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Developing Insurance Mathematical Model to Assess Economic Burden of Dengue Outbreaks

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Abstract Dengue fever is a vector-borne viral disease that has become a worrisome health issue in tropical and subtropical countries. The seasonal trend of dengue incidence encourages outbreaks with a high risk of infection at particular periods annually that potentially resulted in a significant economic burden. The epidemiological mathematical model, the SIR-SI model, is modified by considering the time-dependent and periodic-forced infection rate parameter through sinusoidal functions to obtain well data fitting. We show the existence and the stability of the disease-free and endemic equilibria for the system and their relation to the basic reproduction number of the disease. Next, we adapt the insurance concept to develop an insurance mathematical model that accommodates the proposed dengue transmission model in calculating nominal premiums. An increase in the basic reproduction number as an important indicator of the level of disease transmission risk resulted in an increase in the nominal premium. We also introduce a reserve function that guarantees sufficient premium payments collected by insurer to cover up future expenditure due to dengue outbreaks. Through this reserve function, we obtain an adjusted premium as a minimum value of premium which ensures that the reserve function is always positive. Mathematical models combined with insurance features have the potential to become important tools for relevant authorities to gain insight into disease transmission dynamics as well as assess the economic burden induced by the occurrence of disease outbreaks.

Keywords Dengue, SIR model, insurance, economic burden, premium

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1. Introduction

Globally, dengue is an arboviral infection that is highly endemic in regions featuring tropical and subtropical climates. Over the past few decades, the worldwide dengue incidence has increased significantly in terms of the frequency of epidemics, and severe dengue disease is the notable cause of mortality and morbidity [1]. Dengue has a huge impact on human health and an estimated half of the world's population in more than 128 countries is now at risk with Asia bearing 70% of the global burden [2–4]. According to an estimate, annually, 100 million people are affected by dengue infections, and 500,000 are hospitalized with more than 25,000 reported deaths globally [5]. More than 20% of the annual dengue cases evolve into a high level of dengue disease severity, dengue hemorrhagic fever (DHF) or dengue shock

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syndrome (DSS), which requires intensive medical treatment, whereas the rest of the cases remain in the milder dengue fever (DF) form. Dengue is considered the fastest-growing vector-borne viral disease in the past 30 years, and the number of incidences has increased fourfold [6]. In the 1970s, dengue epidemics were reported in less than 10 countries. However, nowadays, more than 150 countries all over the world were affected by dengue infection [7]. WHO recorded around 5.2 million dengue cases globally in 2019 which increased dramatically compared to 2.4 million cases in 2010 and half a million cases in 2000 [8]. Moreover, within 2000-2019, age-related dengue mortality are higher in younger age group and showed an increase from 960 to 4,032 deaths in a year [9].

The complexities of the mechanism underlying dengue re-emergence are not yet fully understood, which implies that the occurrence of the outbreaks is mostly unpredictable. Various researches have been conducted to examine the possible variables that influence the emergence of dengue outbreaks around the world. Climate change, globalization process, unplanned urbanization, and environmental degradation allegedly play a critical role in the increase and expansion of dengue cases. In general, meteorological factors have been recognized as the major determinant in driving dengue epidemic. Climatic and weather conditions greatly influence the development, ecology, behavior, and survival of the *Aedes* mosquito as the primary vector that transmits dengue virus [10]. The risk of dengue infection in humans is strongly associated to the number of mosquito larvae [11]. The number of mosquito larvae in most tropical and subtropical regions is higher in the rainy season than in other seasons [12–14]. The expansion of egg-laying areas due to high rainfall and a slum environment that allows many water-filled containers has led to an abundance of vector populations. Weather in each region has a trend of repeating each year depending on climatic conditions which in turn encourages the recurrence of dengue outbreaks with a high number of cases at certain periods in a year [15]. The seasonal pattern of dengue cases coincides mostly with the rainy season.

Dengue is a significant economic burden of infectious disease in many dengue affected areas, especially in developing countries. Shepard and others [16] have conducted a research about the economic burden related to dengue in some Southeast Asia countries, and over the decade of 2001-2010, it was estimated that the annual average economic burden was US$950 million (US$610 million - US$1,384 million, with 95% certainty levels). In Sri Lanka, the total cost of dengue case management in hospitals were approximately US$3.45 million or US$1.50 per capita), whereas the total expenditure for dengue prevention programs exceeded US$1.27 million in 2012 [17]. In 2010, economic cost related to dengue in the Americas averaged US$2.1 billion per year, with substantial year-to-year variation ranging from US$1 billion to US$4 billion [18]. Considering all these previous studies, it can be seen that, in recent years, the dengue outbreaks have become a burden on the country's economy and have had a significant effect on the worldwide socio-economic sector. The economic cost induced by dengue epidemic can be generally categorized as direct and indirect cost. Expenses incurred for the prevention program, surveillance and reporting, and medical treatment are included in direct costs [19]. The cost of the prevention program accommodates activities to prevent dengue, such as controlling vector population and awareness campaigns. Surveillance and reporting cost is linked to the efforts of governments and related authorities in observing and disseminating any dengue information to the public. Medical expenses include the costs of diagnosis, hospitalization, and outpatient care [20]. In addition, indirect