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Review

Effectiveness/ The Role of Surveillance in The Prevention of Infectious Diseases

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Abstract: Disease surveillance is the continuous examination of disease occurrences and health-related incidents to allow for timely disease control response. The early identification of disease outbreaks by an efficient and successful disease surveillance and notification system will enable intervention to reduce the morbidity and death that may arise from these infectious disease epidemics. The main components of descriptive epidemiology; time, place, and person can be used to characterize surveillance data gathered from multiple sources, including the community, clinic, and hospital. The advent of modern technology has opened new frontiers for epidemiology, with tools like machine learning, geographic Information Systems (GIS), and big data analytics transforming the field. These tools allow for real-time disease tracking and more accurate predictions, thereby facilitating timely intervention and mitigating potential health crises. The challenges to effective global surveillance and response to human disease outbreaks reflect deficiencies in health infrastructure, scientific methods and concepts of operations of infectious disease surveillance programs, human, technical, and financial resources, and international policies. Leveraging cutting-edge technologies, bolstering health infrastructure, and encouraging global cooperation are the keys to the future.

Keywords: Effectiveness, Role, Surveillance, Prevention, Infectious Diseases.

INTRODUCTION

Disease surveillance is the continuous examination of disease occurrences and health-related incidents to allow for timely disease control response. Data on disease occurrence and public health-related events are continuously gathered, compiled, analyzed, and interpreted. The information gleaned from these data is then disseminated for timely public health action (Cho and Leo, 2016). It has been established that disease surveillance and notification, or DSN, is a successful approach to disease prevention and control, particularly for illnesses that are susceptible to epidemics. The fact that disease outbreaks do not respect national borders or provide advance notification is important to remember.

They are likely to spread like wildfire once they do develop, frequently leading to high rates of morbidity and case fatalities and the ensuing economic effect (Isere *et al*., 2015). The early identification of disease outbreaks by an efficient and successful disease surveillance and notification system will enable intervention to reduce the morbidity and death that may arise from these infectious disease epidemics. There are four different levels of illness surveillance and notification: local, national, international, and individual. Clinicians' active participation in an efficient district/Local Government Area (LGA) disease monitoring and control mechanism is often essential to the effectiveness of the national illness surveillance and notification system (Isere *et al*., 2015).

Disease monitoring and notification in Nigeria include monthly notifications of various diseases of public health significance, as well as quick notifications of diseases that are prone to epidemics and diseases that are intended to be eradicated. Clinicians are essential to effective reporting because they can identify unusual disease manifestations and conditions that rely on clinical signs unrelated to laboratory testing, clusters of illnesses through patient interviews, and clinical judgments (Isere *et al*., 2015). This is necessary for a disease surveillance and notification system at the district/LGA level to be operational and effective in early detection of epidemic-prone diseases.

Due in part to clinicians' lack of understanding of the significance of their role in disease surveillance and notification activities for the prevention of infectious disease outbreaks, public health institutions in Nigeria currently collect, collate, analyze, and interpret disease-related data in an incomplete and timely manner (Isere *et al*., 2015). Over the years, a number of outbreaks in Nigeria have been linked to clinicians failing to record instances of epidemic-prone diseases or reporting them after the fact in different health facilities throughout the nation. It is important to highlight that prior research on disease surveillance and notification has shown that clinicians' failure to comply with mandatory reporting requirements for notifiable diseases has been ascribed to their ignorance of the existence of a surveillance network for notifiable diseases, which includes the need for reporting, which diseases are notifiable, how, when, and to whom reporting should be done (Lee *et al*., 2023).

Historical Development

"Surveillance" originates from the French word for "watching over," "sur," which means "from above," and "veiller," which means "to watch." The police and government surveillance systems in civil society keep an eye on people's actions, behavior, and other evolving information (Cho and Leo, 2016). They are also vigilant for any unusual occurrences that could pose a risk to communities, the country, or the world.

During the mid-1900s, when infectious illnesses were a significant issue and threat to public health, two medical professionals made an effort to establish surveillance as a crucial part of public health practice (Cho and Leo, 2016). Alexander Langmuir, who was the Chief Epidemiologist at the Centers for Disease Control and Prevention (formerly the Communicable Disease Center), created the foundation for the control programs and systematic surveillance of infectious diseases. Langmuir defined surveillance in 1963 as the active and systematic gathering of relevant facts on the target disease or diseases, their evaluation and practical reporting, and the prompt delivery of these findings to those in charge of creating action plans (Cho and Leo, 2016). It is crucial to remember that surveillance would be useless unless the information gathered is turned into knowledge that the people in charge of starting action plans communicate and act upon (also known as "surveillance for action"). In theory, the control measures are not part of a monitoring system. It is preferable for a surveillance system to be separate from the control system (Cho and Leo, 2016).

Experience has demonstrated that, occasionally, those in charge of control measures manipulated illness prevalence in an attempt to achieve apparently better outcomes than those that actually transpired. Karel Raska, the Director of the World Health Organization's (WHO) Division of Communicable Diseases, considerably broadened the scope of surveillance in the 1960s by incorporating epidemiological research into surveillance operations. In 1967, Raska granted extra money for research into bolstering the surveillance system for the newly enhanced smallpox eradication campaign in order to encourage research in surveillance. After epidemiological studies comparing the prevalence of malaria in Wepeople who used and did not use mosquito nets showed that mosquito nets were an efficient method of controlling the disease, malaria surveillance was also improved.

We might need to reconsider the limits of surveillance in the field of public health practice. It could be wise not to broaden its scope to include epidemiological studies that might be interesting to researchers and health officials but might not result in useful public health initiatives that lower the risk or hazard right away. Therefore, it could be necessary to further hone and solidify the use of monitoring as a tool for public health action.

Given the recent assaults in Chile and the United States in 2001 that used anthrax as a bioweapon, bioterrorism has presented the most recent monitoring problem. Many wealthy nations closely monitor bioterrorism agents, including the smallpox virus, *Clostridium botulinum*, and *Bacillus anthracis*.

Disease Surveillance: Concepts and Types

i. Community-Based Surveillance

Villagers, town residents, or medical staffs at the clinic or dispensary who treat patients with the target diseases are the primary reporters. In order to promote disease reporting to the closest health facility or designated office in the village, which will then convey the information to the appropriate health authorities, public campaigns using the mass media such as radio, television, and the press were essential.

ii. Clinic- and Hospital-Based Surveillance

Physicians who treat patients and identify the target illnesses are the primary reporters. This surveillance technique is essential for detecting rare diseases and illnesses that are challenging for the community to recognize. It works in conjunction with community-based surveillance. If hospitals and clinics comply completely with the notification of target diseases, the benefit of this method is the comprehensiveness of the surveillance coverage. It goes without saying that the administration of the clinic or hospital should be well-informed and aware of the significance of this kind of surveillance system.

A specially established committee should be in charge of managing nosocomial or healthcare-associated infections, which are a special surveillance target in healthcare settings. In order to prevent and control nosocomial infections, hospital administration should be kept informed on a regular basis.

iii. Active or Passive Surveillance

Passive surveillance is conducted in hospitals and the community using reports from the general population and medical professionals (Ogboghodo *et al*., 2021). Active surveillance may be necessary for urgent surveillance reports and for non target diseases that are not included in the regular reporting system. This frequently entails the creation of specialized teams that visit homes, clinics, or hospitals to ascertain the prevalence of a newly emerging disease. They do this by speaking with community members or medical personnel directly, reviewing clinical records, or visiting sick patients.

iv. Special Surveillance

To improve the sensitivity and efficacy of current systems, creative solutions could occasionally be required in addition to traditional surveillance techniques.

v. Sentinel Surveillance

Sentinel-based surveillance, which keeps a careful eye on the situation in a designated area, may help to strengthen the shortcomings of target disease surveillance systems. For instance, instability in politics, disinterest, inadequate infrastructure, etc., can result in information gaps in global surveillance on some diseases (Cho and Leo, 2016). To address this, the Japanese nongovernmental organization ACIH has created a voluntary sentinel surveillance system that includes 59 sentinel sites spread across 32 countries in South America, Africa, and Asia for specific target diseases, such as dengue fever, cholera, and measles.

In addition to supporting WHO's worldwide surveillance, the system seeks to offer more data on illness occurrence. When high-quality data regarding a specific disease is required and cannot be collected by a passive system, a sentinel surveillance system can be developed (Cho and Leo, 2016). Health departments in the United States, for instance, enlist a network of clinics and hospitals to provide frequent reports on influenza occurrence.

Laboratory Diagnosis and Surveillance System

Surveillance requires the collaboration of laboratories to confirm the diagnosis if initial reports are based on clinical diagnosis alone. In some cases, though, a test diagnosis might not be required. As long as there is no substantial risk of developing control measures if the other cases are not correctly diagnosed, laboratory testing of only those cases that are representative of the outbreak may be sufficient, for instance, if there are many cases with similar clinical manifestations. This could be useful in determining the usage of vaccinations (Meng *et al*., 2021).

One important factor to take into account while choosing the test type (antigen or antibody test, viral/bacterial isolation, polymerase chain reaction (PCR) test, etc.) to use for monitoring is the turnaround time for the test findings. The testing method's dependability is yet another crucial element, and quality control involving routine evaluation of the lab's procedures and materials as well as recurring confirmation of the findings by a reference lab is crucial. The WHO has selected reference laboratories and partner sites for global laboratory surveillance for vertical disease-specific surveillance programs on human and avian influenza, measles, and poliomyelitis (WHO, 2023). National reference laboratories can also be established by particular nations as and when needed.

Analyzing Surveillance Data

The main components of descriptive epidemiology; time, place, and person can be used to characterize surveillance data gathered from multiple sources, including the community, clinic, and hospital.

Time

The dates of the illness's commencement and specimen collection are important milestones in the disease's clinical progression. The number of illness cases by week or month can be compiled with the help of a line listing of ill people together with the corresponding dates. By epidemiological week, disease incidence is reported in the CDC Morbidity and Mortality Weekly Report (MMWR) and the WHO Weekly Epidemiological Record (WER). In order to monitor an outbreak, disease surveillance and epidemic curve mapping typically use the date of illness onset. The date of reporting is frequently utilized in place of the date of sickness onset, though, when this information is unavailable (Cho and Leo, 2016).

Other dates, such as the day on which the relevant health centers notify the public of an illness, are occasionally noted and tracked in order to evaluate how timely the monitoring system is in some remote areas.

Place

To determine whether the disease is spreading, it is crucial to record the geographic locations and distribution where it has happened and continues to occur. While the movement of the infected person during the sickness is essential for contact tracing to restrict the spread of the disease, the locations visited by the infected person before the illness onset is significant for identifying the source of the infection. As demonstrated by the SARS epidemic in 2002–03, the pandemic influenza A (H1N1) in 2009, the Ebola virus disease (EVD) epidemic in 2014, and the Middle East respiratory syndrome coronavirus (MERS-CoV) epidemic in 2012–15, air travel has accelerated the spread of infections across continents in today's highly connected world (Rahimi *et a*l., 2020).

Person

Along with time and location, sociodemographic information about specific infected individuals, such as age, gender, ethnicity, and occupation, must also be gathered and examined. The activities the infected person engaged in and the animals or people they came into contact with throughout the disease's incubation period should be evaluated in addition to their movement history and details on the locations they visited (Cho and Leo, 2016).

Important information to direct disease preventive and control activities will be provided by the descriptive analysis of surveillance data in terms of time, place, and person. Since the purpose of surveillance is to take action, the data should be distributed to those in charge of planning for disease control and prevention. Health officials will be able to more effectively focus public health prevention and control initiatives with the use of additional analytical epidemiology, which will evaluate and identify risk variables linked to the disease or mortality from the condition (Cho and Leo, 2016).

Global Surveillance Network

As the situation with infectious diseases changes, the WHO keeps a careful eye on it and issues a notice as necessary. From a variety of official and informal sources, the WHO global warning and response methodically compiles official reports and rumors about probable epidemics. Health ministries and departments, national public health institutes, WHO regional and country offices, WHO collaborating centers, civilian and military laboratories, academic institutions, and nonprofit groups all formally report suspected clusters or outbreaks. Additionally, the WHO has created a thorough "event management system" to handle vital outbreak information and guarantee precise and prompt communications amongst important global public health experts, such as WHO Regional Offices, Country Offices, collaborating centers, and partners in the Global Outbreak Alert and Response Network (GOARN) (Figure 2.0).

The WHO and member states renewed the International Health Regulations (IHR) in 2005 with the goal of "ensuring the maximum protection of people against the international spread, while minimizing interference with world travel and trade (Burci, and Eccleston-Turner, 2021). The WHO also uses the IHR to inform countries about public health risks and to work with partners to help countries develop the capacity to detect, report, and respond to public health events. The global surveillance system has been greatly improved by the unprecedented development of technologies, such as the ability to quickly identify novel pathogens like the MERS-CoV virus using advanced molecular techniques and real-time reporting and information sharing made possible by the internet (Hao *et al.*, 2022).

However, rapid global population growth (estimated at 7.3 billion in July 2015) and increased air, sea, and land travel have accelerated the spread of disease, and income inequality has made matters worse. According to the World Bank's most recent estimates, 12.8% of the world's population lived at or below $1.90 per day in 2012, meaning that 902 million people lived on less than $1.90 per day (Jha, 2023). Extreme poverty and the prevalence of severe diseases in sub-Saharan Africa form a vicious cycle that may endanger neighboring geographical regions. In sub-Saharan Africa, monitoring is inefficient due to a lack of funding, poor health care facilities, and political instability in some areas (Aborede *et a*l., 2021). It is impossible to overstate how crucial international cooperation is to bolstering surveillance in these regions.

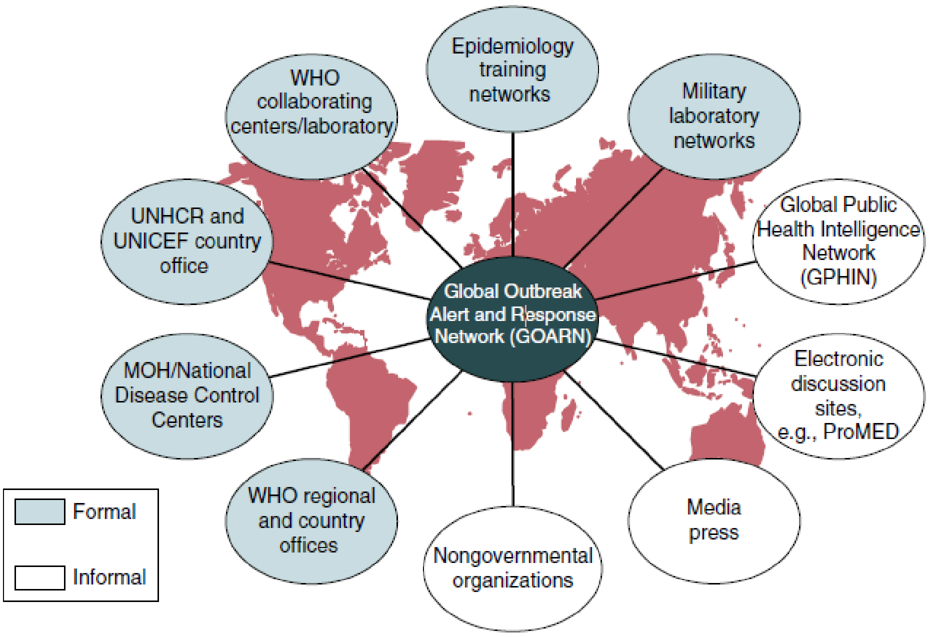

Figure 1.0: Global surveillance network

Effectiveness of Surveillance Systems

Polio Surveillance and Eradication

In many parts of the world, polio has been effectively eradicated via vaccine. International hazards still exist, though, if polio is not eradicated in the remaining nations. To eradicate all forms of polio illness caused by both vaccine-derived and wild polioviruses at once, the WHO developed its Polio Eradication and Endgame Strategic Plan 2013–2018 (Sultan, 2022). The WHO designated the global spread of wild poliovirus in 2014 as a Public Health Emergency of International Concern (PHEIC) on May 5, 2014 (WHO, 2022). Wild poliovirus was transferred to susceptible nations by Afghanistan and Pakistan.

Nigeria has stopped endemic transmission of wild poliovirus, and there has been a general decrease in the incidence of international spread of the virus since the declaration of PHIEC and the implementation of the WHO Director-General's Temporary Recommendations as of November 10, 2015 (Kierman, 2023). No cases have been reported in Africa for more than a year. There were 57 cases of wild poliovirus reported in Afghanistan and Pakistan between January 1 and November 25, 2015, compared to 305 cases from nine countries during the same period in 2014 (Kew and Pallansch, 2018). The highest numbers of polio cases were reported from Pakistan.

Measles Surveillance

Measles has a basic reproduction number (R0) of 12–18, making it the most contagious viral disease (Guerra *et al.*, 2017). This implies that in a vulnerable and previously uninfected population, a single measles case can spread to 12–18 cases over its infectious phase. Until the introduction of the vaccine in 1963, almost all children contracted measles (Parums, 2024). Despite the existence of an effective vaccine, measles outbreaks in unvaccinated populations have occurred as a result of a reduction in vaccination coverage over time. In order to obtain herd immunity, a community must have a 95% vaccination rate.

The Global Measles and Rubella Strategic Plan (2012–2020) focuses on implementing five key elements for the elimination of measles and rubella, including achieving high vaccination coverage with two doses of vaccines containing both measles and rubella and closely monitoring disease through effective surveillance. The main goal of measles surveillance is to detect all areas where the measles virus is circulating in a timely manner, but not necessarily to detect every measles case, which necessitates prompt notification and investigation of suspected cases; the detection of measles-specific IgM antibodies is crucial for confirming measles infection in suspected cases (WHO, 2022). One serum sample obtained within 28 days of the rash's start can serve as presumed proof of an active or recent measles virus infection. A negative IgM test in vaccinated individuals suspected of having measles should not be used to rule out the condition because previously vaccinated individuals frequently have muted and/or transitory IgM production. The best way to confirm such situations might be with a PCR test. In places without medical facilities, community-based measles surveillance can be necessary. A mechanism for the syndromic reporting of acute febrile rash sickness would need to be established, followed by protocols for the collection and analysis of blood samples for laboratory diagnosis.

Influenza Surveillance and Pandemics

Three major influenza pandemics occurred in the 20th century: the "Spanish flu" influenza A (H1N1) in 1918–19, the "Asian flu" influenza A(H2N2) in 1957–58, and the "Hong Kong flu" influenza A(H3N2) in 1968–69 (Gurushankara, 2021). The first influenza pandemic of the 21st century happened in 2009–10, when the new influenza A (H1N1) pdm virus was first isolated from humans in Mexico and the United States in April 2009. This influenza pandemic had two prominent features.

In temperate nations, influenza first caused significant out-of-season outbreaks that happened in the spring and summer (Loconsole *et al*., 2022). Second, it led to exceptionally high rates of illness and mortality in both healthy individuals and children. It was the first influenza pandemic for which national pandemic preparedness strategies were implemented in both industrialized and many low-income countries, and for which antiviral medications and vaccines were used. The WHO's pandemic preparedness guidelines were updated in response to this pandemic to offer a risk-based strategy for managing the outbreak in light of new virological, epidemiological, and clinical information (WHO, 2023).

The Role of Surveillance and Response in Disease

Generally speaking, nations wait to start disease elimination efforts until they have a robust surveillance system in place. The necessity of creating efficient monitoring systems based on the minimum essential data idea is highlighted by this fact, which also helps to create public health response plans for the various endemic environments. This clearly necessitates the implementation of surveillance-response systems that have been validated (Zhou and Tanner, 2013). In order to discuss surveillance-response approaches, the most promising experience to date, and future directions, scientists, disease control managers, and experts from various disciplines and nations convened at the First Forum on Surveillance Response System Leading to Tropical Diseases Elimination.

Case studies like the eradication of lymphatic filariasis in P.R. China and malaria in Zanzibar Zhou and Tanner. (2013) were covered in detail. Early identification of abnormal occurrences is crucial for prompt and efficient response, monitoring, and intervention evaluation in Zanzibar. Additionally, it is essential for directing the choice of suitable corrective actions to lessen the spread of malaria via mobile phone systems (Zhou and Tanner, 2013). Achieving countrywide elimination of lymphatic filariasis in P.R. China required halting mass chemotherapy and stepping up surveillance once the microfilaria rate had dropped to the 1% prevalence level, or below the threshold of transmission (Zhou and

Tanner, 2013). Intensified efforts to eradicate other NTDs, including schistosomiasis, onchocerciaisis, and visceral leishmaniasis, were also prompted by the reported experience. One significant step in moving the focus from general control to elimination is the switch from monitoring morbidity and mortality to detecting infections and measuring transmission.

Based on the notion of "surveillance as an intervention tool," surveillance-responses have emerged as the primary activities, resulting in a period of transition between control and elimination that necessitates the establishment of a surveillance-response system (Zhou and Tanner, 2013). At this point, the focus should be on standard case definitions for priority disease identification and reporting, gathering and using surveillance data to notify higher levels and initiate local public health action, investigating and verifying suspected outbreaks or public health events through laboratory confirmation when found, analyzing and interpreting data from routine monitoring of other priority diseases and data collected during outbreak investigations, using data analysis to implement an appropriate response, giving feedback both within and between health system levels, and assessing and improving the surveillance-response system's performance.

However, during the elimination stage, the surveillance-response system should concentrate on four areas: identifying areas of low transmission (e.g., from symptomatic and asymptomatic infections), detecting diseases quickly, detecting new or re-introduced infections (e.g., crossing national and regional borders), recognizing trends in disease incidence and prevalence (e.g., age group shifts, evolving parasite heterogeneity, seasonality changes), and detecting potential drug resistance (Das, 2023).

Analytical Tools in Diseases Epidemiology and Surveillance

Recent disease outbreaks have reinforced several lessons about surveillance many of which health experts had already learned in the past. The key takeaway is that insufficient information on the risk of disease outbreaks can lead to serious and unforeseen consequences. The need for analytical tools in diseases epidemiology and surveillance has thus garnered increasing attention. As the world faces emerging health threats, the ability to track, predict, and respond timely to outbreaks efficiently has become paramount. The advent of modern technology has opened new frontiers for epidemiology, with tools like machine learning, Geographic Information Systems (GIS), and big data analytics transforming the field. These tools allow for real-time disease tracking and more accurate predictions, thereby facilitating timely intervention and mitigating potential health crises.

Geographic Information Systems (GIS)

A significant strand of research in epidemiology explores the application of GIS in disease surveillance. GIS has been extensively reviewed for its ability to track the spatial distribution of diseases. The most common understanding of the term can be summed up as ‘a powerful set of tools for collecting, retrieving at will, transforming and displaying spatial data from the real world’ as proposed by Burrough (Akindahunsi *et al*., 2024). Classical geographic maps present a limited set of data, such as roads and cities, however, GIS offers dynamic, digital mapping with integrated data processing and analysis (Akindahunsi *et al*., 2024). GIS has the ability to display various map types, including qualitative distribution maps, point-maps, and quantitative maps with proportionate data, such as disease cases, populations at risk, prevalence, and infection intensity (Akindahunsi *et al*., 2024). It also supports methods like transect sampling and Kriging for predicting values at unsampled points based on known data

Machine Learning

The role of machine learning in disease surveillance has been extensively explored, with many scholars lauding its predictive capabilities. The term ‘machine learning was coined by Samuel in 1959 (Akindahunsi *et al*., 2024). It is the practice of using algorithms to analyse data, learn from them, and make predictions or judgments regarding the future state of any new dataset (Akindahunsi *et al*., 2024). It is a subset of artificial intelligence that allows computers to learn from data and improve their performance over time without being explicitly programmed. It works by creating models that identify patterns and make predictions based on large datasets (Akindahunsi *et al*., 2024). Therefore, instead of manually coding software routines with a specific set of instructions predetermined by programmers to accomplish a particular task, machines are taught how to perform the task using large amounts of data and algorithms (Akindahunsi *et al*., 2024). In disease surveillance, machine learning analyses vast amounts of health data, including trends and indicators, to predict potential outbreaks. Unlike traditional statistical methods, machine learning can recognise complex patterns that may not be immediately obvious, making it a valuable tool for early detection and response to diseases (Akindahunsi *et al*., 2024). The key benefits of machine learning are their ability to rapidly process massive datasets that cannot be analysed manually, and the capacity to detect subtle signals that may indicate early-stage outbreak.

Internet of Things (IoT)

In disease epidemiology and surveillance, the Internet of Things (IoT) has emerged as a transformative analytical tool that enables the seamless connection and communication of various physical objects, such as sensors, devices, and software systems, through networks (Akindahunsi *et al*., 2024). The IoT facilitates the real-time generation, collection, exchange, and analysis of vast amounts of data, allowing for intelligent recognition, tracking, monitoring, and management of health-related parameters across different sectors (Akindahunsi *et al*., 2024)]. This innovation provides an integrated framework where the physical and digital worlds converge, creating opportunities for enhanced disease surveillance and epidemiological investigations. IoT systems, composed of components like biosensors, environmental sensors, agricultural sensors, wearable devices, and backend data platforms, enable continuous real-time monitoring of critical parameters related to wildlife, livestock, and human health. For example, biosensors deployed in ecosystems can detect ecological disruptions that might signal zoonotic spillovers, while agricultural IoT devices can monitor livestock health for early detection of potential outbreaks. Wearable sensors attached to individuals track vital signs such as heart rate, body temperature, and respiratory rate, providing real-time data that can be analyzed to detect early signs of infection or health deterioration (Akindahunsi *et al*., 2024). One of the key advantages of IoT in disease epidemiology is its capacity for early anomaly detection. Continuous real-time data streams enable health authorities to identify unusual patterns or signals in environmental, animal, or human health, facilitating prompt investigations and the implementation of preventive measures (Akindahunsi *et al*., 2024).

Statistical Modelling

Another widely studied analytical tool in epidemiology is statistical modelling. Traditional statistical approaches have long been used to analyse epidemiological data, with models such as the SIR (Susceptible-Infected-Recovered) framework providing insights into disease transmission dynamics (Akindahunsi *et al*., 2024). In recent years, statistical models have been enhanced by the inclusion of real-time data, improving their predictive accuracy. A study by Yadav and Akhter illustrates how statistical models were used effectively during the COVID-19 pandemic to predict case numbers and inform public health policies (Akindahunsi *et al*., 2024). This writer acknowledges the enduring value of statistical modelling in epidemiology but argues that these models are increasingly being overshadowed by more sophisticated tools like machine learning and artificial intelligence, which offer greater flexibility in handling complex data sets.

Big Data Analytics

Big data analytics is another area of focus in various scholarly works. It is a new-era technology that aims to extract value more economically by capturing, discovering, and analyzing large volumes of diverse data (Akindahunsi *et al*., 2024). It is a comprehensive approach that involves analysing the quantity, variety, velocity, veracity, and value of different types of data. This approach can be used to act, provide insights, measure performance, and establish competitive advantages. Big data possesses characteristics such as a large quantity, high velocity, and diverse variety, requiring specific technologies and analytical methods to transform its value (Akindahunsi *et al*., 2024). The ability to analyse massive datasets from diverse sources, including hospital records, social media, and environmental sensors, has expanded the scope of epidemiology. However, big data also comes with challenges, particularly in terms of data privacy and security. While big data analytics provides immense benefits, it also raises concerns about the collection and use of personal health data without consent (Akindahunsi *et al*., 2024). This writer contends that as big data becomes more integral to epidemiology, stringent legal frameworks will be needed to protect individual privacy while allowing the full potential of these tools to be realized.

Challenges in Disease Surveillance

The challenges to effective global surveillance and response to human disease outbreaks reflect deficiencies in health infrastructure, scientific methods and concepts of operations of infectious disease surveillance programs, human, technical, and financial resources, and international policies.

i. Health Infrastructure

Healthcare facilities provide the primary opportunity for detecting cases of unusual diseases or unusual clusters of disease, but healthcare facilities are absent or inadequate in resource limited countries in Africa, Asia, and other parts of the world. Consequently, these countries do not have adequate domestic disease detection or response capabilities. The absence of health infrastructure in resource-limited countries creates gaps in coverage in regional surveillance systems (Muttalib *et al*., 2021). The result is a porous patchwork of surveillance systems that is exacerbated by differences in focus, approach, intended audience, and resource base and by inadequate integration and poor coordination between surveillance systems.

ii. Methodology

There is no consensus on the preferred methodologies, performance characteristics, or outcome measures for surveillance programs. There are no clear measures of effectiveness or cost-effectiveness of infectious disease surveillance systems. With the exception of those systems that have as their goals disease eradication or control of vaccine-preventable illness, it is difficult to assess the contributions of the surveillance systems. Given current surveillance methods, it is doubtful that infections that spread rapidly (e.g., influenza) or that spread silently (e.g., HIV infection) can be detected before they are widely disseminated. Regional and/or international outbreak responses may be the first response in containment of these infections.

iii. Technical Resources

Diagnostic tests are essential for rapid screening and confirmatory diagnosis of sick patients in primary care and/or emergency care facilities. Either these tests do not exist for most diseases, or they are too expensive and/or too technical for use in resource-limited health infrastructures. In the absence of an etiologic diagnosis, the opportunity for surveillance and response—including proper medical care treatment, appropriate vaccination, and use of effective infection control procedures—will be lost. Despite the essential role of these tests in diagnosis and response, the resources available for the development, manufacturing, and distribution of these diagnostic tests are inadequate. All components of surveillance and response would be enhanced with these tests. The global communication networks necessary to support infectious disease surveillance systems are inadequate. Countrywide deficiencies in the phone and internet systems weaken surveillance, reporting, outbreak investigation, and response. Even where electronic reporting systems are available, they are often not used regularly for disease surveillance, in part because information technology personnel are inadequately trained and funded.

iv. Policy

Perceived economic consequences due to disruption of trade and travel caused by disease outbreaks deter reporting and delay verification. Although health-related regulatory provisions among WHO, the World Trade Organization (WTO), the International Civil Aviation Organization (ICAO), and the Food Agriculture Organization (FAO) are being coordinated to decrease the economic risk to countries that report disease outbreaks, the economic impact of the SARS epidemic suggests that additional measures are necessary.

V. Opportunities for Improvement

Advanced technology adoption has the potential to revolutionize disease surveillance systems. The accuracy of data collecting and reporting can be improved by digital tools such as data analytics platforms, mobile health applications, and electronic health records (EHRs). Quick and efficient responses to disease outbreaks are made possible by real-time data tracking using cloud-based systems and GIS tools, which guarantee that information is shared promptly. Furthermore, by predicting outbreaks and identifying patterns, the use of machine learning (ML) and artificial intelligence (AI) enables proactive rather than reactive responses.

Developing a strong health infrastructure is essential to enhancing illness monitoring and management. A well-trained personnel, better reporting systems, and investments in diagnostic labs are necessary to increase the ability to diagnose and track diseases. Furthermore, considerable international collaboration is required to address global health concerns. The results of global health initiatives that promote information exchange, collaborative research, and coordinated actions can be greatly enhanced. It is important to give regional health networks and organizations like the World Health Organization (WHO) the authority to establish collaborations, standardize data gathering procedures, and assist settings with limited resources in their surveillance activities.

Conclusion

A strong disease surveillance system is essential to public health because it makes it possible to identify, track, and manage disease outbreaks in real time. We can increase our ability to with stand pandemics and epidemics in the future by recognizing and fixing deficiencies in current system.

Leveraging cutting-edge technologies, bolstering health infrastructure, and encouraging global cooperation are the keys to the future. Local, national, and international stakeholders can collaborate to guarantee a safer and healthier world by giving priority to these areas for change. For the sake of human welfare, effective disease outbreak prevention and control is not only possible, but essential.

Recommendations

Based on the study, the following recommendations are proposed to address the identified challenges:

i. Allocation of more resources towards building healthcare infrastructure in underserved regions. This includes improving internet connectivity, providing modern diagnostic tools, and training healthcare professionals in the use of advanced surveillance technologies.
ii. Strengthening the collaboration between governments, international organisations, and private sector stakeholders to share resources and expertise. This will enhance the global capacity to address public health challenges through coordinated surveillance efforts.
iii. Continuous training and capacity-building programmes should be initiated for healthcare workers to ensure accurate data collection and reporting. Governments should prioritise making relevant health data more accessible to improve the reliability of disease surveillance.

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