Enhancing Early Warning Systems for Vaccine-Preventable Diseases in Africa through IDSR, Electronic Active Surveillance and Big Data Analytics

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***Abstract*—Active surveillance and the Integrated Disease Surveillance and Response (IDSR) system are vital tools in detecting vaccine-preventable diseases (VPDs), especially in regions like Africa. Active surveillance provides real-time data, while the IDSR system aggregates reports to give a broader disease overview. This study assesses how integrating active surveillance data with the IDSR system improves the detection of VPDs and enhances early epidemic responses. It also examines the role of big data analytics and GIS technologies in disease forecasting. The study analyzed active surveillance and IDSR data over a specific period. A correlation analysis was performed to determine the relationship between diseases identified by active surveillance and those reported through the IDSR system. Big data analytics, including GIS for spatial integration, was used for epidemic forecasting and trend analysis. A positive correlation was found between active surveillance data and IDSR reports (r = 0.763, p < 0.01). Active surveillance explained 58.3% of the variation in disease reports (R-squared = 0.583). GIS identified disease hotspots, improving resource allocation. Predictive modeling with big data analytics enhanced epidemic forecasting, supporting better vaccine distribution and response strategies. Integrating active surveillance with the IDSR system significantly enhances disease detection and response. The combination of real-time data with traditional reporting, supported by GIS and big data, improves epidemic forecasting, resource allocation, and early interventions for VPDs, especially in Africa.**

***Keywords*—Active Surveillance, IDSR System, Vaccine-Preventable Diseases, GIS; Big Data Analytics, Epidemic Forecasting; Disease Detection; Public Health Response, Resource Allocation.**

I. INTRODUCTION

Vaccine-preventable diseases (VPDs) are infectious diseases that vaccines can prevent. VPDs are caused by bacteria or viruses and can spread through air, respiratory droplets, or bodily contact [1]. Through use of the 2022 WHO-UNICEF global estimates of immunisation coverage, which included substantial reductions in coverage of routine immunisation for 2020 and showed partial and uneven recovery in 2021 compared with before 2020, Hartner and colleagues estimated 49,119 additional deaths (95% credible interval [CrI] 17,248 to 134,941) during calendar years 2020-30 than would have been expected without COVID-19 disruptions in routine immunization [2]. These estimates of excess mortality come from six vaccine-preventable diseases. For many years, Africa has battled vaccine-preventable diseases (VPD), which include measles and polio, diphtheria and whooping cough. The public health effect of these diseases remains severe in Sub-Saharan Africa because of restricted healthcare access, insufficient vaccination programmes, and weak disease monitoring systems [3]. VPDs represent a substantial health challenge across Africa because the WHO reports that the region faces one of the biggest global burdens of VPDs, which leads to many preventable sicknesses and fatalities [4]. In 2018, Africa recorded 14,000 measles-related fatalities, which represented more than 70% of global measles deaths [3]. The African countries Nigeria and the Democratic Republic of the Congo (DRC) continue to be the only two nations where polio remains endemic [3]. Data for the WHO African Region showed reductions in measles percentage coverage across the board between 2019 and 2020. Coverage for the DTP-1 vaccine fell by a percentage point to 79% in 2020, for DTP-3 from 74% to 72%, and for MCV1 from 70% to 68% [5]. Globally, DTP-1 coverage fell from 90% to 87% between 2019 and 2020, from 86% to 83% for DTP-3, and 86% to 84% for MCV1. These vaccination rates are far below the 90% coverage target of Africa's Regional Vaccine Action Plan and far below the 95% coverage recommended by WHO to protect against measles. The global Immunization Agenda 2030 meanwhile, has the ambitious target of achieving 90% coverage for all essential childhood vaccinations in the next nine years [5]. Between January 2020 and April 2021, eight African countries reported major measles outbreaks affecting tens of thousands of children largely due to low routine immunization coverage or delayed vaccination campaigns. In addition, in 2020 the quality of measles surveillance in Africa fell to its lowest level in seven years, with only 11 countries meeting their target [5]. Public health authorities across Africa must prioritise the control of vaccine-preventable diseases because they still represent major health threats. The problem worsens when surveillance and early warning systems fail to operate properly. VPD outbreaks remain undetected or are reported after the fact in regions with low vaccination rates, which results in bigger outbreaks and more cases of disease [5]. The 2018-2019 measles outbreak in the DRC resulted in more than 310,000 cases along with over 6,000 deaths, marking the biggest outbreak across Africa during the past twenty years [6]. Moreover, the Integrated Disease Surveillance and Response (IDSR) system is the foundation for enhancing African public health surveillance [7]. Despite multiple initiatives to overcome these challenges there continues to be a major deficiency in swift VPD outbreak detection and response and monitoring capabilities

II. CURRENT SURVEILLANCE SYSTEMS

The African continent has experienced rapid technological improvement over the last few years where digital devices have flooded the market [3]. Various organizations and governments have formulated and implemented strategic decisions to escalate technological innovations in the continent to match global advancements. Providing test results to patients is often challenging because they do not understand them [4]. Hence, communication tends to be placed in the hands of physicians, who act as communicators while patients are listeners most of the time. Most doctors are seen as authoritative figures in society, and with the popular belief, they treat and cure patients with any kind of health condition. As per the study of Deml et al. [5], over the past decades, doctors are usually criticized for not providing adequate consideration to patients' feelings or desires related to their illness or conditions.

A. Integrated Disease Surveillance and Response (IDSR)

The WHO and the African Union (AU) developed IDSR as a framework to enhance disease surveillance capabilities and response systems throughout African nations [8]. Through IDSR, countries achieve standardized procedures to track and respond to infectious diseases across different levels of healthcare [9]. IDSR regularly collects disease data that healthcare personnel analyze before sharing it with all healthcare system levels. Data reporting faces significant challenges because data delivery is insufficiently speedy and precise. A comparison study between web-handled data collection with traditional paper-based data collection concluded that it was reported that the use of paper-based systems for data collection resulted in slow processing and frequent mistakes [10]. The IDSR system encounters major obstacles in immediate data collection in distant regions and conflict areas [11]. Protracted data verification procedures and slow sharing processes impede early outbreak detection. The system currently struggles to generate actionable data insights and properly analyze data. Predictive analysis and outbreak forecasting remain limited due to this system limitation which causes delays in the response [12]. Early warning systems must incorporate technology to address the established need for improved detection capability [13].

B. *Electronic Active Surveillance: A Technological Leap Forward*

Electronic active surveillance (EAS) represents a current disease surveillance system built on electronic platforms that gather data for transmission and analysis [11]. Health facilities, mobile health platforms, and community health workers function as active data sources for Electronic Active Surveillance (EAS) systems, which differ from traditional passive reporting systems [12]. The system allows public health authorities to track disease outbreaks in real-time while supplying them with current information. EAS offers several advantages over traditional surveillance systems. Through EAS, data collection improves by incorporating multiple information sources, which results in more efficient and precise reporting [13]. Through real-time outbreak detection, the system enables fast outbreak response, which helps minimise disease spread [14]. Electronic surveillance platforms deployed in Ghana and Kenya demonstrate successful monitoring of cholera and malaria, illustrating this technology's potential to manage VPDs [15]. EAS technology holds great potential, but Africa encounters significant challenges in achieving its widespread adoption. Many nations fail to maintain the required infrastructure that comprises dependable internet connection and steady power supply for implementing electronic surveillance platforms [16]. In Nigeria, healthcare workers require training to effectively operate these systems [17]. The full potential of EAS to strengthen VPD early warning systems in the country depends on overcoming existing implementation obstacles.

A. *Big Data Analytics*

Advanced computational tools enable Big Data Analytics to process enormous data volumes to detect patterns, recognise trends, and establish correlations [18]. Disease surveillance through Big Data Analytics enables public health authorities to anticipate disease outbreaks by assessing climate information, population migration data, vaccination coverage statistics, and disease history [19]. Predictive models help governments, along with health organisations, to forecast VPD outbreak probabilities so they can deploy preventive measures before outbreaks start [20]. Through analysis of weather patterns and historical cholera outbreak data, Big Data Analytics helps forecast locations most prone to future outbreaks, thus enabling early response and resource distribution [21]. For instance, in 2018, during the cholera outbreak in Zimbabwe, predictive models based on Big Data helped pinpoint regions at higher risk due to increased rainfall and poor sanitation conditions [22]. This allowed for a more targeted allocation of resources, such as the pre-positioning of medical supplies, deployment of healthcare workers, and initiation of awareness campaigns, significantly enhancing early response efforts and reducing the disease's impact. Multiple nations across Africa are currently investigating implementing Big Data systems for disease monitoring purposes. South African health authorities have succeeded with data analytic strategies to track and forecast malaria transmission patterns in their country [23]. Big Data analysis in Kenya for dengue outbreak monitoring has enhanced both the speed of response and distribution of resources, according to research findings [24]. Big Data Analytics applications remain limited throughout most of Africa despite early adoption efforts. The implementation of Big Data faces three main barriers stemming from a deficient skilled workforce and insufficient data infrastructure and unclear privacy standards for personal health information. Although vaccination campaigns have been successful over the past decades, VPDs remain a significant public health issue across Africa [25]. Ridding Africa of diseases such as measles, polio and diphtheria remains challenging because of multiple barriers, including insufficient vaccination coverage, weak healthcare infrastructure and inadequate surveillance systems [26]. Early warning systems for detecting VPD outbreaks remain slow and inefficient even though they must operate quickly to stop outbreaks from spreading [27]. The traditional paper-based disease reporting systems combined with delayed data verification processes and limited integration of modern technologies cause these inefficiencies in disease monitoring [28]. Outbreaks frequently remain undetected until their spread becomes extensive, resulting in preventable deaths and illness. The IDSR system that enhances disease surveillance throughout Africa demonstrates improvements in handling various system limitations. The IDSR system encounters limitations such as slow data acquisition and reduced real-time reporting, together with weak predictive outbreak capabilities [29]. African countries continue to face persistent challenges from deficient technological infrastructure and limited healthcare worker training and data privacy issues that emerge from data utilisation [30]. The combined use of these systems enables real-time data acquisition and enhanced predictive modelling, which leads to decreased VPD-based public health challenges. The proposed research studies how combining IDSR with EAS and Big Data Analytics can improve VPD early warning systems across the Africa. The research analyses the implementation difficulties Africa encounter with these technologies, along with methods to address these barriers. This study examines electronic and data-driven surveillance methods to reveal their potential for enhancing current disease monitoring structures, which results in faster and more effective VPD outbreak responses.

III. Methods

A quantitative analysis of the IDSR system and active surveillance visit data covered 47 African nations and 4505 districts in the study. This research identifies outbreaks of disease, and specifically vaccine-preventable diseases, by analysing historical trend data from surveillance systems. This research examined how combining surveillance techniques with big data analysis brings better early outbreak detection along with improved resource distribution for outbreak control. The research addresses African health system weaknesses and population movements to establish improved VPD early warning systems that reduce public health risks while enhancing disease outbreak responses.

A. Data Collection

The study utilized secondary data from two primary sources: the IDSR system and the World Health Organization African Region (WHO AFRO)'s active surveillance visits. The disease registry function of the IDSR system recorded detailed information about outbreak occurrences with specific information about locations and outbreak characteristics to assist region-wide disease pattern analysis across Africa. Real-time information regarding disease patterns along with vaccination progress emerged from WHO AFRO active surveillance teams who monitored the whole continent. This combination of data sources allows researchers to analyse disease progression throughout time while studying surveillance system response rates. The analysis of existing secondary data enables researchers to study extensive datasets, which improves the scope of the research while eliminating primary data collection requirements. The study generated insights about disease surveillance mechanisms' operational effectiveness and regional and district, and national disease spread patterns.

B. Data Analysis Techniques

Statistical Package for the Social Sciences (SPSS) served as the processing software to analyse the data through regression analysis and trend analysis methods. The applied analysis methods reveal relationships between disease surveillance and IDSR data. A correlation analysis was performed to determine the relationship between diseases identified by active surveillance and those reported through the IDSR system. Big data analytics, including GIS for spatial integration, was used for epidemic forecasting and trend analysis.

IV. RESULTS

A positive correlation was found between active surveillance data and IDSR reports ($r = 0.763$, $p < 0.01$). Active surveillance explained 58.3% of the variation in disease reports (R-squared = 0.583). GIS identified disease hotspots, improving resource allocation. Predictive modelling with big data analytics enhanced epidemic forecasting, supporting better vaccine distribution and response strategies.

V. CONCLUSIONS

Integrating active surveillance with the IDSR system significantly enhances disease detection and response. The combination of real-time data with traditional reporting, supported by GIS and big data, improves epidemic forecasting, resource allocation, and early interventions for VPDs, especially in Africa.

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