A Literature Review of Methods for Dengue Outbreak Prediction

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***Abstract*—This review provides the current dengue surveillance situation including (i) the factors that contribute to dengue transmission and (ii) the method to combat the disease. Dengue fever now is the most common mosquito-borne disease that infected around 100 billion population, mostly from Asia Pacific. This alboviral disease not only worsens people's health, but also has a great social and economic impact in areas where these endemics arise. Currently, the transmission of this disease is influenced not only by the climatic factors (e.g., rainfall, temperature, wind speed and humidity) but also by non-climatic factors like socio-environmental factors (e.g., population density, land use activity, vector control and transportation). Previously, prevention methods such as vector control, were used by public health agencies in combating the transmission of dengue outbreak. Recently, with the improvement of knowledge and technology, new methods and models are developed, not only for detection but also for prediction of dengue trends and outbreaks. An effective prediction model would be particularly helpful to detect unusual occurrences of disease and to allow for targeted surveillance and control efforts of the disease. In this paper, we review and summarize the development of dengue outbreak tools by researchers in the Asia Pacific region.**

Keywords–Dengue Outbreak Prediction, Statistical Analysis, Spatial Analysis, Machine Learning

I. INTRODUCTION

Dengue is a mosquito-borne viral disease that has rapidly spread in all regions of the world in recent years. This arboviral disease is transmitted by two main vectors, which are Aedes Aegypti and Ae. Albopictus [1]. Both mosquitoes have adjusted to human neighborhood with larval habitats and ovipositor in natural and artificial (e.g., rock pools, tree holes, blocked drains, pot plants and food and beverage containers, and leaf axis) collections in the urban and peri-urban environment [2].

Dengue can be brought on by any of four viral serotypes (Dengue Virus (DENV) 14), and is transmitted by day-biting urban-adapted Aedes mosquito species [3]. After an incubation period ranging from 4 to 14 days, patients normally can encounter a range of symptoms, from a sub-clinical disease to debilitating but transient Dengue Fever (DF) to life-threatening Dengue Hemorrhagic Fever (DHF) or Dengue Shock Syndrome (DSS) [4] [5]. The most severe forms of dengue disease are DHF and DSS. They are life debilitating, and youngsters with DENV disease are especially at danger of advancing to severe DHF/DSS [6]. Until now there is no specific treatment or vaccine for dengue.

DF is a major public health concern and also re-emerging infectious disease that affects millions of people worldwide. It is also a major public health concern for over half of the world's population and is a main source of hospitalization and death especially for youngsters in endemic nations. The majority of the poor nations are particularly vulnerable to the transmission of dengue infection [6]. This vector borne disease always can be found in urban and suburban areas of regions such as Africa, South-East Asia, Americas, Eastern Mediterranean and Western Pacific [7]. It is assessed that consistently, there are 70500 million dengue infections, 36 million cases of DF and 21 million cases of DHF and DSS, with more than 20000 deaths per year [7].

An expected 50 million cases of dengue diseases occur annually and approximately 2.5 billion people live in dengue endemic countries [8]. Other than that, DF inflicts a significant health, economic, and social burden on the populations of these endemic areas. A scientific working group report on dengue published by the World Health Organization (WHO) shows that nearly 75% of the global disease burden is due to dengue [9]. Demographic change, urbanization, deficient local water supplies, relocation led to an increase in the global incidence of dengue and about 3.6 billion people are currently at risk [10]. These parameters can also be defined as non-climatic parameters that have an impact on the dengue outbreak. But other researches also found that the spread and establishment of dengue is also mainly facilitated by a changing climate around the world [11].

The rest of this paper is organized as follow: Section II provides an overview of different types of dengue data that were used in previous studies. Section III outlines several climatic and non-climatic factors that were commonly used in previous studies for dengue outbreak prediction. Section IV then summarizes and describes different techniques for dengue outbreak prediction from the three main streams: (i) spatial analysis, (ii) statistical and mathematical analysis, and (iii) machine learning. Finally, the paper discusses potential directions for future work in Section V and summarizes the conclusion in Section VI.

II. DENGUE DATA

Dengue data is very important to dengue surveillance study since it can trace and identify the dengue incident from the dengue data results. For this review, we considered the data for both DF and DHF cases as 'dengue incident'. In many dengue epidemiology studies, the dengue incident data that was collected either in hospitals or medical centers can be classified into 3 groups, namely suspected, probable and confirmed cases [4]. A suspected case is a clinically compatible case of dengue-like illness, dengue, or severe dengue with an epidemiological linkage. A probable case is a clinically compatible case of dengue-like illness, dengue, or severe dengue with laboratory results indicative of probable infection. Lastly, a confirmed case was a clinically compatible case of dengue-like illness, dengue, or severe dengue with confirmatory laboratory results. A confirmed case refers to a dengue case that was confirmed by the serological tests IgM capture enzyme-linked immunosorbent assay (ELISA) with single positive IgM in the lab [12]. Most research reviewed in this paper used the suspected and confirmed cases.

III. Dengue Factors

Identifying key factors that contribute to dengue infection is very valuable in controlling and predicting dengue outbreaks. In this section, we review and summarize the key climatic and non-climatic factors that were found to have an impact on the spread of dengue.

A. Climatic Factor

Over the last decade, the climatic changes around the globe have had a major impact on the transmission of dengue. Climate change happens when there is an increase in greenhouse gases that make the air and Earth's surface warmer. This actually happens when there is a high concentration of greenhouse gases in the atmosphere, including carbon dioxide, methane, and nitrous oxide. This is due mainly to human factors, for example, the utilization of fossil fuel, changes in the use of an area, and agriculture [13]–[15]. These changes will have an influence on the dynamic pattern of climate variables around the world, especially the temperature, rainfall, precipitation and humidity, and extreme weather occurrences such as El Nino Southern Oscillation (ENSO) [16]–[18].

Studies have demonstrated that a change in these factors can influence various aspects of the arthropod vector's life cycle and survival, the arthropod population, vector pathogen interactions, pathogen replication, vector behavior and, of course, vector distribution [19] [20]. For example, temperature increases not only effect the reproduction and mosquito activity, but also decrease the incubation time of larvae [16]–[19]. Various studies recorded different lag times for the larva incubation period ranging from 4 to 16 weeks [17] [21]–[24]. The increase in the larva incubation period will exacerbate the rate at which mosquito vectors transmit the disease.

Extremely hot temperatures also impact the DF expansion by extending the season in which transmission occurs [25] [26]. This occurs when lengthy drought conditions exist in endemic areas without a stable drinking water supply. The storage of drinking water increase the number of breeding sites for the mosquito vector [27] [28]. These extremely high temperatures are also a result of the climate change phenomena and ENSO cycles. Among the studies reviewed, the ENSO phenomena were associated with local temperature and precipitation changes. It was showed that a decrease in ENSO could result in an increased temperature and decreased rainfall leading to increased water stockpiling. This favors mosquito reproducing places and, in this way, increases dengue transmission [16] [29] [30].

The changes in the world climate have also impacted rainfall trends, and, in combination with the temperature increase, it becomes the main regulator of evaporation that directly affects the availability of water habitats [31]. Rainfall itself, can influence the conditions in the case of both high and low precipitation. In the high precipitation conditions, it can flush away eggs, hatchlings, and pupae from compartments in the short term [32] [33]. In the longer term situation, residual water can create breeding habitats, thereby expanding the adult mosquito population [34]. For the low rainfall condition, together with dry temperature it can lead to human behavior of saving water in water storage containers, which may become breeding sites for Ae. Aegypti [35] [36]. In the end, climatic conditions can be seen affecting the virus, the vector and human behavior both directly and indirectly.

Looking into the previous research from years before, especially the association between climatic factors and the transmission of dengue, we can see that there is a link between them either in a positive or negative correlation [37]–[44]. However, the connection between dengue and the climatic factors still remains debatable because of the potential influence of other socio-demographic factors that can have an impact on dengue transmission [13] [45]–[47].

B. Non-Climatic Factor

In recent years, a few authors have begun looking at several non-climatic factors, such as, human growth, human movement, and socioeconomic constraints as effect to dengue transmission [20] [45] [48] [49]. A recent study done by Gubler [50] shows that the growing population in developing countries became a contributing factor to the increase of dengue transmission and expansion. This unprecedented population growth, mostly in high density population area may provide new man-made breeding sites through discarded automobile tires, non-biodegradable plastics, cell phones, and tin [51] [52]. These consumer products will become ideal breeding sites for the most potent dengue vector, A. aegypti. Finally the increasing density of A. aegypti mosquito population combined with increased human populations contributed to the transmission of dengue in urban area. The effect of human growth factor can also be dangerous when it is combined with the rapid urbanization process that actively happens in the urban areas, especially in low and middle income countries [20] [53].

Rapid urbanization not only contributes to the population explosion but also has an impact on people's socioeconomic behavior in urban and suburban areas. Recent studies found that non-climatic factors, such as housing types, poor garbage disposal, poor water storage, and cross-border travel, strongly correlate to the number of dengue cases [12] [54]–[56]. It was also showed that other socioeconomic factors, such as low level of education and low coverage of infrastructure, can contribute to the number of dengue cases in urban areas [57]–[59]. People who live in high population density areas are highly vulnerable to dengue infection because of poor housing conditions and/or the lack of public services, such as inadequate drainage or improper sanitation system [60]–[62]. Indeed, several residual water containers, which are key mosquito breeding sites, are naturally or artificially created in these areas. Thus, poor living conditions play an important role in the spread of dengue [46] [63] [64].

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In addition, it was showed that the geographical distribution of dengue is potentially influenced by travel and trade factors [7] [54] [65]. Urbanization has increased the population mobility and consequently contributes to the spread of dengue between urban and rural areas [25] [66]. Globally, increases in international passengers were identified as the main cause for dengue transmission between countries and continents [67]. This is very dangerous because an infected immigrant or visitor from a dengue-endemic country can carry a new virus strain into another country and causes a dengue spread [47] [68]. Global trade was also identified as one main driver in the global transmission of dengue [66] [69]. Indeed, the higher the number of cargo and goods are transported around the world, the higher the chance mosquitoes carrying the virus arrive in a new place that has suitable environmental conditions for their survival and breeding.

IV. Research Method

As discussed in the previous section, there are several factors that have an impact on a dengue outbreak. Several methods have been developed and studied to comprehend the complex relationship between these factors and dengue in order to accurately predict the number of dengue cases for better prevention and/or proactive mitigation. In general, the existing methods for dengue outbreak prediction that we reviewed can be classified into three groups: (i) spatial analysis, (ii) statistical and mathematical analysis, and (iii) machine learning system.

A. Spatial Analysis

Kernel density is the most popular method that is used in dengue transmission studies in the geographical epidemiology field [70]–[73]. This method was applied to identify and map out hotspots with a high concentration of reported dengue cases [74]. It can detect dengue clusters and generate risk maps based on the correlation with climatic and non-climatic factors. Another popular method is Geographically Weighted Regression (GWR) [75]. It can predict the risk levels of a dengue outbreak and identify the spatial dependency between DF cases and the factors involved [76] [77]. In addition, Local Indicators of Spatial Autocorrelation (LISA) has been used to study the impact of climatic and non-climatic factors on dengue transmission [78] [79]. LISA can be regarded as a spatial risk index to identify both significant spatial clusters and outliers [80]. Thus, it is often used to examine the spatial temporal patterns of the spread of dengue.

Recently, the integration of spatial statistics and non-spatial statistics has become more prominent. Although spatial statistics can improve the comprehension of dengue surveillance by enhancing the detection of patterns , users can potentially misinterpret the results. Integration of both statistical approaches not only maintains the visualization advantage of spatial statistics but also enables the testing of statistical significance of relationships between dengue parameters and the number of dengue incidents. In our review, spatial statistical analysis was mostly integrated with linear regression techniques, such as logistic regression and Poisson regression [81]–[84].

B. Statistical and Mathematical Analysis

Infectious dengue surveillance and control efforts encompass a wide variety of fields and require integration, synthesis, and analysis of information. This requirement can be met by the application of quantitative analysis, especially the combination of different analytical models. The past decade has witnessed a large increase in dengue research activities on statistical and mathematical methods. Following an apparent trend in surveillance research, statistical methods have become popular in dengue outbreak detection and control, especially in generating early warning of dengue outbreaks. A statistical model can be defined as an empirical relationship between the location of known virus occurrences and a set of underlying parameters, such as climatic and non-climatic variables [85] [86].

The two most popular statistical approaches that are used in the dengue studies are regression and time series techniques. The regression technique is a method that has two functions, one for detecting outbreaks in surveillance process that support the basis of laboratory reports, and second is for syndrome surveillance. The regression technique commonly used by the clinical and epidemiological researchers is Poisson regression [18] [87]–[90]. It is normally used to analyze the correlation between the number of dengue cases and one or more dengue factors in order to predict the number of future dengue cases [91]. Poisson regression, using a Generalized Additive Model (GAM), was often used when dealing with nonlinear data as it can improve the prediction accuracy by automatically calculating the optimal degree of nonlinearity of the model directly from the data [92]–[94].

A part from that, time series methods were also commonly used by the researchers to find the variable that have an impact on dengue incidents. This approach has been widely used in the early detection of infectious disease outbreaks, especially focusing on the emerging or re-emerging infections. Unlike other statistical approaches, this type of analysis was chosen based on the assumption that the incidence of infectious diseases is related to the previous incidence and the population at risk [95]. One of the most popular time series methods for studying the correlation between dengue and its variables is the Autoregressive Integrated Moving Average (ARIMA) method [96]–[99]. The advantage of this method is that it can provide a comprehensive set of tools for arrangement model distinguishing proof, parameter estimation, and gauging. In addition, it offers incredible adaptability in investigation, which is added to its prevalence in a few dengue research.

The ARIMA model can be extended to handle occasional parts of an information arrangement. The seasonal ARIMA (SARIMA) model is an extension of ARIMA to an arrangement in which a pattern repeats seasonally over time. This statistical model is particularly interesting when there are time conditions between observations [100]. The assumption that each observation is associated to past ones makes it possible to model a temporal structure, with more dependable expectations, particularly for regular diseases [101] [102]. The example research that used this model can be seen in the study done in Thailand and India [49] [103] [104].

Recently, numerical procedure has been progressively used as an alternative to statistical models to interpret and anticipate the number of future infectious diseases. Many complex mathematical models have been developed to predict the occurrence, dynamics and magnitude of dengue outbreaks using a combined environmental and biological approach. These models have the capability to produce an useful approximation and thus enable the conduction of conceptual experiments that would otherwise be difficult or impossible. Mathematical models allow precise, rigorous analysis and quantitative prediction of dengue transmission and outbreak [105] [106]. Examples of mathematical models that were applied in the dengue surveillance research are the Susceptible-Infected-Recovered (SIR) model and its extensions [107]–[109].

C. Machine learning system

Technology improvement, in the computer science field, already gives a new hope in the dengue surveillance research and study. As mentioned in the previous section, statistical methods have been widely used in dengue outbreak prediction. Given a specific theory, statistical tests can be applied to epidemiological data to check whether any correlations can be found between different parameters. However, machine learning systems can do much more. A machine learning system can automatically hypothesize and derive the associations of dengue factors directly from the raw data. The advantage of this approach is that it can be used to develop the knowledge bases used by expert systems. Given a set of clinical cases, a machine learning system can produce a systematic description of those clinical features that uniquely characterize the clinical conditions. Several machine learning approaches have been used to predict dengue outbreaks, such as Artificial Neural Network (ANN), Alternating Decision Tree Method (ADT), Support Vector Machine (SVM), Fuzzy Inference System (FIS) and its hybrid model called Adaptive Neuro-Fuzzy Inference System (ANFIS) [110]–[116]. This new approach has a potential role to play in the development of dengue prediction and it will be great importance to the relevant decision makers who are typically responsible for budgets and manpower in the public health sector.

V. Future Work

Research into dengue surveillance methods has increased dramatically over the last two decades. Many new methods are designed for specific monitoring systems or still in experimental and developmental stages and not used in real practical surveillance. From the past research, this review has noted that there's need to an advancement of tools to assist dengue prevention and control. Tools like [117] allow scientists to easily model data and apply different spatio-temporal kriging techniques. The combination between spatial, statistical and mathematical analysis together with machine learning system can become a holistic solution to this problem. This hybrid application has the potential to understand the complex relationship between climatic factors, non-climatic factors and dengue, and thereby can obtain better prediction. As information sorts and sources turn out to be progressively vast and complex, there's need to procedures to coordinate dissimilar and frequently inadequate information into fitting tools. This obstacle can be solved by using Big Data Analytic (BDA). Big Data is a term used to portray data arrays that make customary information, or database, preparing risky due to any combination of their size, frequency of updated, or diversity [118]. The research team of IBM, teamed up with the university researchers, used BDA to predict the outbreak of deadly diseases such as dengue fever and malaria [119]. Another research on the application of BDA in dengue study was carried out by the Telenor group in collaboration with Oxford University, the U.S. Center for Disease Control, and the University of Peshawar [120]. Looking to the sources of data collection, there's need to a new platform for catering the information with current vast technology. The online data sources such as social media networking like Twitter and Facebook can become new valuable data sources and can assist the epidemiologist on real-time dengue scenario. With this new technology, dengue cases mostly the under reported cases can be captured and it can overcome the problem such as the accessibility to public health center.

VI. Conclusion

The improvement of dengue prediction frameworks holds incredible potential for enhancing general well-being through right on time cautioning and checking of infection. There are numerous perspectives to consider when pondering techniques for dengue observation. A hefty portion of the routines depicted in this survey are dynamic zones of exploration and new strategies are continually being produced. As more information sources get to be accessible, this pattern is relied upon to proceed, and the systems depicted here give a preview of alternatives accessible to general well-being investigators and specialists. We trust that it is essential to create, utilize and coordinate spatial, factual and scientific examination together with machine learning framework approaches for dengue transmission perfect with long haul information on atmosphere and non-climatic changes and this would propel projections of the effect of both components on dengue transmission. With progressing upgrades in the information and philosophies, these studies will assume an inexorably essential part in our comprehension of the perplexing connections in the middle of environment and well-being.

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