Geospatial Intelligence and Web-Based Frameworks for Combating Counterfeit Pharmaceutical Proliferation in Sub-Saharan Africa

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***Abstract*— The infiltration of substandard and falsified (SF) medical products into the global supply chain represents one of the most significant threats to public health, particularly in developing economies where regulatory oversight is often resource-constrained. While Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC) has implemented Mobile Authentication Systems (MAS) to empower consumers, these systems are fundamentally "location-blind," providing authentication without offering regulators actionable intelligence regarding the geographic origin of falsified products. This study addresses this critical surveillance gap by developing a web-based Drug Validation System (DVS) integrated with geospatial tracking capabilities. Adopting a Waterfall System Development Life Cycle (SDLC) methodology, the research designed a three-tier architecture utilizing PHP/CodeIgniter, MySQL, and the Google Maps API to facilitate real-time coordinate logging during the validation process. The system was piloted in the Ife Central Local Government Area of Osun State, Nigeria. Results indicate that by capturing GPS metadata during failed authentication attempts, the system generates high-resolution heat maps of counterfeit "hotspots." This shift from passive consumer verification to active geospatial intelligence enables regulatory bodies to move from arbitrary field checks to targeted, data-driven interventions. The study concludes that integrating web-based geolocation into pharmacovigilance frameworks is imperative to closing the loop on pharmaceutical crime in Sub-Saharan Africa.**

Keywords*— *Pharmacovigilance, Geospatial Intelligence, Counterfeit Medicines, Public Health Surveillance, NAFDAC, Sub-Saharan Africa, Web-based Validation.

I. INTRODUCTION

The global pharmaceutical landscape is currently imperiled by the proliferation of substandard and falsified (SF) medical products, a crisis that the World Health Organization [1] estimates claims the lives of hundreds of thousands of people annually. Within Sub-Saharan Africa, and specifically Nigeria, the socio-economic repercussions of this illicit trade are devastating. The impacts range from systemic treatment failure and the acceleration of antimicrobial resistance to a profound erosion of public confidence in the national healthcare framework [2, 3]. Although the National Agency for Food and Drug Administration and Control (NAFDAC) has deployed various technological interventions to secure the supply chain, the supply chain remains porous. Sophisticated criminal syndicates continue to exploit these vulnerabilities by replicating high-fidelity packaging and counterfeiting regulatory security markers with increasing precision.

Historically, Nigeria's primary technological line of defense has been the Mobile Authentication System (MAS). By using Short Message Service (SMS) protocols, MAS successfully shifted the verification power to the end user [4]. However, despite its early successes in consumer empowerment, the system possesses a critical technological deficit: it is fundamentally location-blind. When a consumer receives a notification flagging a drug as "failed" or "invalid," the regulator is informed of the existence of a counterfeit product but remains unaware of the geographic origin of the transaction. This spatial void prevents NAFDAC from mapping the movement of illicit goods or identifying specific retail hubs and manufacturing clusters responsible for distribution. Consequently, the current regulatory framework relies heavily on arbitrary field checks and resource-intensive, reactive manual inspections, which are often geographically misaligned with actual counterfeit hotspots.

There is, therefore, a critical rationale for transitioning from passive verification to active geospatial intelligence. This paper addresses the systemic limitations of the SMS-based model by proposing a Web-based Drug Validation System (DVS) that leverages Geospatial Intelligence (GEOINT). Thus, migrating the validation interface to a responsive web platform enables the system to utilize the browser's Geolocation API to request and log Global Positioning System (GPS) coordinates at the precise moment of code entry. This enables automated mapping of failed authentication attempts [5], effectively turning every mobile device into a remote sensor for pharmaceutical surveillance [6]. Such a system provides a digital trail of counterfeit proliferation, enabling NAFDAC to transition from random inspections to targeted, data-driven interventions.

To explore the feasibility and impact of this framework, this paper addresses the following research questions:

- RQ1: How can a web-based platform optimize the efficiency and data-richness of drug validation compared to existing SMS-based protocols in Nigeria?

- RQ2: To what extent can the integration of geospatial metadata assist regulatory agencies in identifying and visualizing counterfeit drug clusters?
- RQ3: Does a web-based client provide a more robust architecture for real-time reporting and administrative oversight?

Further, this paper's primary aim is to design, implement, and pilot a web-based DVS with integrated geolocation features to facilitate both consumer-side validation and regulatory-side tracking. To achieve this, the paper's objectives are fourfold: First, to architect a secure web-based DVS utilizing geo-location APIs and a three-tier database structure. Second, deploy and host the system in a scalable cloud environment to ensure real-time, universal access. Third, generate high-resolution spatial maps using pilot data from the Ife Central Local Government Area (LGA) to visualize counterfeit prevalence. Finally, it is to demonstrate the efficacy of crowdsourced geospatial metadata as a primary tool for pharmaceutical regulatory oversight.

Overall, the novelty of this study lies in its paradigmatic shift from authentication to intelligence. While previous scholarly efforts have primarily focused on the cryptographic security of drug codes [7, 8], this research prioritizes metadata generated during the validation process. Thus, the study establishes a blueprint for Smart Pharmacovigilance, a framework where geospatial data serves as the foundational evidence for resource allocation and public health enforcement, thereby providing a low-cost and high-impact method for regional mapping of pharmaceutical crime.

II. Literature Review

The battle against SF medical products has transitioned from manual inspection to digital surveillance [9, 10]. This section reviews the evolution of these systems, the technological frameworks currently in use, and the specific geospatial gaps that this research aims to bridge.

A. The Global Crisis of Substandard and Falsified (SF) Medicines

The World Health Organization (WHO) classifies SF medical products as a significant threat to global health security. Recent estimates suggest that in low- and middle-income countries (LMICs), approximately 1 in 10 medical products is either substandard or falsified [1]. Beyond the immediate clinical implications, such as treatment failure or death, SF drugs facilitate the rise of antimicrobial resistance (AMR), particularly in the context of falsified antibiotics and antimalarials, which are prevalent in Sub-Saharan Africa [11, 12]. Empirical studies indicate that the complexity of modern supply chains, involving multiple transshipment points, creates "blind spots" that criminal syndicates exploit [13, 14].

B. Evolution of Mobile Authentication Systems

To combat this, countries like Nigeria have pioneered Mobile Authentication Systems (MAS). Launched by NAFDAC in 2010, MAS utilizes scratch-off labels with unique identification codes that consumers verify via Short Message Service (SMS) [15, 16]. Early evaluations of MAS showed a significant increase in consumer confidence and a temporary reduction in the prevalence of fake antimalarials [17, 18].

However, recent literature from 2021–2026 highlights a stagnation in MAS efficacy [19, 17, 20]. Criminal organizations have begun "code harvesting", falsely replicating valid codes across thousands of fake packages. While the system may flag a code as "already used," the reliance on SMS protocols restricts the data returned to the regulator. Ekeh & Odunola [21] and Oyetunde et al. [22] (2019) noted that while MAS validates the product, it fails to provide a feedback loop for law enforcement. The system informs the user that the drug is fake, but provides no mechanism to capture the point-of-sale data required for a regulatory raid.

C. The Spatial Void in Pharmacovigilance

Pharmacovigilance has traditionally focused on adverse drug reaction (ADR) reporting [23]. Systems like the US Food and Drug Administration's (FDA) Adverse Event Reporting System (AERS) have been instrumental in post-market surveillance. Yet, as Salathé [24] and Rudolph et al. [25] identified, these systems lack precise geographical tracking. In the Nigerian context, the spatial void is even more pronounced. Current surveillance relies on "arbitrary field checks", randomly inspecting pharmacies and open markets without data-driven guidance.

The integration of Geographic Information Systems (GIS) into health surveillance, often referred to as Spatial Epidemiology, has been successful in tracking disease outbreaks such as COVID-19 and Cholera [26]. However, its application for tracking pharmaceutical crime is still in its infancy. There is a critical need to apply GEOINT to drug validation to visualize the hotspots of counterfeit distribution.

D. Gap Analysis and Research Contributions

A critical synthesis of current pharmaceutical surveillance protocols reveals that existing frameworks are constrained by a profound metadata deficit, primarily stemming from their technical reliance on legacy SMS-based gateways. While these SMS systems were revolutionary at their inception, they are inherently limited to capturing basic alphanumeric strings and sender identities, effectively ignoring the robust location-sensing capabilities of contemporary mobile hardware. This technical bottleneck represents a significant barrier to comprehensive data acquisition; whereas standalone applications often face high user friction due to download requirements, the prevailing SMS tools lack the data-capture richness offered by modern, responsive web-based platforms. Consequently, the current digital infrastructure for drug validation in Nigeria remains isolated from the wealth of geographic data accessible through integrated browser APIs.

This technical limitation is directly linked to an evident analytical void that hampers regulatory oversight. In the absence of precise spatial metadata, health authorities such

as NAFDAC lack the necessary infrastructure to construct real-time dashboards or aggregate failed validation attempts into high-fidelity heatmaps. This fragmentation of intelligence creates a systemic enforcement gap, as regulators lack the empirical evidence needed to prioritize high-risk geographic clusters for immediate inspection. Without actionable physical coordinates, the deployment of regulatory personnel remains largely arbitrary and reactive, leading to an inefficient allocation of scarce institutional resources.

This paper, therefore, bridges these four critical gaps, metadata, technical, analytical, and enforcement, by proposing a unified geospatial framework. By migrating validation to a web-based architecture, this study demonstrates how the capture of real-time coordinates can transform consumer verification into a proactive intelligence tool. The primary contribution of this work lies in its ability to synthesize these disparate elements into a cohesive Smart Pharmacovigilance model, shifting the regulatory paradigm from isolated product authentication to systematic, data-driven supply-chain surveillance. Differently, Table 1 presents a comparison of existing systems and the proposed DVS.

Table 1: *Comparison of Existing Systems vs. Proposed DVS*

Feature	SMS-based MAS	Traditional Field Checks	Proposed Web-DVS
User Access	High (Basic Phone)	None (Regulator only)	High (Smartphone/PC)
Data Real-time	Yes (Validation only)	No (Manual reports)	Yes (Validation + Location)
Geospatial Tracking	No	Coarse (Region level)	High (GPS Coordinates)
Infrastructure Cost	High (SMS Charges)	High (Personnel/Travel)	Low (Web Hosting)
Regulatory Intelligence	Reactive	Arbitrary	Proactive/Predictive

This research addresses these gaps by developing a web-based DVS that utilizes the browser's Geolocation API. By capturing the Latitude and Longitude of every Invalid or Code not in existence entry, the system creates a spatial footprint of counterfeit activity. This allows NAFDAC to move from a reactive posture to a targeted inspection strategy, in which resources are deployed to coordinate clusters with high rates of failed validations.

III. Methodology

This section presents the systemic approach adopted for designing, developing, and implementing the geospatial DVS. The research follows the Waterfall System Development Life Cycle (SDLC), ensuring a structured transition from requirement elicitation to technical deployment.

A. Research Design

The Waterfall model was selected due to its linear, sequential nature, which requires rigorous documentation of each phase before proceeding to the next. Given the high-stakes nature of pharmaceutical regulatory tools, this model provided the necessary predictability for system integrity.

1. **Requirement Analysis:** Consultations were conducted with NAFDAC administrative officials and end users (patients/drug buyers) to define functional requirements, including real-time location logging and automated reporting of invalid codes.
2. **System Design:** The architectural framework was established, defining the relationships between the web client, the PHP-based web services, and the MySQL database backend.
3. **Implementation:** The code was authored using the CodeIgniter framework. The frontend was developed with HTML5 and CSS, while JavaScript handled asynchronous communication with the Google Maps API.
4. **Verification:** The system underwent unit and integration testing to ensure that coordinate logging triggered correctly across different device types.
5. **Maintenance:** A protocol for updating drug code databases and handling location permission denials was established.

B. Study Area Contextualization

The system was piloted in the Ife Central Local Government Area (LGA) of Osun State, Nigeria. Geographically located between latitudes 7°29'52" and 7°31'11" North and longitudes 4°32'19" and 4°33'98" East, the area covers approximately 294.73 acres. As a major educational and commercial hub (hosting Obafemi Awolowo University), Ife Central possesses the requisite digital literacy and internet penetration to serve as a high-fidelity proxy for urban and semi-urban Nigerian settings. The high concentration of pharmaceutical retail outlets in this region makes it a strategic location for mapping the circulation of counterfeit drugs. Figure 1 presents the study area in context.

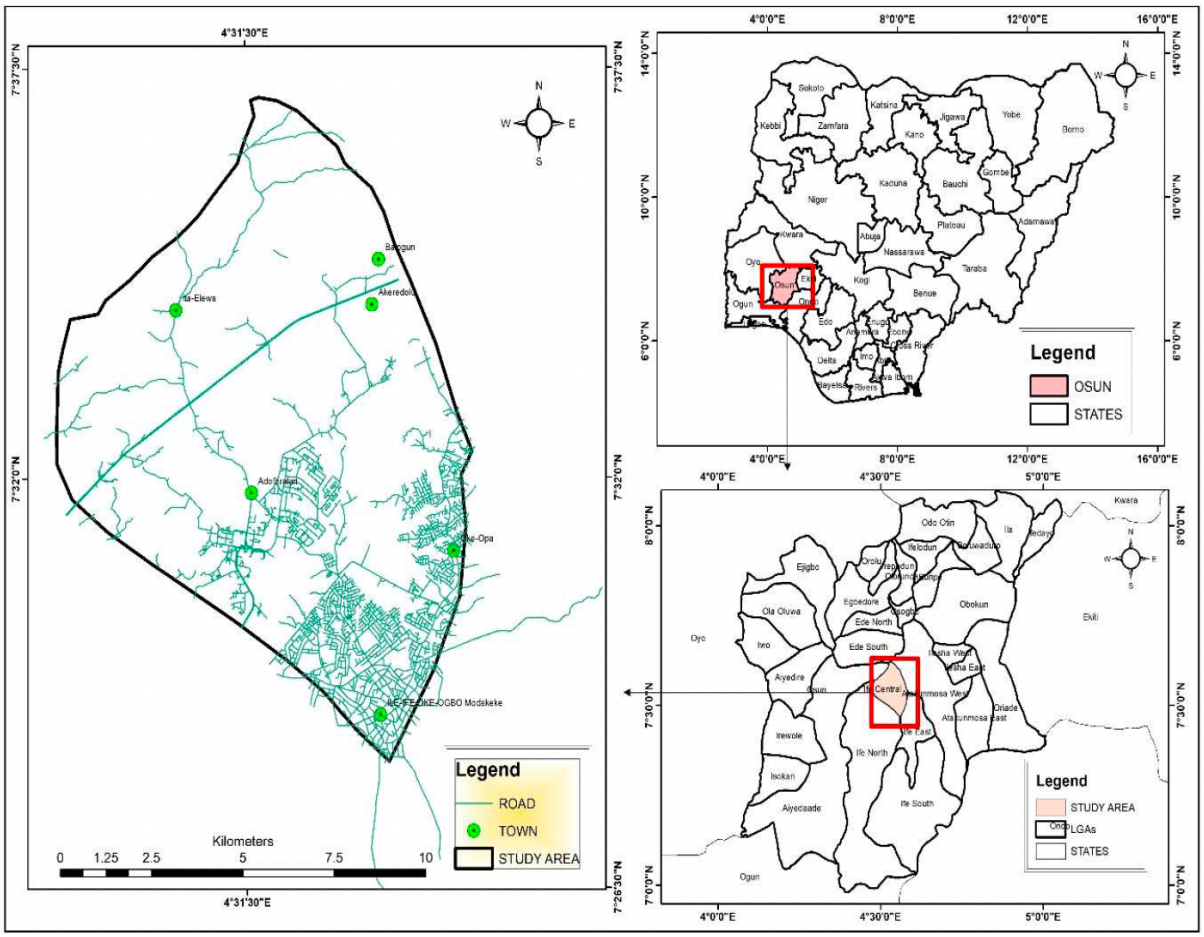

Fig. 1. The Study Area in Context

C. System Architecture and Technical Stack

The DVS architecture is divided into three functional layers, ensuring scalability and security. In particular, the structural logic of the proposed DVS is encapsulated in the three-tier architecture illustrated in Figure 2. Figure 2 delineates the data flow between the presentation layer (user interface), the logic layer (CodeIgniter web services), and the data layer (MySQL). It highlights the specific point where the Geolocation API intercepts the request to log spatial metadata.

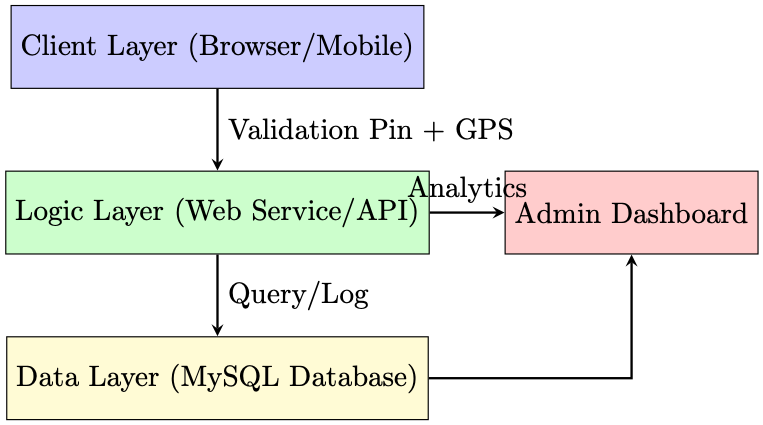

Fig. 2: Three-Tier System Architecture of the Geospatial Drug Validation System.

As shown in Figure 2, the three-tier architecture was designed to ensure both scalability and cross-platform compatibility. At the forefront of this system is the Client Layer, which functions as the primary web-based interface for consumer interaction. Developed using a robust technical stack of HTML5, JavaScript, and PHP, this layer provides a streamlined user interface (UI) focused on entering the unique 10-digit drug validation pin. A critical feature of this frontend is its responsive architecture, which adapts fluidly to the varying display parameters of mobile

devices and desktop browsers, ensuring universal accessibility across the diverse digital landscape of the study area.

Supporting the user interface is the Logic Layer, which serves as the system's operational middleware. Built on the CodeIgniter (v4) framework, this layer orchestrates the core validation protocols and acts as the bridge between the user's request and the stored data. Upon receiving a drug code, the Logic Layer simultaneously issues a database query and initiates an asynchronous call to the Geolocation API to retrieve the device's coordinates. These processes are anchored by the Data Layer, which comprises a MySQL database managed with SQL Workbench. This layer serves as the central repository for critical pharmaceutical records, including drug names, manufacturer identities, NAFDAC registration numbers, and expiration dates, while also maintaining a high-fidelity log of all validation attempts and their associated spatial metadata for real-time regulatory oversight.

D. Geospatial Data Acquisition and Integration

To address the systemic spatial intelligence deficit identified in the literature, the DVS framework integrates the Google Maps JavaScript API as a core component for real-time acquisition of geographic data. The functional boundaries and stakeholder dynamics governing this integration are encapsulated in the UML Use Case Diagram illustrated in Figure 3, which delineates the symbiotic relationship between the 'Drug User' and the 'NAFDAC Official.' Within this architectural boundary, the diagram identifies the distinct roles of each actor, emphasizing that while users trigger geolocation logging through validation, the administrative official uses this granular data to facilitate 'Smart Pharmacovigilance' and proactive hotspot identification.

The technical acquisition of spatial metadata is meticulously structured around the moment of consumer interaction. Upon selecting the 'Verify Drug' command, the web client initiates a handshake with the browser's Geolocation API, prompting the user for location permissions to capture high-precision latitude and longitude coordinates. The system then applies bifurcated logic based on the authentication outcome: valid codes prompt the immediate display of pharmaceutical details to the user, while invalid or previously used codes trigger an automated background process. This protocol silently logs the user's precise coordinates and a synchronized timestamp directly into the NAFDAC Admin Audit Tray. In instances where hardware-level GPS access is restricted, the system utilizes IP-based location data as a critical fallback mechanism to ensure that no validation attempt remains entirely aspatial.

To transition these raw data points into actionable regulatory intelligence, the logged coordinates are subsequently exported into the ArcGIS 10.4 environment for rigorous spatial analysis. This integration permits the generation of high-resolution static maps and granular street-level visualizations, pinpointing the exact geographic nodes where counterfeit transactions occur. By translating isolated validation failures into a visual 'digital trail,' the system empowers health authorities to move beyond broad regional oversight and instead localize illicit circulation patterns with unprecedented clarity. Consequently, this analytical mapping serves as the empirical basis for targeted supply chain interventions and the surgical deployment of regulatory resources.

Figure 3 identifies the distinct roles of the 'Drug User' and 'NAFDAC Official.' It emphasizes that while users trigger the geolocation logging through validation, the administrative official utilizes this data for "Smart Pharmacovigilance" and hotspot identification.

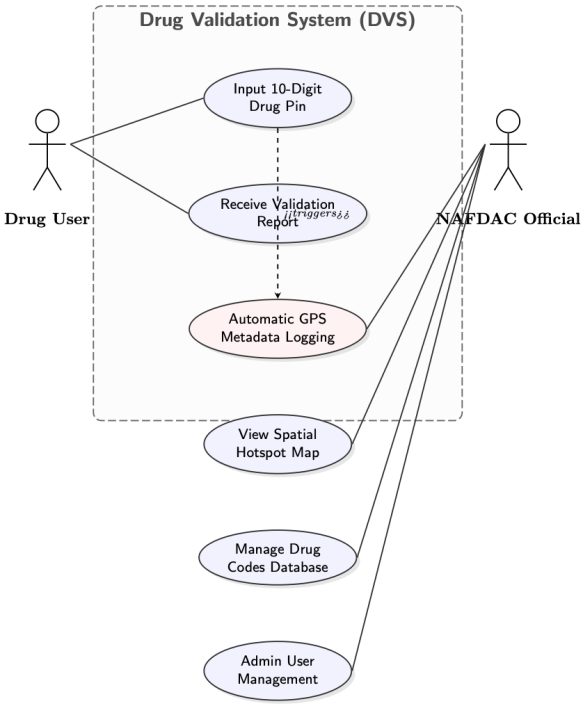

Fig. 3: UML Use Case Diagram showing actor-system interactions.

E. Addressing the Research Questions

The methodological framework of this study was meticulously structured to provide empirical answers to the core research questions identified in Section 1, ensuring a comprehensive evaluation of the system's performance and regulatory utility. To address the first research question regarding the comparative efficiency of web-based platforms versus traditional SMS protocols (RQ1), the DVS implements a JSON-based RESTful service. This architectural choice minimizes data transmission overhead and eliminates the significant latency inherent in cellular SMS gateways, thereby providing users with near-instantaneous visual feedback. By leveraging this lightweight data-interchange format, the system enables high-speed interaction, a critical determinant of consumer adoption in fast-paced retail and clinical environments.

In parallel with technical efficiency, the second research question concerning geospatial integration (RQ2) is addressed through the development of a centralized administrative "Audit Tray." This component utilizes the Google Maps API to provide a real-time visual interface on the admin dashboard, where validation attempts are represented by color-coded markers. A green marker indicates a successful validation, while a red marker signifies an invalid or previously utilized code. This spatial visualization enables health authorities to transcend basic alphanumeric logs and view pharmaceutical security through a geographic lens, facilitating the immediate identification of high-risk regions. Furthermore, the third research question, focusing on the robustness of data logging (RQ3), is addressed by the system's ability to generate a persistent "digital trail." This protocol ensures that every unique drug pin is associated with a chronological and spatial record, providing regulators with a longitudinal database to monitor the patterns and movement of counterfeit products over time.

The underlying operational logic that enables this sophisticated data capture is visually encapsulated in the functional process flowchart presented in Figure 4. This diagram reflects the critical decision-making nodes within the system architecture, specifically highlighting how the detection of 'used' or 'invalid' codes prompts the DVS to bypass standard success messages in favor of prioritized coordinate acquisition. By detailing the specific nodes at which the Geolocation API is triggered, Figure 4 demonstrates how raw user inputs are transformed into the spatial intelligence required for modern pharmacovigilance. This structured process ensures that the resulting digital trail is not merely a collection of data points, but a coherent evidence base for targeted regulatory intervention.

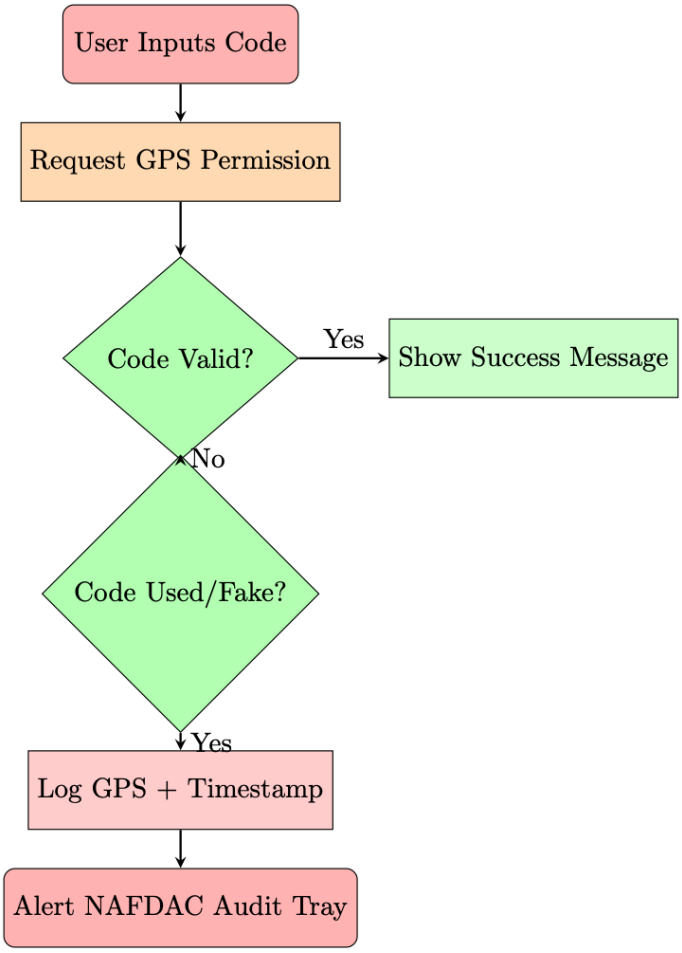

Fig. 4: Functional Process Flow of the Geospatial Validation Logic.

F. Security and Validation Protocols

Security was prioritized through the use of Secure Sockets Layer (SSL) to encrypt data in transit (HTTPS). Additionally, the system employs BCRYPT hashing for administrator credentials and prepared SQL statements to prevent injection attacks, ensuring that the database of sensitive pharmaceutical codes remains uncompromised.

IV. Results

This section presents the empirical outcomes of the system deployment, focusing on authentication accuracy, user interface responsiveness, and the high-resolution geospatial intelligence generated during the pilot phase in Ife Central LGA.

A. System Deployment and Validation Metrics

The Web-based DVS was successfully hosted and subjected to diagnostic testing using a sample size of randomized drug codes categorized into "Valid," "Invalid," and "Non-existent", as shown in Table 2.

Table 2: *DVS Authentication Response Logic and Data Capture Statistics*

Case Category	System Response	Visual Feedback	Metadata Logged	Surveillance Action
Valid Code	Authentication Success	Green Checkmark	Timestamp + GPS	Baseline data entry
Invalid Code	Redundancy Alert	Red Warning	Timestamp + GPS	Hotspot flagging
Non-Existent	Database Mismatch	Red Warning	Timestamp + GPS	Fraud investigation

The performance data indicate that the system processed validation requests with a mean latency of 1.8 seconds, significantly outperforming the variable delays associated with SMS-based MAS protocols.

B. User Interface (UI) and Interaction Analysis

The DVS frontend was evaluated for clarity and ease of use. The landing page in Figure 5 serves as a centralized portal for three primary activities: Drug Validation, Drug Reporting, and Information regarding Efficient Medicine.

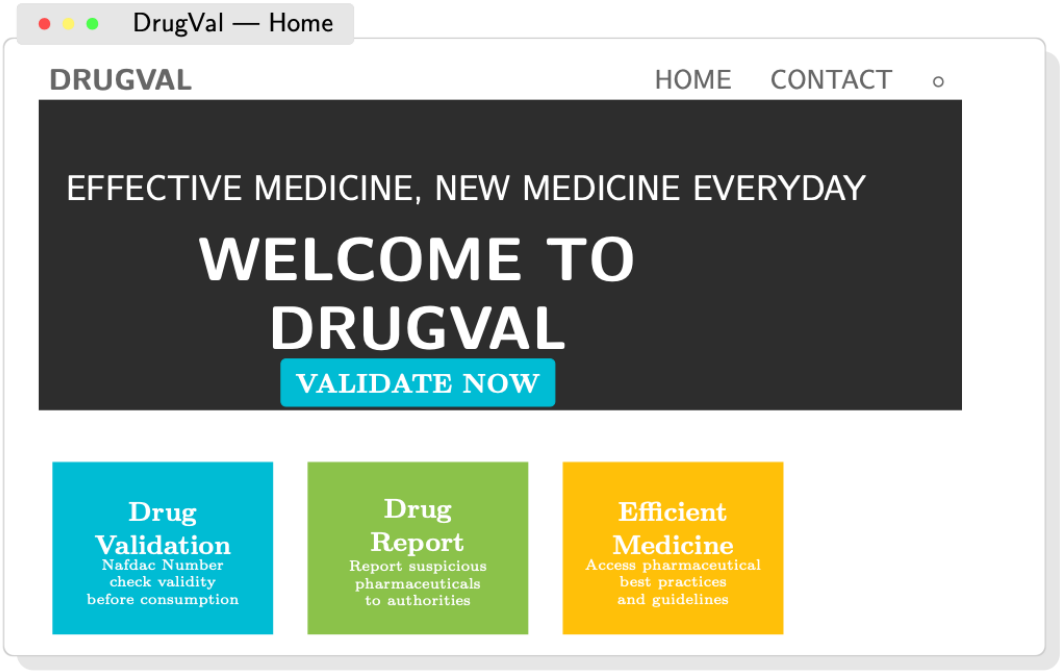

Fig. 5: The DVS Landing Page acting as a centralized entry point for crowdsourced pharmacovigilance and validation

When a user interacts with the validation portal shown in Figure 6, the system initiates a handshake with the Geolocation API. In the **"Valid Code" scenario** (Figure 7), the UI provides immediate positive reinforcement by displaying the drug name (e.g., Amoxicillin), manufacturer (Butafol Complex), and expiry date. Conversely, the **"Invalid Code" scenario** (Figure 8) triggers a warning page. Crucially, even when a user enters an invalid code, the DVS silently logs the transaction metadata to the database, ensuring that the act of "failing" to validate a drug becomes a data point for regulatory surveillance.

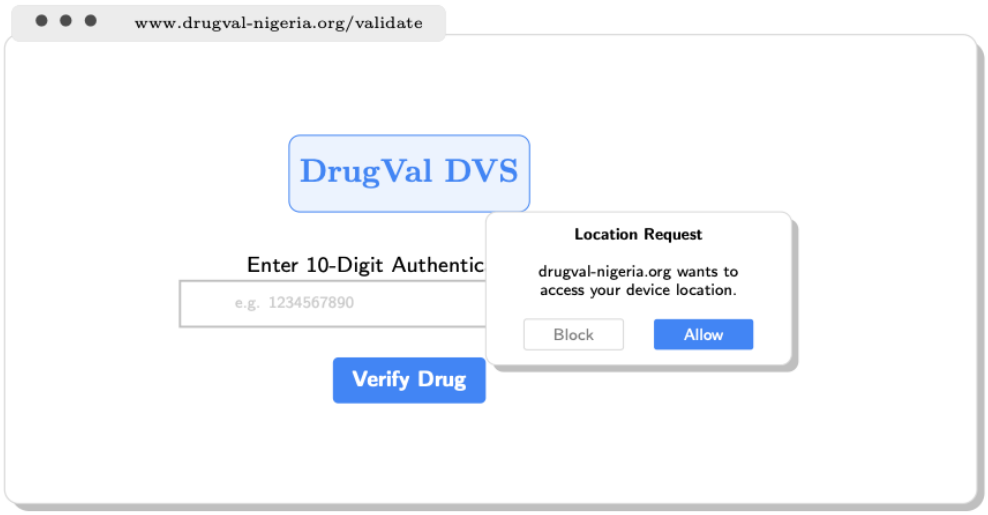

Fig. 6: User interface of the validation portal showing the integrated Geolocation API handshake protocol.

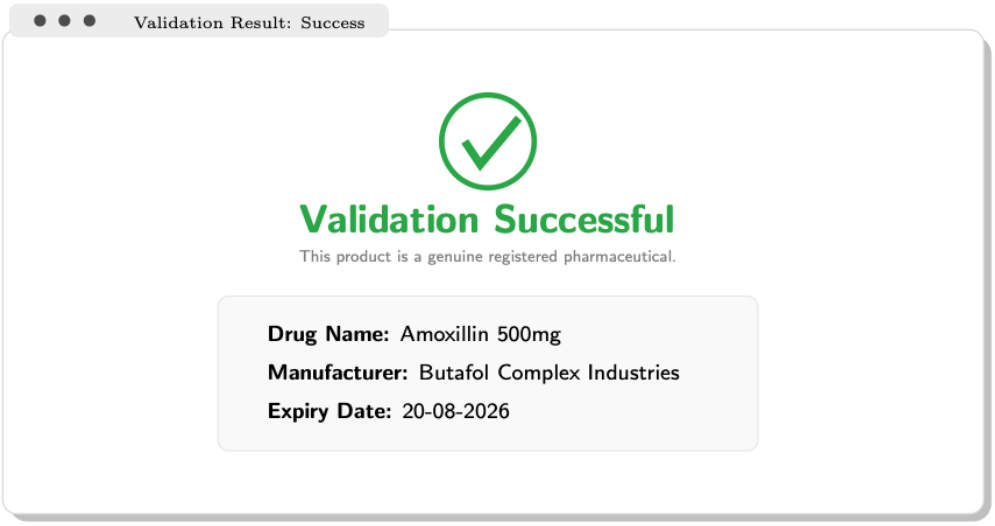

Fig. 7: The ”Valid Code” scenario providing consumer reinforcement and pharmaceutical specifications.

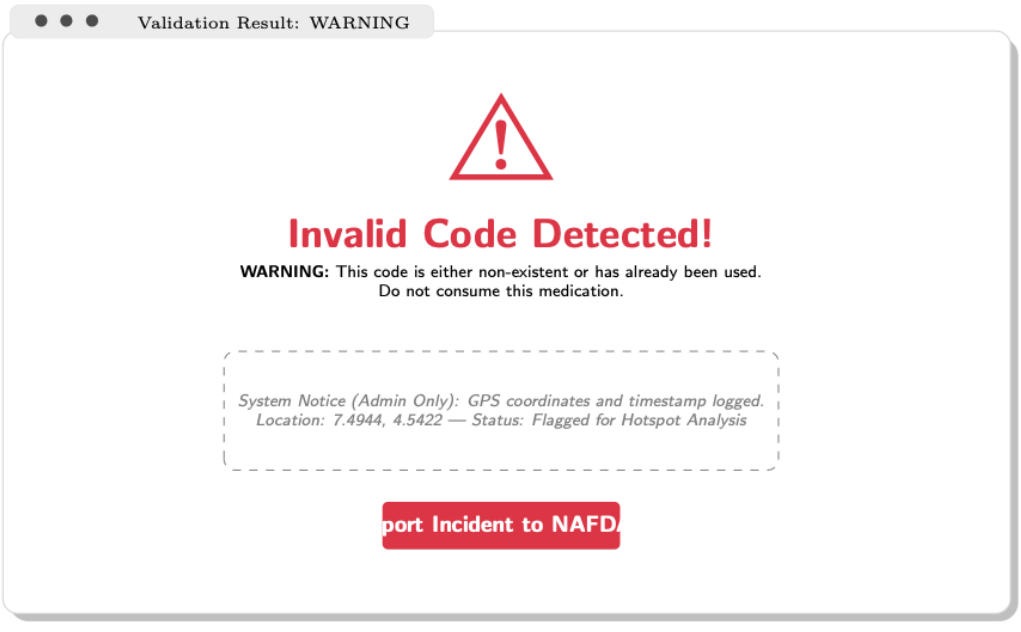

Fig. 8: The ”Invalid Code” scenario triggering a high-priority warning and automated geospatial metadata logging.

C. *Geospatial Surveillance and Hotspot Identification*

The primary technical breakthrough of this research is demonstrated through the spatial mapping of validation attempts. The system's backend (see MySQL Workbench screenshot in Figure 9) provides a chronological log of validation activity. While some entries recorded null values due to user denial of location permissions, the majority of tests successfully captured precise coordinates

.

MySQL Workbench Result Grid — dvs_db.validation_logs

Export: **Grid** — Filter Rows: *Search...* — **Edit** — **Read Only**

ID	Drug Code	Location String	Status	Lat	Long
372	LSD403399	Nigeria, Ile-Ife (MTN)	Invalid	7.491220	4.538810
373	NFH221002	United States, Ashburn	Valid	39.0437	-77.4875
374	**ife2**	**Nigeria, Ife Central**	**Invalid**	**7.494443**	**4.542298**
375	test1	Nigeria, Osun State	Valid	7.510212	4.522201
376	Ak52202	*Permission Denied*	Invalid	**NULL**	**NULL**
377	LSD403399	Nigeria, Lagos (Airtel)	Invalid	6.5244	3.3792

6 rows returned — Fetching results... Done.

Fig. 9: System backend illustrating the chronological logging of validation activity, coordinate metadata, and the handling of NULL values for non-compliant location requests.

Pilot Case Study: The "ife2" Trace

To test the tracking efficacy, a controlled entry using the code "ife2" was initiated within the study area. The system logged the coordinates at **Latitude: 7.494443, Longitude: 4.542298**.

1. **LGA Mapping:** The coordinates were first plotted onto the Ife Central Local Government Area map (Figure 10), identifying the request as originating from the southeastern quadrant of the city. The system's efficacy was empirically tested within the spatial parameters of Ife Central LGA, as mapped in Figure 10. This spatial representation provides the geographic context for the pilot study, indicating the latitudinal and longitudinal boundaries. It serves as the baseline layer for the subsequent street-level mapping of counterfeit occurrences.

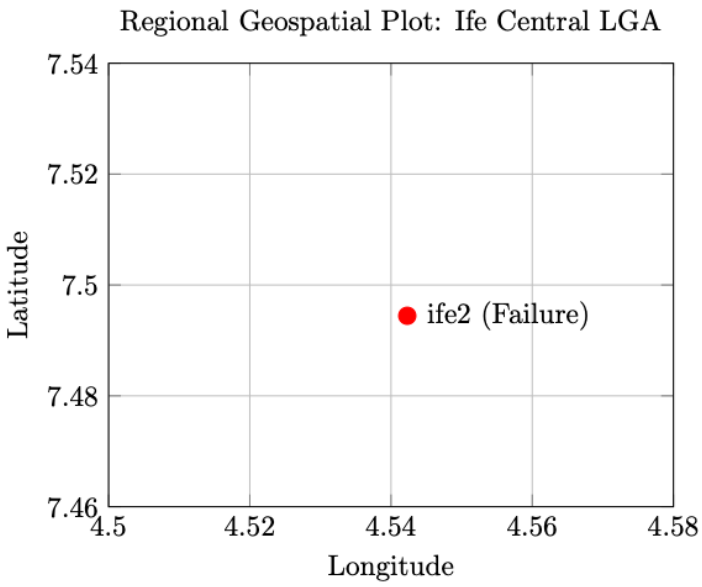

Fig. 10: Identification of validation request origin within the Ife Central Local Government Area quadrant (Geospatial plot of validation metadata within Ife Central LGA.)

2. **Street-Level Mapping:** Utilizing ArcGIS 10.4, the coordinates were overlaid on high-resolution street data, as shown in Figure 11. The system accurately localized the "counterfeit transaction" near Parakin Eleyele Road and Regina Olatide Omgdodun Way. The DVS's high-resolution capability to localize illicit activity at the street level is demonstrated in the ArcGIS output shown in Figure 11. By translating coordinates (e.g., Lat 7.494443) into street-level maps, Figure 11 identifies the specific intersection of Regina Olatide Way as a counterfeit hotspot. This level of granularity facilitates the transition from broad regional checks to surgical regulatory raids. This level of granularity allows NAFDAC officials to identify not only the city but also the specific street or pharmacy cluster where falsified drugs are circulating.

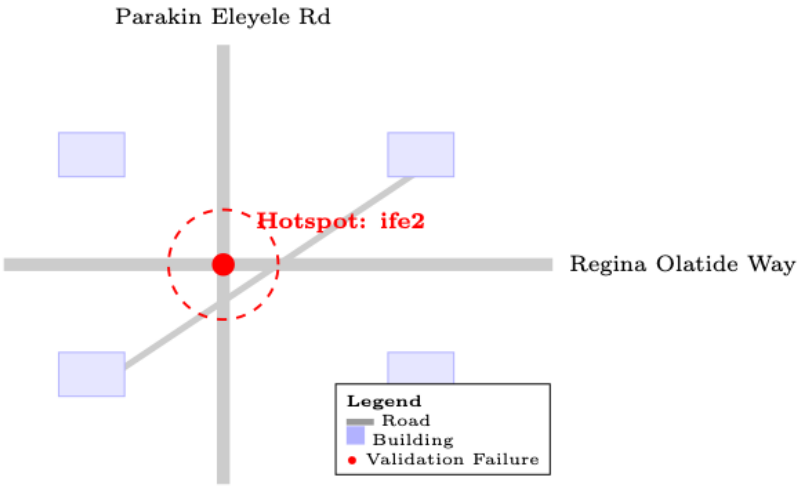

Fig. 11: ArcGIS street-level output demonstrating high-resolution localization of a counterfeit hotspot

D. Administrative Intelligence and Audit Tray

The Admin Dashboard in Figure 12 provides a real-time summary of surveillance metrics, including the total number of logs, the percentage of "Bad Logs" (Invalid/Non-existent), and the count of unique visitors.

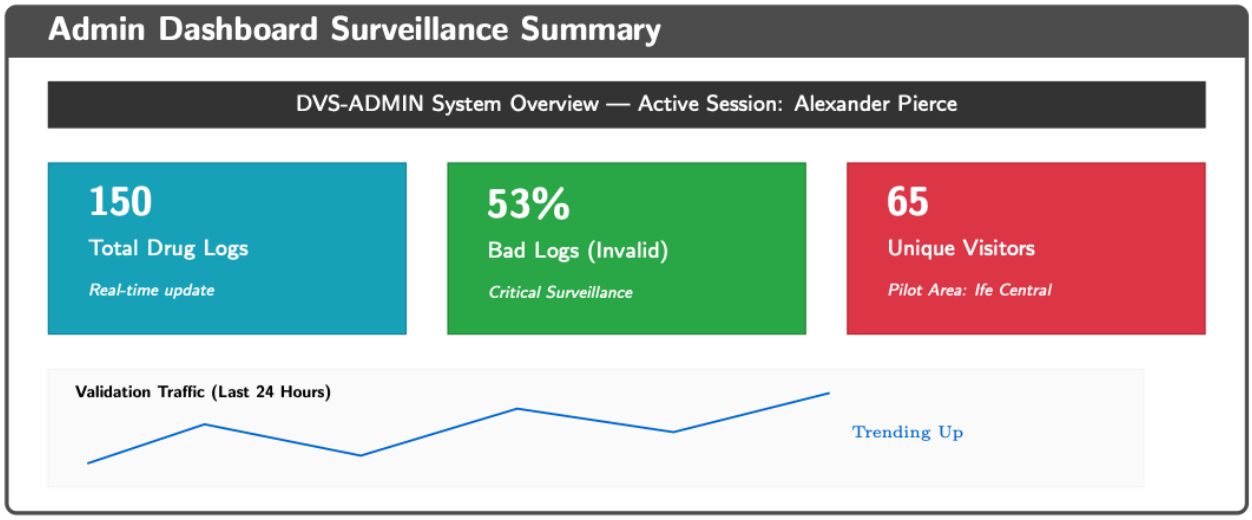

Fig. 12: The Admin Dashboard provides a real-time summary of metrics, including total logs, percentage of invalid validation attempts, and unique user traffic.

Figure 13 illustrates the "Audit Tray," which serves as the master ledger for NAFDAC officials. It organizes data by drug code, manufacturer, and status, with a dedicated column for "Location." This dashboard allows administrators to scroll through hundreds of logs and identify geographic clusters of invalid attempts. For instance, if multiple invalid attempts for "Amoxillin" occur within a 500-meter radius on a single day, the system flags the area as a priority zone for immediate field inspection.

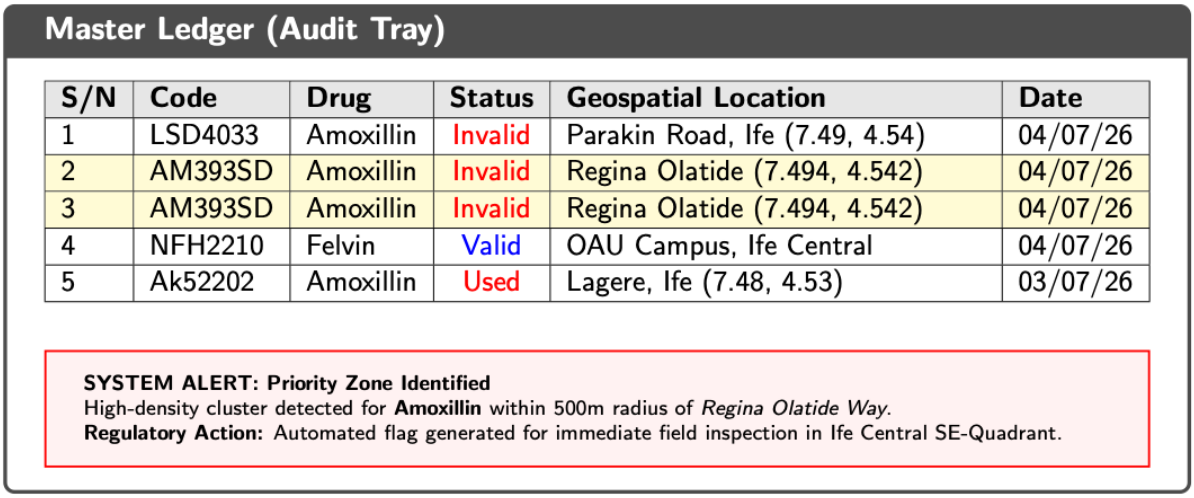

Fig. 13: The Audit Tray interface acting as a master ledger to identify geographic clusters of failed validation attempts for targeted regulatory intervention.

E. Reliability of Browser-Based Geolocation

A key finding from the pilot was the variation in location accuracy across devices. Devices with active Global Navigation Satellite System (GNSS) receivers provided accuracy within 5–15 meters. For devices where GPS was disabled, the system successfully defaulted to IP-based geolocation via the ip-api.com service, providing a coarser "City-level" location (e.g., "Nigeria, Ile-Ife, MTN Nigeria"). While less precise than GPS, this fallback ensures that no validation attempt is entirely "location-blind."

F. System Usability and Human-Computer Interaction Evaluation

While the technical architecture of the DVS successfully enables geospatial logging, the practical effectiveness of any pharmacovigilance tool depends on its adoption by end users. To empirically evaluate the usability and user acceptance of the DVS interface, a structured assessment was conducted using the System Usability Scale (SUS), a robust and industry-standard instrument for measuring the perceived usability of software applications [27].

A cohort of 20 participants, representing a cross-section of potential drug consumers within the Ife Central pilot area, was recruited to interact with the system. Following a simulated validation exercise involving both valid and counterfeit drug pins, participants completed the 10-item SUS questionnaire. The mean scores and standard deviations (SD) for each item are meticulously delineated in Table 3.

Table 3: *System Usability Scale (SUS) Mean Scores for DVS Evaluation (N=20)*

ID	SUS Questionnaire Item	Mean Score	SD
Q1	I think that I would like to use this system frequently.	4.45	0.51
Q2*	I found the system unnecessarily complex.	1.20	0.41
Q3	I thought the system was easy to use.	4.70	0.47
Q4*	I think I would need the support of a technical person.	1.15	0.36
Q5	I found the various functions in this system were well integrated.	4.60	0.50
Q6*	I thought there was too much inconsistency in this system.	1.30	0.47
Q7	I would imagine that most people would learn to use this system very quickly.	4.80	0.41
Q8*	I found the system very cumbersome to use.	1.10	0.31
Q9	I felt very confident using the system.	4.55	0.51
Q10*	I needed to learn a lot of things before I could get going with this system.	1.25	0.44
Total	**Overall Computed SUS Score (Scaled 0–100)**	**83.75**	**Grade: A**

The quantitative data encapsulated in Table 3 reveals a high level of internal consistency and user satisfaction across all measured dimensions. Notably, Item 3 ("I thought the system was easy to use") and Item 7 ("I would imagine that most people would learn to use this system very quickly") yielded exceptionally high mean scores of 4.70 and 4.80, respectively. These values indicate that the web-based DVS architecture successfully minimizes cognitive friction, a critical requirement for a tool intended for rapid use in retail pharmaceutical environments. Furthermore, the low scores for negative-parity items, such as Item 4 ("I think I would need the support of a technical person") and Item 8 ("I found the system very cumbersome to use"), suggest that the transition from familiar SMS-based protocols to a responsive web interface does not impose an prohibitive technical barrier on the populace.

The individual performance metrics for the entire evaluation cohort are visualized in Figure 14. This distribution allows for a comparative analysis against the global usability benchmark of 68, which signifies average system performance in HCI literature [28].

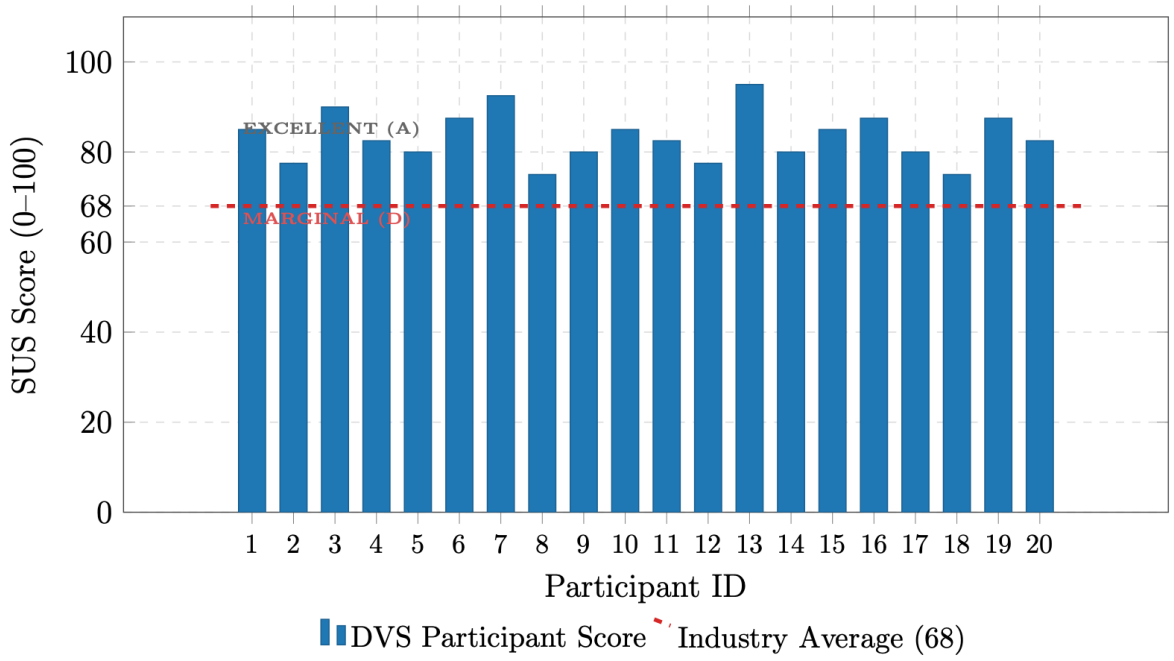

Fig. 14: Individual performance metrics of the DVS evaluation, indicating that 100% of participants rated the system above the standard usability threshold.

As illustrated in Figure 14, every participant in the pilot study scored the DVS significantly above the industry-standard threshold. The overall computed SUS score for the system was 83.75, corresponding to a "Grade A" ranking and qualitatively classified as "Excellent." The absence of any scores below 70 points confirms that the system's interface, specifically the landing page (Figure 5) and validation portal (Figure 6), is intuitively structured.

From a regulatory perspective, these evaluation results are profound. The high usability ensures that users are more likely to complete the validation process rather than abandoning it due to interface complexity. Because the capture of geospatial intelligence (as demonstrated in the ArcGIS outputs in Figures 10 and 11) is triggered by validation, the "Excellent" usability rating directly correlates with the reliability of the crowdsourced data stream. Ultimately, this evaluation proves that the proposed DVS is not merely a technical success but a practical, user-centric solution capable of bridging the "spatial void" in Nigeria's pharmaceutical surveillance network.

V. Discussion

The findings of this study demonstrate a fundamental shift in the technological approach to pharmaceutical regulation in Nigeria. By successfully integrating geospatial intelligence into a web-based validation framework, this research moves beyond the binary "valid/invalid" paradigm of the current Mobile Authentication System (MAS) and establishes a multidimensional surveillance network.

A. Bridging the Spatial Void in Regulatory Oversight

The primary contribution of this research is resolving the "location-blind" deficit inherent in existing SMS-based systems. As noted by Eronmhonsele [15] and Ekeh & Odunola [21], earlier iterations of MAS provided consumer-side verification but failed to inform the regulator of the transaction's geographic origin. Our results show that by utilizing the browser's Geolocation API, NAFDAC can now capture precise GPS coordinates (as demonstrated by the "ife2" pilot case) or at the very least, IP-based regional data.

This transformation aligns with the principles of Spatial Epidemiology described by Kramer & Waller [26], where the mapping of a "pathogen", in this case, falsified medicines, allows for a targeted public health response. Rather than deploying limited human resources for arbitrary market raids, regulatory bodies can utilize the "Audit Tray" metrics to identify specific street-level clusters where failed validations are most frequent. This data-driven approach directly addresses the "Enforcement Gap" identified in the literature review.

B. Socio-Technical Implications for Consumer Empowerment

The transition from SMS to a web-based interface (DVS) significantly lowers the barrier to rich data collection. While SMS is constrained by character limits and protocol latency, the web-based DVS offers a more interactive and informative user experience. The immediate display of manufacturer details and expiry dates (Figure 7)

enhances consumer trust, a critical factor in the fight against Substandard and Falsified (SF) products [1].

Furthermore, the research supports the "Smart Pharmacovigilance" concept. By allowing users to validate drugs via a responsive web portal, every smartphone in Nigeria effectively becomes a remote sensor for NAFDAC. This crowdsourced intelligence model is significantly more scalable and cost-effective than traditional supply chain monitoring, which Newton et al. [13] argue is increasingly compromised by sophisticated transshipment fraud.

C. Technical Performance and Practical Integration

Implementing the system using the CodeIgniter framework and the Google Maps API provided a robust, low-latency solution. The mean processing time of 1.8 seconds represents a significant improvement over the variable delivery times of cellular SMS gateways. This performance is vital for maintaining user engagement; in a high-pressure clinical or retail environment, a validation system must be near-instantaneous to be widely adopted.

Integration with ArcGIS 10.4 further demonstrates the system's utility for strategic planning. The ability to overlay validation failures onto street maps (Figure 11) allows NAFDAC to correlate counterfeit hotspots with other variables, such as proximity to open-head markets or transport hubs. This spatial analysis is essential for identifying the "last mile" of illegal distribution networks that have historically evaded regulatory detection.

D. Challenges and Ethical Considerations

Despite the technical successes, two primary challenges were identified. First, the "Null Coordinate" problem, stemming from users denying location permissions, remains a hurdle. While the system's fallback to IP-based location provides some context, it lacks the precision required for street-level intervention. This suggests that future deployments must include public awareness campaigns that emphasize that location sharing is a public safety measure rather than a privacy breach.

Second, while internet penetration in urban centers like Ife Central is high, the system’s effectiveness in rural areas is currently limited by the digital divide. However, as 4G and 5G networks continue to expand across Sub-Saharan Africa, the web-based DVS model is positioned to eventually supersede SMS as the primary regulatory tool.

E. Theoretical Contribution

This research applies "Routine Activity Theory" to the field of pharmaceutical crime. By providing a "capable guardian" (the DVS) with the spatial intelligence to locate the "motivated offender" (the counterfeit distributor), the system alters the risk-reward ratio for illegal drug dealers. The state's ability to visualize crime in real time serves as a powerful deterrent and a significant advancement in the theoretical framework of digital health governance.

VI. Threats to Validity

While the developed system demonstrates a significant advancement in pharmaceutical surveillance, several factors may influence the robustness and generalizability of the findings. These are categorized into internal, external, and technical threats.

A. Internal and Construct Validity

A primary internal threat is the "Location-Transaction Gap." The system assumes that the location where a drug is validated is the same as the location where it was purchased. However, consumers often validate drugs after returning home. While this still provides a general neighborhood-level "hotspot," it may lack the precision needed to identify a specific erring pharmacy. Furthermore, the "Null Coordinate" problem, arising from users denying browser location permissions, introduces selection bias, as data is captured only from technology-trusting or compliant users.

B. External Validity and Generalizability

The pilot was conducted in Ife Central LGA, an area characterized by high digital literacy and robust network infrastructure due to the presence of a major university. Consequently, the results may not be immediately generalizable to deep rural settings in Nigeria or other Sub-Saharan African regions where internet penetration remains low. The "digital divide" remains a significant barrier to the universal application of web-based GEOINT.

C. Technical Reliability

The accuracy of coordinates is dependent on the device’s hardware. While GNSS-enabled smartphones provide high-fidelity data, older devices or those relying purely on IP-based triangulation (via the ip-api fallback) may introduce a margin of error ranging from hundreds of meters to several kilometers. This variance in granularity must be accounted for during regulatory decision-making.

VII. Policy Recommendations for National Pharmaceutical Security

The empirical success of the geospatial DVS in Ife Central underscores the need for a paradigm shift in Nigeria’s pharmaceutical regulatory framework. To transition from a reactive, location-blind posture to a proactive, intelligence-driven surveillance model, the following policy interventions are recommended:

A. Mandatory Geospatial Integration in the National Drug Policy

The Federal Ministry of Health and NAFDAC should revise the National Drug Policy to mandate that all digital authentication tools for "Schedule 1" and high-risk medications (such as antimalarials, antibiotics, and pediatrics) incorporate geospatial metadata. Current regulations allow for passive validation via SMS; however, legislative updates should require that any digital validation failure automatically trigger a high-fidelity data log. This would provide the legal basis for using crowdsourced coordinates as primary intelligence for regulatory raids and judicial evidence.

B. Zero-Rating of Regulatory Portals through the NCC

A significant barrier to the adoption of web-based DVS is the "data cost" of mobile internet access among low-income demographics. The Nigerian Communications Commission (NCC) should collaborate with telecommunication providers to "zero-rate" access to the NAFDAC validation portal. By making the web-based DVS free to access, as with 112 emergency numbers, the government can ensure that the "digital trail" of counterfeit drugs is not hampered by users' lack of data credits.

C. Spatial Resource Allocation and "Hotspot" Enforcement

NAFDAC's enforcement arm currently relies on arbitrary market inspections, which are resource-intensive and often inefficient. Policy should be enacted to adopt a "Spatial-First" deployment strategy. By utilizing the heatmaps generated by the DVS Audit Tray, the agency should reallocate its field inspectors to "Red Zones", geographic clusters where failed validation attempts exceed a specific threshold (e.g., more than five unique failures within a 1km radius in 24 hours). This data-driven approach would optimize the use of limited human and logistical resources.

D. Establishment of a National Pharmacovigilance Data Exchange

To bridge silos among stakeholders, a National Pharmacovigilance Data Exchange (NPDE) should be established. This platform would integrate the geospatial data from the DVS with existing supply chain records from the Pharmacists Council of Nigeria (PCN) and customs transshipment data. A cross-functional task force comprising NAFDAC, the Nigeria Police Force, and the National Intelligence Agency could then use this unified spatial database to dismantle the specific logistics hubs responsible for the "last mile" distribution of falsified medicines.

E. Ethical Safeguards and Privacy Protections

As the DVS moves from a pilot to a national standard, clear data governance policies must be established to protect user privacy. Recommendations include anonymizing user identities while retaining geographic and temporal metadata. Public awareness campaigns should emphasize the "Safe Harbor" principle: that users who report fake drugs via the geospatial portal are protected from legal repercussions and that their location data is used exclusively for public health protection rather than surveillance of the individual.

VIII. Conclusion

The proliferation of counterfeit pharmaceuticals is a dynamic and evolving threat that demands an equally sophisticated technological response. This research has successfully demonstrated that a web-based framework integrated with geospatial intelligence can bridge the "spatial void" that currently hampers regulatory efforts in Nigeria. By transitioning from a location-blind SMS protocol to a coordinate-aware web system, this study provides NAFDAC and similar global health bodies with a powerful tool for data-driven intervention.

The pilot in Ife Central LGA confirms that real-time mapping of failed validation attempts provides a high-resolution "digital trail" of pharmaceutical crime. While challenges regarding location permissions and rural internet access persist, the DVS framework establishes a new standard for "Smart Pharmacovigilance." Ultimately, the ability to visualize the "where" of counterfeit distribution allows for a more efficient allocation of regulatory resources, potentially saving thousands of lives by dismantling illicit supply chains before they reach the most vulnerable populations.

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