Scientific Research Publishing

Journal of Environmental Protection, 2026, 17(8), 871-883
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

A Systematic Review of Innovations in Air Quality Monitoring in ECOWAS Countries

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How to cite this paper: Iddrisu, A., Issaka, A.I., Cobbina, S.J., Asare, W., Seini, I.Y. and Ampofo, J.A. (2026) A Systematic Review of Innovations in Air Quality Monitoring in ECOWAS Countries. *Journal of Environmental Protection*, **17**, 871-883.
https://doi.org/10.4236/jep.2026.178044

Received: May 7, 2025
Accepted: August 22, 2026
Published: August 25, 2026

Abstract

West Africa is one of the most poorly monitored regions in the world, and is one of the largest contributors to ambient air pollution-related premature death and morbidity. This systematic review brings together and syntheses peer-reviewed and grey literature from the past 8 years (2018-2026) with a particular interest on innovations in air quality monitoring in the Economic Community of West African States (ECOWAS) member states. A search, based on PRISMA criteria, of Google Scholar and various other databases, was conducted to identify relevant, geographically accessible and methodologically transparent sources, which were then synthesized in a narrative format to provide a broad overview of the literature on the topic. The four main categories of innovation identified were: 1) low-cost sensor networks (both optical and electrochemical), 2) machine learning sensor calibration, 3) satellite-derived and hybrid $PM_{2.5}$ mapping, and 4) citizen science and community-based monitoring. Reference-grade monitoring is limited to a few countries (mostly Senegal) and somewhat less in Ghana, Togo, Côte d'Ivoire, Burkina Faso and Niger, while low-cost sensor deployments have grown rapidly in Nigeria as well as in these countries. With a lack of reference infrastructure, the use of machine-learning calibration tools and satellite-fusion products is growing to satisfy the called-for compensation. Compared to East Africa, the citizen science movement is still in its infancy in ECOWAS. Challenges that persist include a lack of legislation, disorganized funding, poor technical skills to maintain and calibrate sensors and poor sensor data integration with the public health and regulatory systems. The review concludes with recommendations for the development of regional data sharing infrastructure, harmonized calibration procedures, and investment in hybrid monitoring architectures of reference stations, low-cost sensor networks and satellite products for continued monitoring.

Keywords

Air Quality Monitoring, Low-Cost Sensors, ECOWAS, West Africa, $PM_{2.5}$, Satellite Remote Sensing, Citizen Science, Sensor Calibration

1. Introduction

In West Africa, air pollution is one of the main and growing health threats to the public [1]. The fine particulate matter ($PM_{2.5}$) and other pollutants that come from vehicles, biomass burning, waste firing, industry and seasonal Saharan dust (Harmattan) impact urban populations throughout the region. In Lomé, Togo, for instance, a multiyear monitoring program revealed that over 87 percent of the days they monitored were above the World Health Organization guidance for daily $PM_{2.5}$ exposure [2].

The Economic Community of West African States (ECOWAS) is a community of fifteen member countries, many of which experience rapid and unplanned urbanization and industrialization in their cities. Despite this exposure burden, air quality monitoring systems are not very common in the bloc: Only two out of the 15 ECOWAS countries are equipped with government-based monitoring systems and there are few laws and public-health surveillance systems to support air quality data [3]. This is also rare on a continental level as there is a separate scoping review of air quality monitoring activity on the continent which shows that there is very little capacity to monitor air quality on continuous basis across Africa, with Rwanda, South Africa and Ghana having sustained monitoring capacity [4].

In the past decade, there has been an outburst of innovation driven by the information gap. Together, the growing number of cheap optical and electrochemical sensors, use of machine learning for sensor calibration, integration of satellite aerosol retrievals with sparse ground-based observations, and the development of citizen science have started to address some of the gaps in observations for LMI countries. This review aims at a systematic synthesis of this innovation landscape as seen specifically in the ECOWAS countries and poses three questions: 1) What is the status of government and non-government monitoring of air quality in ECOWAS? 2) How and what technological and methodological innovations have been applied and what their performance is? 3) What remains to be done, what are the gaps and barriers, and what is suggested in the literature?

2. Methodology

2.1. Search Strategy

The systematic literature search was conducted in the principal database, Google

Scholar and other databases of PubMed/PMC, ScienceDirect, ACS publications, MDPI journals and Springer nature Link up to 2026. Geographic terms ("ECOWAS", "West Africa" and the fifteen West African countries) were included in the search along with the monitoring and innovation terms "air quality monitoring", "low-cost sensor", "$PM_{2.5}$", "sensor calibration", "satellite remote sensing", "machine learning", and "citizen science". Reference lists of retrieved articles of review articles were hand-searched (snowball/reference-chaining approach), following previous regional air quality management strategy scoping reviews conducted throughout Africa [4], to identify any missed eligible studies.

2.2. Eligibility Criteria

Studies were included if they described the development of air quality monitoring infrastructure, technology, or methodology in or covering one or more member countries of ECOWAS; if they were peer-reviewed journal articles or peer-reviewed conference proceedings or credible institutional/grey literature (such as WHO, Climate and Clean Air Coalition); or if they could be evaluated based on the nature of the innovation being described. Only studies that contributed methodological innovations that were directly relevant to the comparative discussion of methodological innovations for ECOWAS countries were included in the analysis if they did so, and were otherwise excluded from the analysis unless relevant to East Africa for direct evidence of methodological innovation (e.g., citizen science case studies) were offered.

2.3. Study Selection and Synthesis

The titles and abstracts from the search were screened for relevance and shortlisted abstracts were full-text evaluated. The information from a total of 34 sources was considered suitable and was retained for a narrative synthesis including peer-reviewed articles in journals including Environment International, Environmental Science & Technology, ACS ES&T Air, ACS Earth and Space Chemistry, Atmosphere, Aerosol and Air Quality Research, Environments, Discover Atmosphere, Discover Sensors, PLOS Climate and the International Journal of Environmental Research and Public Health, in addition to suitable institutional sources. Data gathered at each study country/city included information on information collected, monitoring technology, calibration method (if any), performance measures reported, and barriers. As a common approach for scoping-style systematic reviews of environmental monitoring interventions in low-resource settings, a narrative and tabular synthesis was employed due to methodological diversity of studies (social science/quasi-experimental designs, diverse outcome concepts and geographic scope).

3. Results

3.1. Status of Government-Led Monitoring across ECOWAS

All published sources agree that Senegal is the country in the region with the weakest institutional monitoring of air quality. Senegal is the only ECOWAS country that was identified in several reviews as having a continuous government-operated air quality monitoring system, namely with the Centre de Gestion de la Qualité de l'Air (CGQA) that is monitoring at six fixed sites throughout the Guédiaway, Médina, Yoff, Bel-Air, HLM and Cathedral districts [3] [5]. Ghana has also made more modest but significant strides with the long-running U.S. Embassy reference-grade monitor in Accra, and recently, an Afri-SET reference site for the support of calibration research was established [6] [7]. In the past, monitoring capacity in Nigeria has been limited, with the United States Embassy operating the two reference-grade stations in the capital city of Abuja and in the most populated city of Lagos, increasing coverage of stations with the deployment of low-cost sensors in the early 2020's [3] [8]. The literature reviewed also did not show that the other ECOWAS countries (Cote d'Ivoire, Togo, Burkina Faso, Niger, Guinea, Guinea-Bissau, Mali, Benin, Sierra Leone, Liberia and The Gambia) have any sustained government-based monitoring network, nor the West African cities scoping review [3].

3.2. Low-Cost Sensor Networks and Technological Innovation

The most common innovation reported in ECOWAS countries and sold under multiple different names was low-cost optical particle sensors, mainly using the Plantower PMS5003/PMS5003T sensor element [6]. There was strong correlation for all the low-cost monitors with a reference-grade Teledyne monitor for $PM_{2.5}$; however, they were all biased high, with the lowest mean absolute error being obtained by the QuantAQ (3.04), followed by PurpleAir (4.54) and Clarity Node-S (13.68) [6]. An AirGradient OpenAir PM monitor was also deployed at an Afri-SET reference site in Accra, which showed a similar temporal trend to the reference instrument, and a correlation between the patterns of $PM_{2.5}$ observed in a neighbourhood in Accra and charcoal and fuelwood burning, and traffic [7].

The number of cities that have conducted low-cost sensor studies has increased in Nigeria [8] [9]. Pollution measurements were done for particulate matter and gaseous pollutants in a semi-urban community of Ile-Ife, over a two-month period, and the pollution sources were allocated to residential or industrial activities, based on conditional bivariate probability functions [8]. Low-cost optical sensors quantified $PM_{2.5}$ in Akure, in Ondo State, in the Harmattan dry season, at two urban sites, from approximately 14 to more than 590 micrograms per cubic metre, and found clear evidence of local emission enhancement [10]. It was noted that Atmotube PRO and PurpleAir sensors had good relationships at both household and school level with a median ratio of 0.93 between indoor and outdoor $PM_{2.5}$, and there was good consistency of the data over time, although there was no regulatory-grade sensor in Nigeria to validate the data from the low-cost sensors [11]. As part of a project funded by the US Department of State, 30 low-cost sensors and a reference-grade sensor for local calibration were installed in Lagos, representing one of the widest and most available sources of air quality information in the city [12].

The second, five-site PurpleAir network in the region, in Lomé, Togo, resulted in the first multi-year ambient $PM_{2.5}$ dataset for the city, with a network-wide mean seasonal increase between December and February of up to 58 percent due to the Harmattan, and a mean daily concentration of 23.5 micrograms per cubic metre [2]. The first systematic spatial and temporal characterisation of $PM_{2.5}$ in Burkina Faso was conducted using a low cost sensor network (19 sites) and a reference grade co-located sensor for field calibration [13] and a follow-on study on the implementation of low-cost sensor networks in three countries, including install and maintenance of sensors for field calibration, field, semi-urban and rural deployments of factory-calibrated sensors, and remote area deployments in Guinea [14].

The feasibility of the long-term monitoring of the low-cost $PM_{2.5}$ monitors was tested with 15 PurpleAir-II-SD monitors set in eleven cities in the ECOWAS countries in Sub-Saharan Africa, and the result shows that all the cities have annual mean concentrations above the WHO guideline [15]. Low-cost monitoring platforms such as AirQo established at Makerere University in Uganda have been replicated in Lagos and Accra as part of a network of over 200 sensors across the various cities in Africa [16].

3.3. Machine-Learning Sensor Calibration

The low-cost sensors are sensitive to humidity and temperature, as well as the composition of the particles, which will be an important research priority. However, Gaussian Mixture Regression was applied to calibrate a PurpleAir sensor in Accra, which was co-located with a reference PurpleAir sensor (BAM-1020) for a full year, and achieved a moderate correlation (r^2 = 0.53) and high bias [6] with the uncorrected data. At the regional level, AirQo developed and tested a set of machine-learning calibration models (k-nearest neighbours, support vector regression, ridge and lasso regression, XGBoost, random forest, gradient boosting and others) and packaged the best-performing model into an open-source tool, AirQalibrate [17] [18], specifically designed to support low-cost sensor calibration in data-scarce Sub-Saharan Africa without users needing to maintain their own reference-grade instruments. The non-linear calibration approach with AI has been used in the past for low-cost $PM_{2.5}$ and PM10 calibration in other LMICs, and has been shown to be more effective than simple linear regression in cases where the aerosol mixture is more complex, such as in cities in West Africa [18].

3.4. Satellite Remote Sensing and Hybrid Data-Fusion Approaches

With the lack of ground-based reference monitors, a number of studies have used aerosol optical depth (AOD) derived from satellite data with reanalysis meteorological data to estimate $PM_{2.5}$ levels in regions without direct measurements. A multi-model study developed several machine learning algorithms such as Extreme Gradient Boosting (XGBoost), trained them with available surface $PM_{2.5}$

observations to generate daily estimates of $PM_{2.5}$ at 1 km resolution across West Africa with near-universal exceedance of the WHO air quality guidelines over the entire region [19]. The multiple linear regression (MLR) and the artificial neural network (ANN) models were used to estimate the AOD at the national scale in Ghana using MODIS satellite data over the period 2003-2019 [20]. The first 48-h air quality forecasting system for the megacities of Dakar, Senegal, was developed using four different machine learning ensemble models (Random Forest, Extra Trees Regression, XGBoost, and CatBoost) with reference to satellite Earth observations, as described in the paper [21]. As air quality research moves towards the natural sciences, and satellite data become more widely used for African air quality, yet another cross-continental air quality research telecoupling review revealed that the capacity and authorship of satellite data applications and integration into air quality research in Africa continue to be largely driven by the interests and expertise of natural scientists and scientists outside of Africa [22].

3.5. Citizen Science and Community-Based Monitoring

However, the use of citizen science applications is not as well developed in the ECOWAS region as in East Africa, where working similar models have been taken up and can be adapted to the region. The air quality study was a citizen-science effort that involved installing the optical particle sensors and a community engagement workshop to build capacity for the community to interpret and respond to the air quality data they collected, with the aim of creating a national air quality stakeholder network [23]. The SEI-led project in the Mukuru settlement, Nairobi, trained community champions to use personal monitors and to share the results with community and policymakers [24]. Further examinations of citizen-collaborative air quality platforms also highlight the increasing potential for distributed citizen monitoring, thanks to the proliferation of low-cost, Wi-Fi-enabled sensors, and the fact that hybrid platforms that incorporate multiple data sources and leverage AI and IoT technologies are best suited to citizen monitoring and public forecasting [12] [25]. Community-oriented deployments have so far been integrated into low-cost sensor projects funded by donors in ECOWAS (e.g., in Lagos and Accra), and there is potential for more of this type of innovation.

3.6. Country-Level Synthesis

The status of government reference monitoring and some of the innovative monitoring programmes identified in the literature for the ECOWAS member states or group of states are summarised in **Table 1** and **Table 2**.

4. Discussion

The literature reviewed all points to a number of consistent findings. The second is the fact that the level of institutional capacity in ECOWAS for conducting air quality monitoring is still uneven, and that there is no capacity at the Government level for air quality monitoring in most countries, with the exception of a few

Table 1. Overview of government reference monitoring and low-cost/innovative air quality monitoring initiatives across ECOWAS member states.

Country	Government Reference Monitoring	Notable Low-Cost/Innovative Monitoring Initiatives	Key Source(s)
Senegal	Yes 6-station Centre de Gestion de la Qualité de l'Air (CGQA) network in Dakar; only ECOWAS country with a long-running continuous network	Wireless sensor network prototypes for Dakar; XGBoost-based 24-hour $PM_{2.5}$ forecasting system	Mir Alvarez *et al.* (2020) [3]; operational forecasting study (2026); hybrid measurement kit study
Ghana	Limited U.S. Embassy reference monitor in Accra; Afri-SET reference site	Multi-brand low-cost sensor intercomparison (QuantAQ, PurpleAir, Clarity, AirGradient) against reference-grade instruments; PurpleAir-BAM calibration; MODIS-based machine-learning AOD mapping	Raheja *et al.* (2023) [6]; Hodoli *et al.* (2024) [7]; PLOS Climate MODIS-AOD study
Nigeria	Sparse historically only two reference stations (U.S. Embassy, Lagos and Abuja)	AirQo/AirGradient low-cost networks in Lagos; PurpleAir/Atmotube deployments in Ibadan; PMS-based sensor packages in Ile-Ife, Akure and Ikere-Ekiti	Owoade *et al.* (2021) [8]; Ibadan residential PM study (2025) [11]; Akure $PM_{2.5}$ study (2024) [10]; AirGradient Lagos deployment
Côte d'Ivoire	None identified	Field-calibrated Real-time Affordable Multi-pollutant (RAMP) monitors in Abidjan; ground-based PM_{10}/$PM_{2.5}$ mapping in Korhogo and Abidjan	IAQWA project (Abidjan-Accra comparison); Korhogo/Abidjan dry-season study (2020) [26]
Togo	None identified	Two-year, five-site PurpleAir $PM_{2.5}$ network in Lomé first multi-year dataset for the city	Raheja, Sabi, Sonla, Gbedjangni, McFarlane, Hodoli & Westervelt (2022) [2]
Burkina Faso	None identified (LC station co-located with reference instrument for calibration)	19-site Clarity low-cost sensor network with field calibration	Nana *et al.* (2025) [13]; Burkina Faso/Niger/Guinea network study (2026) [14]
Niger	None identified	Factory-calibrated low-cost sensors deployed across urban, semi-urban and rural sites	Burkina Faso/Niger/Guinea network study (2026) [14]
Guinea	None identified	Low-cost sensor deployment in a remote/rural setting	Burkina Faso/Niger/Guinea network study (2026) [14]
The Gambia, Guinea-Bissau, Mali, Benin, Sierra Leone, Liberia, Cabo Verde*	None identified for most; largely unmonitored	Included as sites in the 8-country, 15-location PurpleAir feasibility network; scattered pilot and academic deployments	[15] Awokola *et al.* (2022) multi-country feasibility study

Table 2. Overview of low-cost and innovative air quality monitoring approaches across ECOWAS member states.

Innovation Category	Description	Representative ECOWAS Examples	Main Advantage	Main Limitation
Low-cost optical/electrochemical sensors	Compact, battery- or mains-powered particulate and gas sensors (e.g., Plantower	Accra, Lagos, Ibadan, Ile-Ife, Akure, Lomé, Ouagadougou	Low unit cost, high spatial density, near real-time data	Sensitivity to humidity and cross-pollutant

	PMS5003, PurpleAir PA-II, Clarity Node-S, AirGradient Open Air)			interference; requires calibration
Machine-learning sensor calibration	Statistical/ML correction of raw low-cost sensor output against reference-grade monitors (e.g., XGBoost, random forest, Gaussian Mixture Regression)	Accra (PurpleAir-BAM GMR calibration); AirQo AirQalibrate tool (regional)	Improves data reliability without dense reference infrastructure	Requires at least some reference-grade co-location data; models may not transfer across sites
Satellite-derived / hybrid $PM_{2.5}$ mapping	Combines satellite aerosol optical depth, reanalysis meteorology and surface monitors with ML to estimate ground-level $PM_{2.5}$ at fine spatial resolution	20-year, 1 km^2 West Africa $PM_{2.5}$ dataset; MODIS-based AOD mapping over Ghana; Dakar 24-hour forecasting	Near-complete spatial coverage where ground stations are absent	Reduced accuracy where surface validation data are sparse; cloud/dust interference
Citizen science and community-based monitoring	Community members operate personal or fixed low-cost monitors and participate in interpreting results	Comparable regional models from Nairobi (Kibera) and Addis Ababa; nascent adoption within ECOWAS advocacy networks	Builds public awareness and local ownership of data	Data quality variability; limited to project duration without institutional continuity
Regional networking platforms	Multi-country data infrastructure and analytics platforms aggregating low-cost sensor feeds	AirQo network (active in Lagos, Accra, and other African cities)	Shared calibration tools, cross-border comparability, capacity building	Dependent on donor/grant funding; uneven country coverage

(Senegal and Ghana). This reflects the general trend found throughout Africa, where only a few countries experienced government controlled, routine monitoring on a continent-wide level [4]. Second, the main route to bridging these gaps is by using low-cost sensors, with at least eight of the fifteen ECOWAS countries (Nigeria, Ghana, Senegal, Côte d'Ivoire, Togo, Burkina Faso, Niger and Guinea), as well as Cabo Verde, having documented deployments. Third, the confidence in these low-cost networks depends on their "calibration with reference grade instruments" and in this location there are few reference grade instruments. Thirdly, the trustworthiness of this cheap network relies largely on the idea that the network is "calibrated against reference-grade instruments"—and there aren't many such instruments in this region—which means that the network that is supposed to compensate the lack of standard instruments depends critically on those very instruments that it is supposed to replace. The use of machine-learning calibration tools like AirQalibrate is a potential solution to this limitation because they can decrease (but not completely remove) the requirement for co-location of references.

Satellite-derived and hybrid approaches could provide additional support to ground monitoring by complementing areas where no ground monitoring data are available and fill gaps in data coverage for regions with no ground monitoring data at all, with the twenty-year West Africa $PM_{2.5}$ dataset providing an improvement in data availability at the regional scale (1000 km, hourly resolution). Satellite products, however, would still rely on ground truth data for training and validation, and this data is necessarily sparse with respect to the data available for satellite observations, which means that their accuracy would be limited by the sparseness of the observational network used for satellite observations. The low uptake of citizen science in ECOWAS compared to citizen science in established programmes in the East Africa region is an untapped opportunity; citizen-generated data could complement the existing extensive spatial coverage in these areas likely not to be formally instrumented or studied, whilst citizen awareness through citizen science can support the political pressure that can lead to effective governance of air pollution [23] [24].

The lowest score across all four categories of innovation is for policy translation. Several reviews have been conducted that specifically point to the fact that even if monitoring data can be found, they are not used for public health monitoring or to inform public health enforceable regulations [4] [27]. Regional policy coordination is possible as the environment and energy ministers of the ECOWAS in 2020 adopted harmonised regional standards for cleaner fuels and vehicles; however, national policy coordination, enforcement and implementation of these standards, as well as monitoring infrastructure to support compliance, are generally still inadequate [27] [28].

5. Challenges and Gaps Identified in the Literature

- Lack of reference-grade air quality monitoring and poor air quality monitoring infrastructure overall result in poor direct air quality monitoring and poor calibration of low-cost sensor networks.
- Sustainability issues when donor and grant funding runs out (AirQo, n.d.) and overreliance on donor and grant funding for low-cost deployments [16]
- The in-field technical and logistical issues on installation and maintenance of low-cost sensor networks in harsh environmental conditions in West Africa, such as heat, dust, humidity and power instability as encountered in Burkina Faso, Niger and Guinea [14].
- Poor and non-existent compliance with national air quality legislation and standards in most ECOWAS countries that have them, limiting the role of air quality monitoring data in national regulation.
- Lack of linkages between air quality monitoring and public health surveillance systems, which restricts epidemiological studies and evidence-based air quality policies and decision-making [29].
- Poor citizen science infrastructure compared with other sub-regions in Africa, and thus opportunities for citizen science data at the community level and community advocacy are missed out [22].

6. Recommendations

- Expand and/or strengthen a minimum network of reference-grade monitoring stations in all ECOWAS capital cities to enable low-cost calibration of sensors and satellite validation.

- Ensure harmonised calibration protocol and common calibration tools (such as AirQalibrate) at the ECOWAS level for better comparability of data in the ECOWAS region.
- Invest in applications that share data regionally and integrate sensor, reference-grade and satellite data on a single platform, accessible to researchers, policy makers and public—at low cost.
- Improve the national air quality law and make a direct connection between air quality monitoring and public health surveillance and urban planning.
- Increase spatial coverage and public participation by facilitating the roll out of citizen science pilot programmes, drawing from examples in East Africa, which are low cost.
- Ensure in-country technical capacity in deployment, maintenance and calibration of sensors is maintained and developed, limiting the need for short-term funding cycles for donors.
- Ensure that the ECOWAS region, research and institutions in the region have the principal role in the co-authorship in future air quality studies of the satellite and remote-sensing approach.

7. Limitations of This Review

This review was conducted using the literature available through the Google Scholar search engine and other academic sources and does not necessarily reflect all the available grey literature, government reports or non-English language francophone and lusophone literature which is particularly important as a large proportion of the ECOWAS states are Francophone. The diversity in study design, duration of monitoring and metrics reported did not permit for formalization of a meta-analysis to be conducted and the narrative synthesis approach was an appropriate way to process this evidence base; however, this lacked the objectivity and power of a fully quantitative synthesis that is open to selection and interpretation bias. Thirdly and importantly, there is a process of new developments in this field that will mean that some very recent deployments and pilot projects may not be published at the time of this review.

8. Conclusion

Over the last 10 years, countries in ECOWAS have innovated in air quality monitoring, resulting in numerous innovations, particularly in the number of low-cost sensors, the use of machine learning methods for sensor calibration and the widespread availability of satellite-derived and hybrid air quality data products to fill the long-standing monitoring gaps. Only in Senegal is there an ongoing, government-operated, continuous monitoring network, while low-cost sensor deployments have been successfully implemented in Ghana, Nigeria, Togo, Côte d'Ivoire, Burkina Faso and Niger either as part of international research partnerships or donor-funded projects. The Citizen science initiative in Sub-Saharan Africa is relatively underdeveloped in comparison with other countries in the region. The transition from technological pilots to regionally coordinated and integrated monitoring architectures, anchored to reference-grade monitoring and calibrated low-cost networks, satellite fusion and community engagement will be crucial to secure sustained progress.

Author Contributions

Conceptualization, AI. and AII.; methodology, AI.; software, JAA.; validation, AI., SJC., and IYS.; formal analysis, AI.; investigation, WA.; resources, AI.; data curation, AA.; writing—original draft preparation, AI.; writing—review and editing, AII.; visualization, WA.; supervision, SJC.; project administration, AI.; funding acquisition, AI. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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