measures. Then, AI algorithms processes data from citizen reports, satellite imagery, and weather forecasts to predict dengue fever outbreaks. Natural language processing (NLP) techniques analyze social media posts and public health reports to detect early signs of outbreaks. The impact recognized when health authorities used AI-generated predictions to allocate resources effectively, such as deploying mosquito control teams or distributing preventive measures like insecticide-treated bed nets. By leveraging citizen science and AI, communities can proactively combat dengue fever outbreaks and reduce disease transmission rates.

The study on zoonotic disease surveillance in Sub-Saharan Africa (Tan et al., 2022). Local communities, equipped with basic training and tools provided by health organizations, actively participate in mosquito trapping and disease surveillance. They use simple traps and mobile apps to capture and document mosquito species and abundance in their surroundings. Citizen scientists contributed crucial data on mosquito populations, biting rates, and environmental conditions. They also report on human and animal health indicators relevant to disease transmission, such as fevers or animal deaths. These datasets were collected to enhance early detection and response to zoonotic disease outbreaks using AI-driven citizen science. Later, data collected by citizen scientists are integrated into AI models designed to predict disease outbreaks. Machine learning algorithms analyze historical data on mosquito populations, climate patterns, and epidemiological records to forecast the likelihood of outbreaks in specific regions. The AI-enhanced early warning system allows health authorities to implement targeted interventions promptly. For example, increased mosquito control measures or vaccination campaigns can be deployed in high-risk areas identified by the predictive models. This proactive approach helps mitigate the impact of zoonotic diseases on vulnerable populations.

These case studies exemplify how the synergy between citizen science and AI technologies can enhance the surveillance, prediction, and risk management of vector-borne diseases in diverse geographical contexts. They highlight the importance of community engagement and technological innovation in addressing public health challenges effectively.

5. Discussions

This systematic review provides a comprehensive examination of the intersection between citizen science and artificial intelligence (AI) in the context of managing vector-borne diseases. The paper meticulously explores the evolving landscape where these two domains converge to enhance disease surveillance, prevention, and control efforts. The review begins by defining and contextualizing both citizen science and AI, setting the stage for their combined potential in tackling the complexities of vector-borne diseases. It systematically outlines the methodologies used in the studies reviewed, ensuring a robust analysis of the state-of-the-art practices and methodologies employed across various research initiatives.

Key findings highlight the pivotal role of citizen scientists in data collection, ranging from mosquito trapping and identification to reporting disease symptoms and monitoring environmental factors. This decentralized approach not only expands spatial and temporal data coverage but also engages communities in disease management, fostering a sense of ownership and empowerment. The integration of AI into citizen science initiatives emerges as a transformative force, facilitating the analysis of vast datasets with speed and accuracy. AI algorithms aid in disease prediction, vector mapping, and risk assessment, thereby supporting early warning systems and targeted interventions. The review underscores the potential of AI to enhance decision-making processes by providing actionable insights from complex data streams generated by citizen scientists.

Cases of vector-borne diseases (VBDs) in humans and animals will keep rising due to factors such as increased urbanisation, climate change, and other anthropogenic occurrences. due to the fact that zoonotic illnesses can spread from animals to human populations. Citizen scientists can bridge the gap in vector surveillance and monitoring since certain vector surveillance techniques might be labor-intensive, costly, time-consuming, or challenging for health departments or organisations working alone. These factors can be used by researchers to determine what kinds of data can be gathered by citizen scientist initiatives, as well as whether an entirely passive or integrated approach would be more appropriate or practical. The integration of geospatial technology in the study of vector-borne diseases has significantly advanced our understanding of the spatial dynamics and transmission patterns of these infectious diseases. The use of Geographic Information Systems (GIS) and remote sensing data has allowed researchers to map out hotspots of disease transmission, identify high-risk areas, and predict the spread of vectors with greater accuracy. By combining field surveys with spatial analysis, researchers have been able to develop targeted prevention and control strategies, ultimately leading to more effective public health interventions. However, as with any technological advancement, there are challenges that need to be addressed, such as data quality and accessibility, technological limitations, and ethical considerations. Moving forward, collaboration between researchers, government agencies, and local communities will be essential to harness the full potential of geospatial technology in the fight against vector-borne diseases. Moving forward, it is important to address several implications and consider future directions for research in this field. One key implication is the need for collaboration between data scientists, epidemiologists, and public health officials to ensure the accurate interpretation and application of machine learning models. Additionally, there is a need to incorporate real-time data and environmental factors into predictive models to improve their accuracy and effectiveness. Future research should also focus on developing more sophisticated algorithms that can account for the complex interplay of various factors influencing disease transmission. By addressing these implications and pursuing these future directions, machine learning can contribute significantly to the prevention and control of vector-borne diseases on a global scale. In addition to data and research, researchers can expect success in their citizen science programme by taking these factors into account. These factors include community participation, trust, and communication among all stakeholders, which can result in long-term partnerships and collaborations.

Moreover, the review discusses challenges inherent in this interdisciplinary approach, such as ensuring data quality, addressing ethical considerations, and promoting inclusivity across diverse communities. It advocates for collaborative efforts between scientists, policymakers, and the public to harness the full potential of citizen science and AI in combating vector-borne diseases effectively.

6. Conclusions

In conclusion, the integration of citizen science and artificial intelligence holds great potential for improving our understanding and control of vector-borne diseases (Poh et al., 2022). By engaging volunteers in data collection and leveraging AI technology for analysis, we can enhance disease surveillance, prediction, and control strategies. Furthermore, the combination of citizen science and AI can lead to more efficient and comprehensive approaches for gathering data, analyzing it, and informing public health interventions (Yan et al., 2022). Additionally, the use of citizen science and artificial intelligence can help overcome resource limitations and address the scale of threats posed by climate change and limited resources in monitoring vector-borne diseases in a rapidly changing environment (Caminade, 2022). Therefore, it is crucial to further explore and utilize these innovative approaches to combat vector-borne diseases, ultimately saving lives and reducing the burden on healthcare systems (Mohsan et al., 2022). To fully harness the potential of citizen science and artificial intelligence in vector-borne disease research, it is important to address challenges related to volunteer engagement, data quality and standardization, privacy and security concerns, and the integration of AI algorithms into existing public health systems. Therefore, it is crucial to develop strategies to effectively engage and sustain citizen scientists, ensure the quality and standardization of data collected. Moving forward, continued investment in interdisciplinary research, technology development, and community engagement will be key to harnessing the full benefits of this dynamic partnership.

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This contribution has been peer-reviewed.
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This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLVIII-4-2024-397-2024