Revista **Ciências Exatas**
V.30, N°2, 2024 | Taubaté/SP - Brasil | **ISSN:** 1516-2893 | **DOI:** https://doi.org/10.69609/1516-2893.2024.v30.n2.a3905

SMART DENGUE CONTROL: INTEGRATED USE OF ARTIFICIAL INTELLIGENCE AND BIOLOGICAL METHODS AGAINST AEDES AEGYPTI

Bianca de Cássia Cardoso Beraldo | 202110332@unifoa.edu.br | UniFOA, Centro Universitário de Volta Redonda

Flávia Coelho Rocha | UniFOA, Centro Universitário de Volta Redonda

Marcus Vinicius Faria de Araujo | UniFOA, Centro Universitário de Volta Redonda

Antonio Henriques de Araujo Junior | Universidade do Estado do Rio de Janeiro

Felipe Monteiro Viagi | Universidade de Taubaté

Arcione Ferreira Viagi | Universidade de Taubaté

SUMMARY

This research presents a novel approach to combating dengue by integrating Biological Control methods with Artificial Intelligence (AI). The objective of the study is to reduce the Aedes aegypti mosquito population and decrease dengue transmission through sustainable strategies. A comprehensive research methodology was used, involving extensive literature review, case studies, and data analysis to identify the main factors driving the high incidence of dengue in Brazil. The research applied AI tools to analyze epidemiological, meteorological, and environmental data, allowing for early outbreak predictions and targeted interventions. AI-enhanced surveillance systems were also employed to monitor mosquito populations and identify breeding sites more accurately. These strategies were combined with biological control methods, such as using natural predators and genetically modified mosquitoes, to manage mosquito populations effectively. The study demonstrate that the integration of AI and biological control can significantly improve the efficiency, accuracy, and sustainability of dengue control measures. The study concludes that this data-driven approach, when adapted to local contexts, can reduce reliance on chemical pesticides and offer a more resilient framework for long-term dengue management.

Keywords: Dengue, Aedes aegypti, Biological control, Artificial Intelligence, Public health, Machine learning.

1. INTRODUCTION

The global rise in dengue cases is a growing concern, emphasizing the need for more innovative and effective solutions. Traditional methods, which mainly emphasize public education and awareness, have often fallen short in containing the disease's spread (Da Silva et al., 2024). This calls for a shift towards more comprehensive strategies that address both environmental and biological factors.

In Brazil, the situation is particularly urgent, with almost 900,000 confirmed cases reported by mid-2024 - a 300% increase in certain federal states compared to the previous year (Silva et al., 2024).

According to Rosa et al. (2021), one of the underlying factors contributing to this rise is the failure to consider environmental impacts in land use. Uncontrolled urban expansion and inadequate sanitation are directly linked to the increase in dengue outbreaks. These conditions often exceed the capacity of public health systems to manage and contain epidemics effectively.

In this context, biological control methods are emerging as a promising alternative. Studies by international experts such as Gubler (2011) and Caprara et al. (2018) emphasize the potential of using natural predators and pathogens to target the Aedes aegypti mosquito, the primary dengue vector. These methods aim to reduce reliance on chemical pesticides, which can have harmful environmental effects and lead to pesticide resistance.

De Castro et al. (2022) further support the use of biological control, noting that it leverages the ecosystem's natural balance to curb mosquito populations. Techniques such as introducing larvivorous fish, which consume mosquito larvae, and the use of bacteria like Wolbachia—which reduce the mosquito's ability to transmit dengue—offer environmentally friendly solutions. Moreover, advances in genetic modification, as demonstrated in studies by McGraw and O'Neill (2013), show that releasing genetically altered male mosquitoes, which produce non-viable offspring, can lead to a significant reduction in Aedes aegypti numbers.

These biological approaches not only help in lowering mosquito populations but also play a crucial role in minimizing ecological disruption. By integrating natural mechanisms into vector control strategies, biological control offers a more sustainable and potentially more effective method for long-term dengue management. This shift is essential as the limitations of conventional chemical and educational interventions become increasingly evident in the face of growing urbanization and environmental challenges.

Xavier et al. (2024) present several examples demonstrating that biological control can be an effective and sustainable tool for combating the dengue mosquito, particularly when integrated with other vector control measures. Australia, for instance, pioneered using Aedes aegypti mosquitoes infected with *Wolbachia* bacteria to reduce dengue transmission, significantly lowering the mosquito's ability to spread the disease. In Thailand, a successful initiative involved introducing larvivorous fish into water reservoirs to feed on Aedes aegypti larvae. In Brazil, similar strategies yielded positive outcomes in 2015, following Australia's approach. Additionally, the release of genetically modified mosquitoes, particularly in Juiz de Fora (MG) and Piracicaba (SP), has shown promising results. This technique involves releasing genetically modified male mosquitoes that produce non-viable offspring, leading to a substantial decline in Aedes aegypti populations.

However, according to Dias et al. (2024), despite the expansion of these strategies domestically and internationally, results suggest the need for updated and modernized dengue control methods.

Vieira, De Castro, and De Oliveira (2023) propose bridging this gap by integrating biological control methods with Artificial Intelligence (AI). They argue that AI can play a crucial role in enhancing the effectiveness, accuracy, and sustainability of dengue control strategies. AI can introduce new tools and approaches to optimize biological control measures.

De Lourdes (2023) suggests that when considering the potential of AI combined with biological control for managing mosquito-borne diseases like dengue, certain principles should be adopted: epidemiological data analysis, release of infected/genetically modified mosquitoes, identification of natural predators, detection and elimination of breeding conditions, community engagement/education, and research and development for predictive modeling and adaptive strategies.

2. LITERATURE REVIEW

An extensive bibliographic review of scientific papers and technical reports published by the Brazilian Ministry of Health in Brazil and abroad was conducted on topics such as Introduction to Dengue and Its Global Impact, Traditional Control Measures and Their Limitations, Biological Control Methods, The Role of Artificial Intelligence in Dengue Control, Integration of AI and Biological Control, and Case Studies and Global Experiences, which are presented below.

2.1 INTRODUCTION TO DENGUE AND ITS GLOBAL IMPACT

Dengue fever, a mosquito-borne viral disease primarily transmitted by the Aedes aegypti mosquito, has become a significant public health issue globally. In recent years, dengue outbreaks have surged, with the World Health Organization (WHO) documenting nearly three million suspected and confirmed cases last year alone, making it a top priority for public health authorities worldwide. In Brazil, the number of cases reached alarming levels, with data indicating a 300% increase in certain federal states by mid-2024 compared to the previous year (Silva et al., 2024). This upward trend underscores the inadequacy of traditional control measures and the pressing need for innovative approaches.

2.2 TRADITIONAL CONTROL MEASURES AND THEIR LIMITATIONS

Traditional dengue control methods have heavily relied on chemical pesticides, public education, and vector control strategies focusing on mosquito breeding site reduction. These methods, while partially effective, have shown limitations in terms of sustainability and long-term impact. Studies by Gubler (2011) and others highlight that over-reliance on chemical control can lead to pesticide resistance in mosquito populations, making it increasingly difficult to manage outbreaks effectively. Furthermore, educational campaigns, though essential, have proven insufficient as stand-alone solutions, given the complexities of urbanization and environmental challenges in high-risk areas.

2.3 BIOLOGICAL CONTROL METHODS: A PROMISING ALTERNATIVE

Biological control methods have emerged as a promising alternative to chemical-based approaches, offering environmentally friendly and sustainable solutions. According to Caprara et al. (2018), using natural predators and pathogens to target Aedes aegypti mosquitoes can effectively reduce mosquito populations while minimizing ecological disruption. This section explores several recent studies that illustrate the potential of biological control:

- **Wolbachia Infections**: Research by Hoffmann et al. (2022) demonstrated that introducing Aedes aegypti mosquitoes infected with Wolbachia bacteria significantly reduced the mosquito's ability to transmit the dengue virus. This technique, first trialed in Australia and later adopted in Brazil and Southeast Asia, has shown promising results in field studies.

- **Genetic Modification**: McGraw and O'Neill (2013) conducted a pioneering study on genetically modified mosquitoes, focusing on releasing males that produce non-viable offspring. This approach has led to a significant decline in mosquito populations in test areas. More recent studies by Zhang et al. (2023) have confirmed the long-term viability of genetically modified releases as part of integrated vector management strategies.
- **Natural Predators**: De Castro et al. (2022) emphasized the importance of introducing natural predators such as larvivorous fish, which feed on mosquito larvae in water reservoirs. This method has been successfully implemented in Thailand and Brazil, where it contributed to a noticeable reduction in dengue transmission.

2.4 THE ROLE OF ARTIFICIAL INTELLIGENCE IN DENGUE CONTROL

Artificial Intelligence (AI) offers a transformative approach to enhancing traditional biological control methods. The application of AI in epidemiology has expanded rapidly, providing new tools to improve the accuracy, efficiency, and scalability of dengue control measures. According to Silva (2023), AI can analyze large volumes of epidemiological, meteorological, and environmental data to detect patterns and predict outbreaks, offering a proactive approach to mosquito management. Recent studies have demonstrated several key applications of AI in the field:

- **Predictive Modeling**: Machine learning algorithms can predict dengue outbreaks by analyzing historical weather data, population density, and previous case incidences. A study by Moreno-Madriñán et al. (2023) utilized AI models to forecast high-risk periods, enabling public health officials to allocate resources more effectively.
- **Targeted Mosquito Release**: AI algorithms can optimize the release of Wolbachia-infected or genetically modified mosquitoes by simulating population dynamics and calculating the best release points. This ensures that the intervention is both effective and cost-efficient, reducing unnecessary expenses.
- **Real-Time Risk Mapping**: AI can generate real-time risk maps, identifying vulnerable areas and helping authorities focus biological control efforts where they are needed most. This capability is crucial for urban settings with rapidly changing environments.

2.5 INTEGRATION OF AI AND BIOLOGICAL CONTROL

The integration of AI with biological control methods creates an innovative framework for sustainable dengue management. Vieira, De Castro, and De Oliveira (2023) propose that this combined approach can significantly enhance the effectiveness of current strategies. AI not only facilitates better decision-making but also enables adaptive responses based on real-time data. De Lourdes (2023) outlines several principles for this integration:

- **Epidemiological Data Analysis**: Using AI to assess epidemiological trends can identify hotspots and guide targeted interventions. This can improve the precision of mosquito releases and minimize environmental impact.
- **Identification of Natural Predators**: AI-driven ecological analysis can identify and evaluate the effectiveness of natural predators in specific regions, ensuring that biological interventions are tailored to local conditions.
- **Detection of Breeding Sites**: AI-powered drones and computer vision technology can detect mosquito breeding sites, particularly in urban areas where traditional surveillance is challenging. These insights enable more targeted applications of biolarvicides.
- **Community Engagement**: AI can enhance educational efforts by creating personalized campaigns based on demographic data. Chatbots and virtual assistants provide real-time information and support, increasing community involvement in dengue prevention.

2.6 Case Studies and Global Experiences

Several case studies provide valuable insights into the successful integration of AI and biological control methods:

- **Australia**: Australia's pioneering use of Wolbachia-infected mosquitoes is a prime example of the effectiveness of biological control. This strategy has been enhanced by AI models that monitor mosquito populations and optimize release strategies based on real-time data (Wolff et al., 2023).
- **Brazil**: In Brazil, the application of genetically modified mosquitoes has significantly reduced dengue cases in certain regions. The incorporation of AI-based simulations has allowed for precise adjustments to release schedules, maximizing impact and minimizing

costs (Xavier et al., 2024).

- **Southeast Asia**: Countries in Southeast Asia, such as Thailand and Vietnam, have utilized larvivorous fish and other natural predators in combination with AI-driven monitoring systems. These efforts have led to a sustained decrease in dengue incidence in targeted areas (Zhang et al., 2023).

The reviewed literature highlights the need for a paradigm shift in dengue control, moving from conventional methods to a more integrated, data-driven approach. Combining biological control with AI presents a promising pathway to achieve sustainable and effective dengue management. This section underscores the importance of leveraging advanced technologies to optimize interventions, reduce ecological disruption, and protect public health in the face of a growing global dengue threat. Further research should focus on refining AI models, exploring new biological control agents, and evaluating the long-term sustainability of integrated strategies in diverse environmental contexts.

3. METHODOLOGICAL APPROACH

To effectively map and identify the primary causes behind the high incidence of dengue infections in Brazil and propose AI-driven mitigation strategies, a well-defined research methodology is essential. Below we outline an approach to accurately pinpoint the key factors contributing to this issue.

3.1 RESEARCH DESIGN & OBJECTIVES

Objective: Identify the main causes and contributing factors for high dengue incidence in Brazil and recommend AI-based solutions for mitigation.

The key research questions include:

- What are the environmental, biological, social, economic, and infrastructural factors influencing dengue incidence in Brazil?
- How can AI be applied to predict, monitor, and control the spread of dengue?
- What AI-driven actions can effectively mitigate these factors?

3.2 DATA COLLECTION METHODOLOGY

3.2.1. LITERATURE REVIEW

An extensive review of the literature was conducted using academic databases like PubMed, Google Scholar, and SciELO, focusing on research related to dengue incidence factors. Publications on environmental conditions, biological aspects, socio-economic influences, and Brazil's public health infrastructure were prioritized. Additionally, AI-based solutions for predicting, monitoring, and controlling epidemics were examined.

3.2.2. CASE STUDIES

Case studies from the Brazilian National Health System (SUS) in regions with high dengue incidence were collected and analyzed. These records help to identify patterns and successful dengue control strategies.

3.2.3. DATA COLLECTION FROM PUBLIC HEALTH RECORDS

Data on dengue incidence, both historical and current, were gathered from the Ministry of Health, local health departments, and other public health databases. This included information on environmental conditions (e.g., rainfall, temperature), socio-economic factors, and public health interventions.

3.3 DATA ANALYSIS & MODELING

3.3.1. DESCRIPTIVE AND CORRELATIONAL ANALYSIS

The collected data were analyzed to detect trends, correlations, and potential risk factors linked to high dengue incidence in Brazil. Statistical tools were used to identify relationships between climatic conditions, urbanization, public awareness, economic status, and dengue outbreaks.

3.3.2. AI MODELING

Machine learning models, such as regression analysis, decision trees, and random forests, can be employed to predict high-risk areas for dengue. Algorithms were developed to categorize regions based on similar risk factors, and neural networks were utilized to improve predictive accuracy through deep learning.

3.4 MITIGATION STRATEGIES USING AI

3.4.1 AI-BASED PREDICTION MODELS

Predictive models using machine learning were created to forecast dengue outbreaks by analyzing weather, socio-economic conditions, and biological data. These models supported the implementation of early warning systems, which were shared with public health agencies and communities for targeted interventions.

3.4.2 AI FOR MOSQUITO MONITORING

AI-enhanced surveillance systems were deployed to monitor mosquito populations via image recognition, sensors, and drones. AI was also used to identify breeding sites and assess the effectiveness of biological control methods, such as releasing sterile male mosquitoes and introducing natural predators.

3.4.3 AI IN PUBLIC AWARENESS CAMPAIGNS

AI algorithms analyzed social media and public opinion to uncover gaps in awareness. Targeted campaigns were developed based on AI insights, particularly focusing on regions with lower awareness levels.

3.4.4 DATA-DRIVEN DECISION MAKING

AI analytics were applied to evaluate the success of control measures, like insecticide use and public campaigns, while optimizing resource allocation. Feedback loops were established to continuously update AI models with new data, refining predictions and strategies.

3.5 EVALUATION & VALIDATION

The AI models were validated using real-world case studies and data from dengue hotspots in Brazil. Field trials measured the effectiveness of AI-recommended interventions, and evaluation metrics like accuracy, recall, and precision were used to gauge AI model performance.

3.6 IMPLEMENTATION & POLICY RECOMMENDATIONS

Collaborations with public health authorities are crucial to deploying AI-based monitoring and prediction tools in high-risk areas. Policy guidelines can be developed to integrate AI into dengue control programs, ensuring ethical use, data privacy, and community involvement. Recommendations also might included enhancing public health infrastructure, improving economic conditions in vulnerable areas, and increasing public education on preventive measures.

4 MODELING: CAUSE-AND-EFFECT RELATIONSHIP BETWEEN DENGUE INCIDENCE AND INFLUENCE FACTORS

An extensive bibliographic review was conducted using academic databases such as PubMed, Google Scholar, and SciELO to explore existing research on the causes and factors influencing dengue incidence. The review prioritized publications that address environmental conditions, biological factors, socio-economic influences, and public health infrastructure in Brazil. Additionally, current AI-based solutions for predicting, monitoring, and controlling epidemics were evaluated.

Outlined below are the primary factors, identified through bibliographic research, that contribute to the high incidence of dengue infections, along with proposed solutions and interventions using biological control and AI.

4.1 ENVIRONMENTAL FACTORS

- **Climate**: Warm temperatures, high humidity, and heavy rainfall increase mosquito breeding.
- **Solution:** Use AI for climate pattern analysis to predict breeding seasons and outbreaks. Implement biological control in high-risk seasons (e.g., release of larvivorous fish or Wolbachia-infected mosquitoes).
- **Urbanization**: Unplanned development leads to more stagnant water.
- **Solution:** Use drones equipped with AI for aerial surveillance to detect potential breeding sites in urban areas. Target these sites with biological control measures like biolarvicides.

4.2 BIOLOGICAL FACTORS

- Mosquito Adaptation: Development of resistance to chemical pesticides.
- **Solution**: Shift from chemical to biological controls, using natural predators and genetically modified mosquitoes. AI can analyze mosquito resistance patterns to adapt strategies.
- **Mosquito Population Growth:** Increased breeding sites and favorable conditions for mosquitoes.
- **Solution:** AI-driven population modeling to determine the optimal times and locations for releasing genetically modified mosquitoes to control populations effectively.

4.3 SOCIAL AND BEHAVIORAL FACTORS

- **Public Awareness & Behavior:** Lack of community engagement in eliminating breeding sites and following preventive measures.
- **Solution:** Use AI-powered chatbots and virtual assistants to educate and engage the community on mosquito control. Personalized campaigns can be created using AI demographic analysis.
- **Human Mobility**: Movement of infected individuals spreading the virus.
- Solution: AI-based analysis of mobility patterns to predict areas at risk of outbreaks. Use this data to preemptively target those areas with biological control measures.

4.4 ECONOMIC FACTORS

- **Funding for Control Programs**: Limited budget for comprehensive control efforts.
- **Solution:** AI can optimize resource allocation by identifying priority areas for intervention. Cost-effective biological control measures (e.g., targeted release of Wolbachia-infected mosquitoes) can be implemented in high-risk areas.
- **Living Conditions**: Poor housing and lack of access to proper sanitation.
- **Solution:** AI analysis of socio-economic data to identify high-risk communities and tailor interventions accordingly. Biological control methods like the introduction of natural predators in stagnant water areas can be targeted based on these findings.

4.5 PUBLIC HEALTH INFRASTRUCTURE

- **Surveillance and Response**: Ineffective monitoring of mosquito populations and delayed response to outbreaks.
- **Solution:** Deploy AI-driven real-time monitoring systems for early detection of mosquito populations. Use biological control in response to data collected (e.g., adjusting release schedules of genetically modified mosquitoes).
- **Health System Capacity**: Limited capacity to diagnose and treat dengue cases.
- **Solution:** AI prediction models for early detection of outbreaks allow public health systems to prepare and respond. Biological control methods can be scaled up during predicted outbreak periods.

4.6 TECHNOLOGY & MONITORING

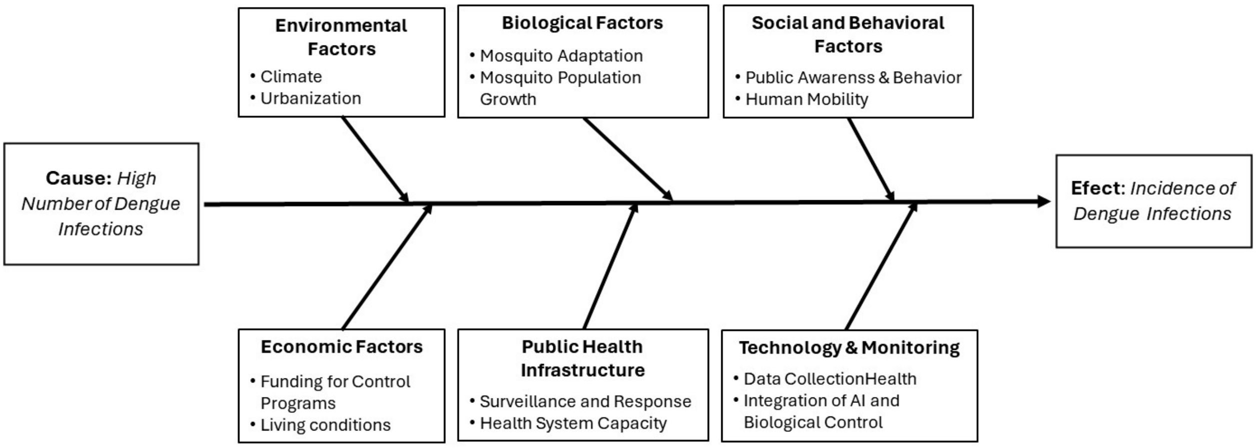
- **Data Collection**: Limited access to accurate and real-time data.
- **Solution:** Implement AI-based surveillance systems using data from environmental sensors, drones, and satellite imagery. AI algorithms can predict outbreak patterns, allowing for timely biological interventions.
- **Integration of AI and Biological Control**: Lack of coordination between traditional and technological measures.
- **Solution:** Develop AI platforms to manage and integrate data from multiple sources (epidemiological, environmental, and entomological) for informed decision-making. Coordinate biological control actions based on AI analysis to enhance effectiveness.

4.7 DIAGRAM OVERVIEW

Figure 1 presents an overview, based on the Ishikawa Diagram, summarizing the analysis of biological control and AI methods, correlating the aforementioned principles to effectively combat the dengue mosquito.

The Ishikawa diagram visually displays the problem (**High Number of Dengue Infections**) at the head of the fish, with each of the six factors (Environmental, Biological, Social and Behavioral factors, Economic factors, Public Health Infrastructure, and Technology & Monitoring) branching out as the main “bones” of the model; each factor have smaller sub-branches indicating the specific causes and corresponding AI and biological control interventions.

Figure 1 | Fishbone (Ishikawa) - Cause-and-effect relationship between Dengue incidence and influence factors



4.8 APPLICATION OF THE MODEL

The main steps of the model are as follows:

1. **Identify Key Factors**: Use the diagram to analyze the main contributing factors to dengue infections in a specific country or region.
2. **Develop Solutions**: Based on the analysis, develop targeted interventions using a combination of biological control methods and AI-driven insights.
3. **Monitor and Adapt strategies**: Utilize AI for continuous monitoring, adapting strategies in real-time based on emerging data and changing conditions.

By using this structured approach, public health officials can prioritize resources, implement effective biological control measures, and leverage AI technology to reduce the incidence of dengue in a sustainable and data-driven manner.

CONCLUSION

This study has outlined an innovative and integrated approach to combat the spread of dengue, combining Biological Control methods with Artificial Intelligence (AI) to create a more sustainable and effective strategy. Given the alarming rise in dengue cases, particularly in Brazil, the limitations of traditional approaches have become evident, necessitating a shift toward comprehensive solutions that can address the complexity of this challenge.

The research emphasizes the importance of understanding the underlying factors that contribute to dengue incidence, including environmental conditions, biological adaptations, socio-economic influences, and limitations in public health infrastructure. A well-structured methodology was applied, involving extensive bibliographic research, case study analysis, and the use of AI for predictive modeling and targeted interventions.

The integration of AI into dengue control has shown significant potential for improving the accuracy, efficiency, and adaptability of current strategies. AI-driven predictive models can anticipate outbreaks based on weather patterns, socio-economic factors, and epidemiological data, enabling more timely and effective responses. Moreover, the application of AI in mosquito monitoring—using tools such as drones, image recognition, and population modeling—enhances the precision of biological control methods, reducing mosquito populations in a targeted and environmentally friendly manner.

By utilizing AI to optimize the deployment of natural predators, genetically modified mosquitoes, and other biological control agents, this integrated approach minimizes the need for chemical pesticides and reduces the risk of pesticide resistance. Additionally, AI's capacity to analyze social and behavioral data supports the design of personalized awareness campaigns and community engagement, addressing one of the critical barriers to effective dengue control.

The proposed model provides a clear framework for public health authorities to prioritize resources, make data-driven decisions, and adapt strategies in real time as conditions evolve. This data-centric, adaptive approach ensures that interventions remain relevant, efficient, and cost-effective.

Future research should focus on refining AI algorithms, exploring new biological control techniques, and testing the long-term sustainability of these integrated strategies in different regions and contexts. The success of this model relies on collaboration between local governments, health organizations, and technological innovators to ensure that AI and biological control are harmonized effectively.

In conclusion, the integration of AI with biological control offers a promising pathway for sustainable dengue management, reducing infection rates and safeguarding public health. This innovative approach not only addresses the current limitations of traditional methods but also provides a resilient and adaptive strategy for combating dengue in the face of evolving global health challenges.

REFERENCES

Caprara, A., Lima, J. W. O., Marinho, A. C., et al. (2018). Biological Control of Aedes Aegypti: Promising Strategies for Dengue Prevention. *Journal of Vector Ecology*, 43(1), 105–112.

Castro, A. L. G. et al. (2022). Efficacy of Dengue Prevention and Control Measures in Brazil. *Revista Educação em Saúde*, 10, 22-30.

De Lourdes Araújo, I. et al. (2023). Comparing Machine Learning Algorithm Performance for Predictive Analysis of Yellow Fever in Minas Gerais.

Dias, G. M. C. et al. (2024). Dengue Epidemic: A Projection Analysis for 2024. *CONTRIBUCIONES A LAS CIENCIAS SOCIALES*, 17(8).

Gubler, D. J. (2011). Dengue, Urbanization and Globalization: The Unholy Trinity of the 21st Century. *Tropical Medicine and Health*, 39(4), 3–11.

Hoffmann, A. A., et al. (2022). Harnessing Biological Control for Mosquito-Borne Disease Management. *Science*.

McGraw, E. A. & O'Neill, S. L. (2013). Beyond Insecticides: The Genetic Control of Mosquito-Borne Disease. *Annual Review of Entomology*, 58, 353–370.

Moreno-Madriñán, M. et al. (2023). Applications of AI in Ecological Modeling for Vector Control. *Journal of Public Health Informatics*, 15(2).

Rosa, B. B. et al. (2021). Evolution of Sanitation and Its Relationship with Public Health. *J Health Sci Inst.*, 33-41.

Silva, J. M. da (2023). Bias in Machine Learning Algorithms for Healthcare: A Systematic Review.

Vieira, G. F. F., De Castro, A. F., & De Oliveira, A. G. (2023). Dengue Data Analysis in Northeast Brazil Using Python. *IEEE*.

Wolff, A. et al. (2023). Natural Predators and Biological Control in Aedes Aegypti Management. *Journal of Vector Ecology*, 48(1).

Xavier, F. et al. (2024). Big Data and Planetary Health Approaches for Dengue Control. *Revista de Saúde Pública*, 58.

Zhang, W. et al. (2023). Ecological Approaches to Dengue Control: Lessons from Asia. *Environmental Health Perspectives*, 131(3).