Research Article

BIOMEDICAL Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2025.63.009831

Vector Surveillance and Control (VSC): A Scientific-Technical Perspective within the One Health Paradigm

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ARTICLE INFO

Received: August 11, 2025

Published: August 22, 2025

Citation: Diéguez FL, Rodríguez R, del Valle LD, Torrente D, Bujardón AR, Molina MC and Fimia DR. Vector Surveillance and Control (VSC): A Scientific-Technical Perspective within the One Health Paradigm. Biomed J Sci & Tech Res 63(1)-2025. BJSTR. MS.ID.009831.

ABSTRACT

This work presents the existing challenges and opportunities in vector surveillance and control, with a scientific-technological approach under the One Health context. A documentary review was conducted using indexed databases. Theoretical methods of analysis, synthesis, induction, deduction, historical, and logical approaches were applied to structure the research object. Findings indicate that successful programs combine traditional methods with innovative approaches, enhancing community involvement, which improves intervention effectiveness. Essential challenges and opportunities were identified for addressing issues in Cuban medical entomology with a multidisciplinary perspective. The interaction of science, technology, and society reveals a rich relationship of concepts that must be systematized and enriched by new research. Successful interventions can positively impact community contexts through scientific and technological development globally, reaffirming the importance of theoretical foundations for public health.

Keywords: *Aedes Aegypti*; Arboviral Diseases; One Health; Vector Surveillance and Control

Introduction

Vector-borne diseases represent 17 % of the global burden, with high rates of mortality, morbidity, work disabilities, and economic losses [1]. In this context, dengue stands out across almost the entire tropical and subtropical region, involving mosquitoes with marked anthropophilic and synanthropic habits [2], with a particular preference for feeding on human blood and closely linked to human settlements. In the Americas, *Aedes aegypti* and Ae. albopictus play an important role as transmitters of Dengue, Chikungunya, and Zika, as well as Culex quinquefasciatus, which transmits a zoonotic viral encephalitis, complicating the entomological and epidemiological situation. Additionally, there has been a recent report in our region of Ae. (Fredwardsius) vittatus (Diptera: Culicidae), an exotic aedine mosquito that also participates in the biological transmission of important vector - borne diseases [3-5]. The authors emphasize that the presence of collaborators in endemic areas of diseases not reported in Cuba increases the attention that the scientific community directs towards arthropods; therefore, antivector research lines are developed to reduce the risk of illness and to determine the climatic influence on their behavior. In this regard, the island exhibits significant production of work in the field of medical-veterinary entomology, among which we can cite those carried out by other authors [6-9], while maintaining intense cooperation with several Caribbean, Central American, and African countries [10-13].This work aims to present the existing challenges and opportunities in vector surveillance and control (VSC), with a scientific-technological approach under the context of health.

Materials and Methods

Information was retrieved using search engines and the Boolean operators 'AND'/'OR' in databases such as SciELO Cuba, ClinicalKey, Cumed, Lilacs, Latindex, and Doaj, focusing on Cuban scientific journals related to vector surveillance and control, as well as public policy reports and documents. Additionally, the experience accumulated by experts in the field over the last 10 years was considered. Indexed terms from the Health Sciences Descriptor (DeCS) facilitated indexing and navigation within the information sources of the Virtual Health Library, which was organized into key categories. The particularities of the approach used were examined to identify and highlight the importance of science in the vector control network. Through theoretical methods of analysis and synthesis, induction and deduction, and historical and logical reasoning, the object of research on vector surveillance and control (VSC) was deconstructed and structured in its different components, allowing for the identification and prioritization of its elements and an appreciation of the overall functional dynamics.

Results and Discussion

Approach to the Theoretical Framework Supporting Vector Surveillance and Control (VSC) and Its Importance for Public Health

Research and theoretical contributions regarding the entomological risk posed by aedine populations in the field of VSC have been limited. However, the authors wish to highlight studies conducted by Valdés, et al. [14], who proposed a system for stratifying entomological risk based on certain indicators at the municipal level. Meanwhile, Rodríguez, et al. [15] classified city blocks into two strata (very high and high risk) by combining epidemiological variables (reported cases), considering only the patient's place of residence, with two entomological variables: House Index (HI) and Breteau Index (BI).

It is important to emphasize several key definitions related to the topic under investigation:

Science: The conceptual evolution of science reveals a progressive and dynamic understanding of scientific knowledge: from Egg's [16] view of science as a set of rationally and methodically obtained knowledge, through Kröber's [17] perspective of science as a system of concepts and propositions, to Castellanos, et al. [18] view of science as a complex human phenomenon transcending the spiritual. Bunge [19] characterizes it as rational, systematic, and verifiable knowledge, while Tamayo [20] reaffirms its nature as a set of rational knowledge. All converge on a fundamental vision: science as an organized, methodical, and rational system of knowledge whose central purpose is to understand and explain reality through a rigorous knowledge-building process.

Technology: The conceptual trajectory of technology shows an evolving understanding of its transformative essence: from Beckmann's [21] initial perspective as a "set of systematic techniques," through Quintanilla's [22] interpretation of technology as a mechanism of transformation, Feenberg's [23] critical view of it as a socio-productive structure. In this sense, Ochoa, et al. [24] conceptualize it as a "strategy for applying available knowledge." All converge on a core vision: technology as a dynamic system of knowledge that transcends mere functionality, constituting a socio – cultural practice capable of systematically reconstructing human reality through the continuous innovation of resources and knowledge.

Society: The conceptual evolution of society reveals a dynamic understanding of human connections: from Aristotle's (4th century BC) approach viewing society as a natural congregation of people within a territorial space [25], through the Marxist perspective interpreting it as a structure of economic relations determined by group antagonisms [26,27] defines society as a network of social interconnections [28], sees it as a fabric of collective relationships, and Saint Leo University [29] conceptualizes it as a gathering of human beings sharing cultural codes, principles, and traditions. All converge on an essential vision: society as a complex and multidimensional organism of human interaction that surpasses mere juxtaposition to form a system of permanent collective construction.

One Health: The conceptual genealogy of "One Health" reveals a progressive transformation in understanding health ecosystems: Virchow's [30] initial proposal pioneered perspectives on connections among living organisms, later developed by the integrative vision of the WHO [31], which broadened intervention horizons [32]; deepened this by introducing interdisciplinary methodologies, while the Pan American Health Organization [33] expanded the vision toward multi-actor collaborative strategies, culminating with the FAO [34] proposal consolidating an intervention model recognizing the profound interdependence among biological systems. This conceptual journey shows an evolution from fragmented views toward a comprehensive paradigm, where health is understood as a complex, interconnected, and interdependent phenomenon that transcends traditional disciplinary boundaries.

Entomological Surveillance: The process of monitoring vector populations, essential for identifying and controlling outbreaks of mosquito – borne diseases such as Dengue [35].

Focal Control: Inspection and treatment of vector breeding sites, fundamental for reducing infestation and preventing diseases [35].

Health Education: Training the population on vector prevention and control, crucial for fostering community participation and reducing transmission risks [35]. It is necessary to emphasize, based on these definitions, that success indicators are crucial for evaluating and improving control strategies in the field of vector surveillance and control (VSC), ensuring the prevention of vector - borne diseases. One such indicator is the infestation index behavior, which helps measure the proportion of infested households; therefore, a low index indicates effective vector control. Another indicator is the Breteau Index, which reflects the number of positive containers per 100 houses. In this case, a high value suggests deficiencies in control actions. A third indicator is the percentage of positive city blocks, which represents the extent of infestation in a locality; thus, a low percentage is desirable. Finally, it is necessary to investigate why the risk does not decrease, what the population thinks, and what is being done wrong, focusing on policies developed in the fields of science and technology to understand the causality behind the persistence of high focality and the maintenance of practically the same breeding sites despite all efforts [36]. Determining risk and protective factors at the family level, as well as within and outside the health sector, is essential to improve the quality of services provided, strengthen sustainable actions, and refine strategic design direction. This requires identifying the macro and micro determinants influencing the current (re)emergence of vector-borne diseases [3], to create a movement aimed at enabling the community to leverage technologies, promote learning, and foster collaborative work [4].

The authors of this article consider that, within the One Health context, science and modern technologies demand high standards, immediacy, and accuracy to empower specialists in executing and managing the collected information, unify criteria at the local level, improve the quality and timeliness of actions, and systematize accumulated data in vector focus monitoring until completion and incidence reporting. This necessitates developing a government management system based on science and innovation, strategic planning, science - government dialogues, sectoral connections, institutional strengthening, and mindset change to increase the effectiveness of links between universities and science, technology, and research entities with productive sectors of goods and services across different territories. A management model oriented toward innovation is also envisioned, contributing in the short and medium term to achieving the objectives of the National Economic and Social Development Plan through 2030 [37]. In the current global entomological and epidemiological context, it is necessary to strengthen "in situ" research aimed at characterizing species reported in the country [38-41] and especially local species, a topic that contributes to maintaining strict intra- and intersectoral cooperation. The data derived from the above allow various programs, together with the use of epidemiological indicators, to assess the risk of vector populations based on the natural resources they exploit [4,6,7,42,43], there by optimizing resources. Unfortunately, there is no entomological measure to predict infection risk. Science has become, over the years, an evolutionary, favorable, and indispensable process in the development of interconnection among the scientific policies developed by the country. In the bidirectional model science ↔ technology, the advancement of scientific knowledge in society is based, making it impossible to conceive the development of vector surveillance and control (VSC) without up – to – date scientific knowledge that allows mastery of the problem to be addressed [44].

Importance of Scientific and Technological Development in VSC

From the investigative perspective documented in scientific literature, reflections on the true causality of arboviral diseases – where vectors are involved – are insufficient. The root cause is humans themselves, who generate favorable conditions for vector establishment, reproduction, and dispersion, rather than merely focusing on the effect, which is the increasingly abundant, diverse, and dispersed breeding sites. This highlights how much remains to be explored. In this context, due to the scarcity of studies developed in Camagüey, Cuba, it is necessary to gather updated knowledge about biotic, abiotic, and anthropogenic factors that enable the continuous presence or absence of species with marked sanitary relevance. This will improve interpretation of environmental parameters and analysis of the vector – causal agent – susceptible host – environment combination, facilitating the establishment of effective and economically feasible goals with proper environmental protection, and promoting sustainable methodologies to reduce vector populations to levels that do not pose a risk to human health. Based on these premises, it is necessary to promote the pillars of science and innovation activities alongside social communication as transformative forces facing multiple economic, social, political, and cultural challenges in a globalized world [45]. Slow reaction to the inevitable challenges and events in medical entomology and specifically in VSC is not an option. The monopolization of scientific knowledge by wealthy countries, including brain drain, forces countries to solve problems through their own science, demanding knowledge, human resources, scientific and technological capacity, strong intra- and intersectoral relationships in productive and service sectors, and public policies supporting existing capacities to build and strengthen. Scientific and technological development in VSC is currently a focal point in creating human, cognitive, and technological capacities.

Examples of Successful Interventions and Their Community Impact

Successful interventions in Cuba for VSC include the Integrated Management Strategy, which promotes community participation and health education [45]. This strategy reduced dengue-related mortality and morbidity by eliminating mosquito breeding sites and mobilizing social cleaning activities. The impact on Cuban communities has been significant, with fewer outbreaks and increased awareness about dengue prevention, strengthening community health and resilience. Other effective strategies include popular education, where community work groups promoted reflection and learning about dengue, facilitating community diagnoses and communication and surveillance actions. Social mobilization campaigns involving citizens

DOI: 10.26717/BJSTR.2025.63.009831

in cleaning and eliminating mosquito breeding sites fostered a sense of belonging and collective responsibility. Training and awareness through workshops and educational activities increased knowledge about the mosquito and prevention practices, leading to significant changes in community participation [46]. This had an important impact by enhancing citizens' awareness and commitment to fighting *Ae. aegypti.*

Additional Cuban studies indicated that popular mobilizations and community work groups improved identification of prioritized breeding sites and implemented preventive actions that strengthened social cohesion and outbreak response capacity, ensuring sustainability of public health achievements [4,47]. All this indicates that community participation strategies have been adapted to different localities with specific approaches, which favored response capacity and intervention sustainability. It is important to highlight that local contextual differences are visible in various aspects, adapting to the socioeconomic and cultural characteristics of each locality. For example, in provincial capitals and many municipalities, organization is emphasized through popular councils, while in rural areas social mobilization is direct. Resource availability also determines program complexity and sustainability. In some territories, participation is more formal and structured; in others, it relies on spontaneous initiatives, reflecting the diversity of participatory culture among inhabitants. However, these differences undeniably affect the effectiveness and reach of vector control interventions. Community involvement in disease prevention and control is crucial for the success of public health strategies, as it enables a more effective and sustainable response by fostering education and social mobilization. Notable examples include the Ecosalud strategy in Cotorro (a municipality in Havana), which promoted active community participation in ecosystem management, resulting in a significant reduction of mosquito populations and thus dengue transmission [47].

Challenges and Opportunities in VSC

Based on the experience accumulated by experts in the field, the current challenges include four key areas that require strong efforts [48,49].

Human Resources: Completing the workforce, as the lack of personnel affects the technical quality of the work, along with intense and frequent training on important topics such as integrated control, entomological surveillance, environmental characterization, and health education.

Entomological Indicators: It is a challenge to maintain infestation indices below established standards and to reduce the percentage of positive and recurring city blocks, as these reflect the quality of the initial work performed in those areas.

Community Participation: Promoting community contribution accompanied by educational actions, which was affected by social distancing during the pandemic. Additionally, there is a need to raise awareness about the possibilities offered by new technologies like the sterile insect technique or the use of Wolbachia bacteria, supported by strengthened communication media reinforced by the social communication law. This is reflected in Chapter VI on advertising and environmental protection, Article 50, which addresses advertising actions that encourage behaviors, habits, and technologies that favor environmental protection, as well as the use of ecologically responsible products and services [50], with evident impact on health education to reduce breeding sites.

Integration of Surveillance: Starting from the primary level of care to the population, incorporating doctors, nurses, and hygiene and epidemiology units, which strengthens timely case detection to break the transmission chain.

Strengthening Health Personnel Training: Training must be continuous and supported by operator training programs, improving technical competence and effectiveness in vector control. Regarding community participation, it is essential to foster involvement in prevention activities to increase risk perception and, above all, collective action.

Use of Novel Technologies: Integrate more effective tools and facilitate health education and vector monitoring.

Inter - institutional Collaboration: Establish alliances with other health, education, and sector institutions. Finally, the various VSC programs in Cuba need to continue producing new knowledge supported by an endogenous science, technology, and innovation system capable of creating and assimilating new technologies and quality-standard products with high knowledge content, carrying the highest possible added value to be competitive and respond to integration with Latin America and the Caribbean.

Conclusion

The theoretical and methodological background supporting work in VSC through the interaction of science, technology, and society comprises a rich and vast relationship of concepts, definitions, procedures, and strategies that must be systematized and enriched with new research. Once implemented in successful interventions, these can positively impact the community context based on the scientific and technological development occurring worldwide. This fact presents new challenges and opportunities that contribute to reaffirming all the accumulated knowledge regarding the initial theoretical references and their importance for public health.

Compliance with Ethical Standards

Acknowledgments

The authors especially thank the support provided for developing competencies in article writing for scientific journals by the Institute for Research and Development (IRD) of France and the VECTOCARIBE Project, funded by the Solidarity Funds for Innovative Projects (FSPI) of the French government.

Potential Conflict of Interest

There is no conflict of interest involving the authors.

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ISSN: 2574-1241

DOI: 10.26717/BJSTR.2025.63.009831

Rigoberto Fimia Duarte. Biomed J Sci & Tech Res