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*Original research article*

# Understanding the Dynamics of Dengue Haemorrhagic Fever (DHF) in Indonesia and its Sustainable Solution: a Qualitative Perspective

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**ABSTRACT**

Dengue haemorrhagic fever (DHF) remains a threat to the global population, especially in tropical regions. In Indonesia, due to population growth and human mobility, almost all Indonesian provinces have experienced DHF. Some efforts have been conducted to eradicate this lethal disease. Owing to these efforts, the fatality rate has decreased significantly. Nevertheless, despite the reduced fatality rate, there is an indication that the incidence rate has increased. Using system archetypes, this paper aims to provide insights into the dynamic patterns of this vector-borne disease, and offers a theoretical premise of why this lethal disease still exists in Indonesia. Upon the application of system archetypes, it was found that a combination of vertical and horizontal mechanisms leads to the persistence of DHF in Indonesia. Fortunately, the Wolbachia strategy offers a promising way to eliminate DHF incidence.

**Keywords**: Dengue haemorrhagic fever; System archetypes; System thinking; Wolbachia strategy; Vector borne diseases

## 1. Introduction

The dengue haemorrhagic fever (DHF) is a mosquito-borne disease and the dengue virus is mostly transmitted by female mosquitoes. The main transmitter is *Aedes aegypti* and to a lesser extent, *Aedes albopictus*. These mosquitoes can thrive in urban areas, which are densely populated with people. They breed mostly in water pooled in man-made objects and containers, such as bathtubs or abandoned bottles and cans. During rainy seasons, mosquitoes are able to lay many eggs, as standing water is their preferred environment for egg laying.

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Their optimum temperature for life ranges between 25$^0$-32$^0$C. This is the main reason why DHF is found mostly in tropical and sub-tropical areas such as Indonesia and Thailand.

As seen in Fig. 1, Asian countries such as Indonesia, and South American countries such as Brazil are among the countries with the highest incidence rates in the world; in fact, Indonesia has the second-highest DHF incidence rate in the world [1- 2]. Human mobility, favorable climate, and population density are among the factors affecting DHF prevalence in Indonesia [1-3] and across the globe [2].

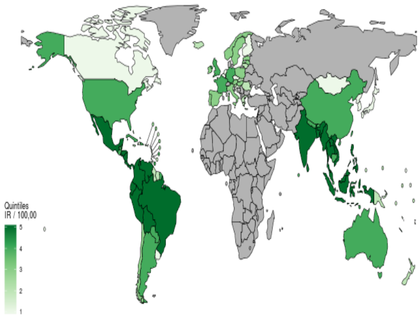

**Fig. 1.** The map of incidence rates (IR) across the world.

DHF was first identified in 1968 in Indonesia [1, 3-4]. Over time, DHF has spread to almost all the districts of Indonesia [3-5]. As seen in Fig. 2, the affected provinces have increased from only 2 provinces in 1968 to about 30 affected provinces in 2017. However, data shows that there has been a decrease in the fatality rate despite an increase in the incidence rate.

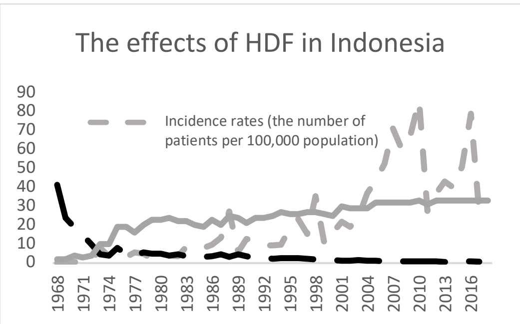


**Fig. 2.** The incidence rates and the fatality rates of DHF in Indonesia (1968-2017).

Since DHF has been a concern of the Indonesian government going back several decades, it has allocated an annual budget to eliminate DHF incidences within the country. As infections increase, the government deploys resources to cure infected people. The Indonesian government for instance, allocates about 300 million USD each year in anticipation of the coming spike of DHF cases [6]. The designated resources for fighting DHF includes medicine, doctors, and nurses, employed with the aim of decreasing infections and the possibility of contagious effects. Through effective medical care, Indonesia was able to decrease the fatality rate to less than 1 % by the 2000s [5].

In response to repetitive DHF outbreaks and the large size of affected areas, some Indonesian scholars investigated the patterns and causes of DHF. Several studies [7-10] have confirmed that climate factors, such as rainfall and temperature, positively influence DHF incidence. In general, more rainfall and higher temperatures tend to increase DHF incidence rates. Other studies [3-11] have pointed out that human mobility and high population density are two main causes of DHF epidemics in Indonesia.

Those studies [3-4, 11-12] also affirmed that sanitation and preventive measures can decrease DHF incidence rates. It was also found that an integrated analysis is needed, as the DHF phenomenon involves the interactions of human behavior, environment, vectors, and climate [11].

In terms of a system dynamics approach, existing studies [13-14] have used the system dynamics model to investigate infectious diseases such as DHF. Unfortunately, those studies [14-15] only focused on comparing different policies related to DHF. Missing from those studies is any explanation for how preventive and corrective maintenance can decrease the persistence of DHF, and why despite some efforts, DHF incidence continues to increase.

This study aims to explain why, despite mosquito-control programs and health management, DHF incidence rates continue to increase in Indonesia.

This study intends to use system archetypes, as they can provide insights into observed systems [16-18]. Existing studies successfully applied system archetypes to the European organic food system [13], the Asian agriculture system [13], business [19], and organisational issues [20]. Using system archetypes, we can gain insights into the dynamics of DHF in Indonesia. System archetypes can also be a basis for developing computer simulations for conducting policy analysis. Please see appendix A for further discussion about feedback loops and system archetypes.

## 2. Materials and Methods

### 2.1 System archetypes

Many studies have shown that qualitative system dynamics tools i.e., system archetypes are useful for analyzing different kinds of observed systems such as agricultural systems [13], organic food systems [15], and business [19]. This paper explains the application of the causal loop diagram and system archetypes to identify (1) feedback loops, (2) system archetypes, and (3) possible solutions to cope with the negative impacts of climate change on rice production.

There are two types of feedback loops, reinforcing loops (R) and balancing loops (B). Reinforcing loops represent growth in the observed system while balancing loops represent a self-correcting mechanism [19; 21]. This study uses Vensim Plus® to translate a conceptual model into a causal loop diagram (CLD). Afterward, system archetypes were identified based on an identified CLD.

The application of system archetypes is very useful because it provides a simple insight into the system structures. Further discussion of system archetypes can be found in many studies, of note is one from 2007 [19]. Senge [20] points out that system archetypes enable researchers to identify leverage points, which in turn can improve system performance.

There are some qualitative criteria of system archetypes [19]. The first criteria is that behaviour patterns are based on existing theories or data. Second, a CLD that describes connections between elements of the observed system. Last, it needs to provide potential solutions that enable policymakers to tackle the identified problems.

### 2.2 Case definition

Humans infected by dengue virus can show mild to severe symptoms. In turn, dengue virus infection can lead to mild illness or fatality [22]. Dengue fever and DHF are two frequent types of disease caused by dengue virus infection. While dengue fever rarely leads to fatality, DHF does usually lead to fatality. As such, this study focused on DHF caused by dengue virus infection.

Furthermore, in terms of DHF definition, this study uses the WHO definition of DHF. Recently, DHF was recognised by the WHO to be based on four criteria including: (a) sudden onset acute fever of 2 to 7 days duration; (b) spontaneous haemorrhagic manifestations or a positive Tourniquet test; (c) hepatomegaly; and (d) circulatory failure, in combination with meeting the haematological criteria of thrombocytopenia (≤105 cells/mm3 ) and an increased haematocrit over 20% [22].

## 3. Results and Discussion

As Indonesia is a country with positive economic growth, some driving endemic factors such as urbanization and human mobility can induce future dengue endemics. As mosquito's fever has a limited range, humans can be an effective carrier of the dengue virus through human mobility and urbanization [3].

Throughout system archetype patterns, the following paragraphs explain the roles of urbanization and humans in spreading the dengue virus.

Mosquitoes, and other dengue vectors, usually bite people during dusk. As infected vectors bite moving people, vectors may have a limited biting time. So, there is a high possibility that vectors bite multiple people within a single day in order to fill their stomachs. The feeding pattern of a multiple biter can lead to the transmission type known as horizontal transmission. The first type of horizontal transmission is called a transmission mechanism. This occurs when uninfected *Aedes aegypti* bite infected people. Then, the infected vectors transmit the dengue virus in the next bites of susceptible people.

It is also possible that susceptible people can be infected after infected vectors bite them. This is the second type of horizontal transmisison, a so-called biological mechanism. These two mechanisms are joined together as a reinforcing loop (R1) as seen in Fig. 3.

Infected people, however, can be healed through good nursing care, leading to a lower incidence rate (B1) – represented by a "-" sign between the nursing care and the incidence rate. While a reinforcing loop (R1) tends to increase the incidence rate, a balancing loop (B1) tends to decrease the incidence rate.

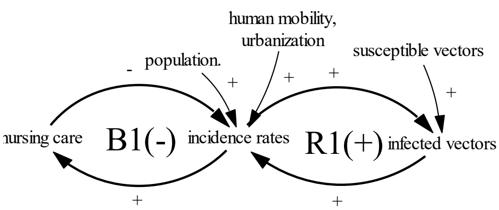


**Fig. 3.** Limits to growth #1.

The interaction between a reinforcing and a balancing loop is called the limits to growth, meaning that a rise in infected people will be bounded by the efforts to cure infected people, decreasing the incidence rates. As previously mentioned, human mobility, population, and urbanization can increase the incidence rate, so as seen in figure 3, relationships between them and the incidence rate are positive – represented by a "+" sign.

As infected people are healed through quality nursing care, infected people become healthy which means that quality nursing care may lead to a lower incidence rate (B1) and a lower fatality rate (B2). The incidence rate and the fatality rate can also be reduced through insecticide spraying to eradicate adult dengue vectors (B3).

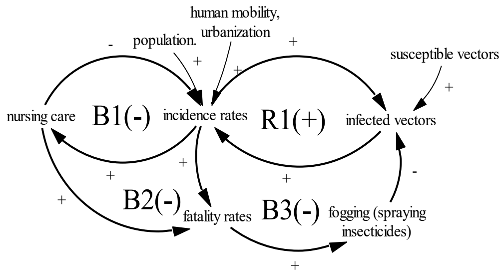


**Fig. 4.** Limits to growth #2.

Fig. 4 shows that the fatality rate and incidence rate may be reduced through two action types: preventive actions and corrective actions. Nursing care is an example of a corrective action taken to cure infected people and reduce the fatality rate. Two examples of preventive actions include insecticide spraying and proper sanitation. In Indonesia, proper sanitation is conducted through disposing of abandoned bottles and cans that may otherwise increase the vector breeding process. These preventive actions are represented as a balancing loop (B5) in Fig. 5.

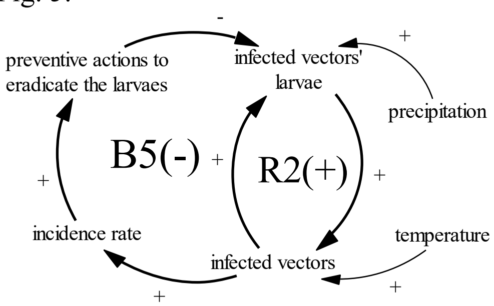


**Fig. 5.** Limits to growth #3.

Overall, as seen in Fig. 6, there are four balancing loops that aim to decrease the fatality rate, the incidence rate, and infected vectors. The fatality rate has decreased over time in Indonesia as two reinforcing loops (R1-R2) are restricted by 5 balancing loops (B1-B5). This is the main reason for the reduced fatality rate in Indonesia.

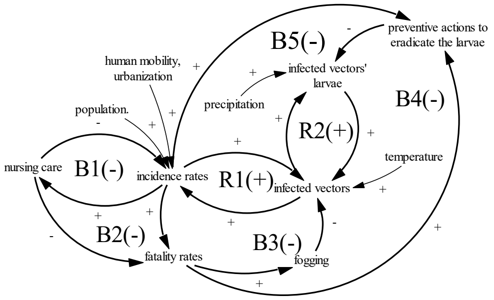


**Fig. 6.** Limits to growth #3 i.e. a CLD.

However, the interactions between the two reinforcing loops and the five balancing loops cannot guarantee a low incidence rate in Indonesia. According to existing studies [22-23], actions to eradicate DHF such as fogging and larval eradication strategies are difficult and unsustainable [22-23]. This is especially true in regions with limited resources [24], sustaining the persistence of DHF cases and outbreaks in tropical countries such as Indonesia.

The reality of decreasing fatality rate and intermittently increasing incidence rate, as seen in figure 2, is evidence that we need sustainable options for tackling the incidence rate. We do, however, need these existing actions such larval eradication programs and fogging as emergency options. But developing and implementing sustainable actions should not be neglected. As will be discussed, the Wolbachia strategy is a sustainable solution for minimizing the incidence rate.

To fully understand the persistence of the DHF incidence rate, this study looks further at an interaction between two reinforcing loops (R1 and R2). The vertical transmission mechanism represents the inheritance of the dengue virus by progeny. This means that the second reinforcing loop, R2, would not decrease 'infected vectors', rather R2 supplies infected vectors for R1. In other words, horizontal and vertical transmissions may act together to increase incidence rates.

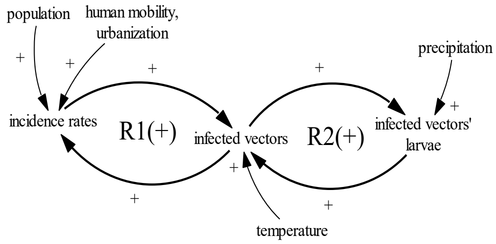


**Fig. 7.** The interaction between two reinforcing loops (R1 and R2).

The life expectancy of Aedes mosquitoes is about 30 days [25-26]. However, one study [25] explained that desiccated eggs (desiccated larvae) of Aedes mosquitoes may survive under a limited environment for more than 1 year, emerging when climate is favorable, then growing to become adult vectors, ready for the next dengue outbreak or endemic. This means that vectors may be available throughout the year to distribute the dengue virus. This premise is supported by Arsin [27], stating that many Indonesian regions have experienced DHF throughout the year. As long as infected people exist, vectors can be infected in the environment. Moreover, as long as vectors are available, future endemics are still possible.

Recent studies [12, 22, 24] argued that releasing vectors with Wolbachia can decrease DHF cases, as there is evidence in some regions that introducing vectors with Wolbachia is an effective way to eradicate DHF IRs [22].

There are two ways vectors with Wolbachia decrease DHF incidence [12]. The first is by increasing vector mortality. Vectors with Wolbachia, after mating with female vectors will lead to more dead larvae – decreasing vector mortality, represented as B6 in Fig. 8.

The second is mating between female vectors with Wolbachia will lead to the inability of vectors to distribute dengue viruses through biting humans. In this case, Wolbachia bacteria kill dengue viruses by eating the food supply in vectors (B7). In other words, Wolbachia bacteria will act as parasites of dengue viruses, leading to fatalities of dengue viruses.

This study must be interpreted with caution, as system archetypes are only a simplified qualitative representation of the real world. In turn, this study should be seen as an early assessment rather than the end of investigation of DHF patterns. Moreover, system archetypes should be quantified when researching DHF dynamic patterns, leading to more effective attempts at decreasing the DHF incidence rate.

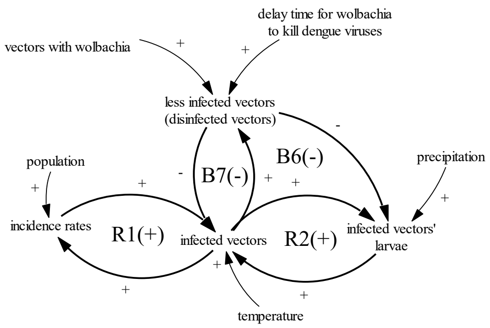


**Fig. 8.** The Wolbachia strategy #1.

## 4. Conclusion

This study aimed to address the continued persistence of DHF in Indonesia and possible solutions for disease control. This study, through interactions between reinforcing loops and balancing loops, explains the dynamic patterns of DHF. The limits to growth structure explains a decrease in the fatality rate. A possible increase of the fatality rate is restricted by quality care and management to heal infected people.

This study also shows that the Wolbachia strategy can be an effective and sustainable solution to decrease DHF cases. Through releasing vectors with Wolbachia and the subsequent mating with vectors can lead to high vector mortality and the inability of vectors to spread the dengue virus.

One policy action recommended by this study is to build a computer model for investigating the interactions between horizontal and vertical transmission mechanisms relating to DHF dynamic patterns. This is important as existing studies have focused on horizontal transmission mechanisms [28] but have neglected vertical transmission mechanisms [29]. In turn, understanding the horizontal and vertical mechanisms, as well as the Wolbachia strategy is important in determining the best policy for reducing the DHF incidence rate.

The rest of the world has also experienced increasing DHF incidence rates [18]. Thus, this study may offer a plausible explanation for the increasing incidence rates in other geographic areas. This study can also be a basis for understanding and finding the best policy for decreasing DHF incidence rates around the world.

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# Appendix

## A. Feedback Loop and System Archetypes

### A1. Feedback Loop

This material describes the concept of feedback loops. Feedback is the process once a signal or an action travel through a chain of causal relationship. There are two types of loops: reinforcing and balancing loops. A reinforcing loop happens if an increase in a variable, after a delay, leads to a further increase in the same variable. A reinforcing loop tends to amplify systems that produce exponential behavior. On the other hand, a balancing loop occurs if an increase in a variable eventually leads to a decrease in the variable. A balancing loop tends stabilize systems, producing asymptotic or oscillatory behavior. This material describes theoretical background of the loops.

In a common place, "feedback" is a word describing when people critics someone else as "all people critics me after my presentation". This is NOT our feedback definition, especially in the system dynamics approach. Giving someone else your opinion will be called a FEEDBACK as long as your colleague act on your opinion and thus lead you to revise your opinion. Also, receiving someone else opinion, and then you give him your reply means a FEEDBACK.

A feedback loop is a combination two or causal links between elements that are connected in such a way, one eventually returns to the first element. For example, if a change in variable A directly causes a change in variable B which directly causes a change in variable C, which in turn directly causes a change of our initial variable A, then we are dealing with a feedback loop (see Figure A1). Feedback loops tends to show nonlinear behavior, although given causal relationships are linear.

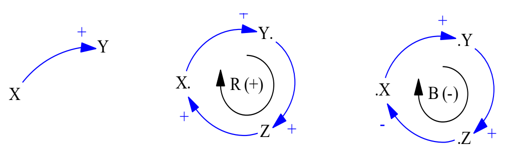


**Fig. A1.** A causal link and feedback loops. Reinforcing loop (R+) & balancing loop (B-).

### A2. System Archetypes

The system archetypes describe universal or common patterns of the observed systems. So, regardless of the types of the observed systems,, system archetypes structures usually occur. Some papers povide evidence that system archetypes structures occur in agricultural systems [13], organic food [15], and business [19].

In addition, the system archetypes structures provides us insights into the underlying structures, revealing dynamic interaction in the observed systems.

Through visible dynamic interactions inside the observed systems, policymakers can see critical issues such as potential problems, sustainable solutions, and potential benefits. In turn, the system archetypes structures are useful in analyzing different kinds of the observed systems and then in improving system performances.

In the following paragrahps, two frequent system archetypes structures are shortly described.

**Limits to Growth: The growth has its limit**

A combination of a reinforcing loop (R3) and a balancing loop (B1) is called Limits to Growth (Braun, 2002; Senge, 2006). As the balancing loop tells us about a limiting factor i.e. water, the expansion of the tourism industry has a threshold. This means that water supply will support the tourism industry until water availability limits tourism growth.

As seen in figure A2, an increase in water supply will boost land-use change, leading to more tourism facilities such as hotels and swimming pools. As land-use change increases, tourism facilities such as buildings and swimming pools are developed, leading to a higher tourism accommodation or rooms as seen in figure A2. As tourist arrivals are supported by more rooms, total population (resident and tourists) will increase, causing more land-use change. The latter is summarized as a reinforcing loop (R3). In this case, a reinforcing loop (R3) confirms that the engine of tourism growth is population.

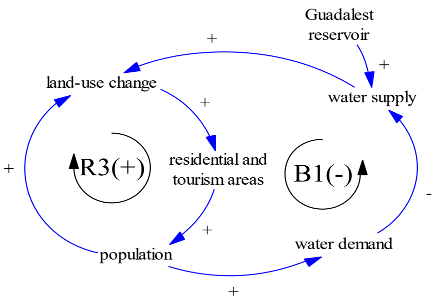


**Fig. A2.** Limits to Growth archetype.

This situation can be visually described as seen in figure A2. Figure A2 explains that an increase in "water supply" leads to an increase in "land-use change", leading to an increase in "water demand" (R3). As a consequence of high water demand, the available water supply will be decreased. This means that relationships among water supply, water demand, and land-use change are categorized as a balancing loop (B1). A balancing loop means there is a situation where a limiting factor i.e. water supply will hamper land-use change or a population increase.

**The Success to Successful: the abandonment of agriculture**

In general, tourism and agriculture require water directly. Tourist activities such as bathing and swimming require a lot of water. Similarly, agriculture needs water to support crop growth. So when tourist arrivals are high available water for agricultural is limited, leading to the abandonment of farming land.

Under the massive tourism expansion, there was land-use change from farming areas to tourism areas. As the massive tourism expansion, water demand owing to the expansion of the tourism industry has increased significantly, diminishing water supply for agriculture. Owing to this, a phenomenon of agricultural abandonment may be occurred.

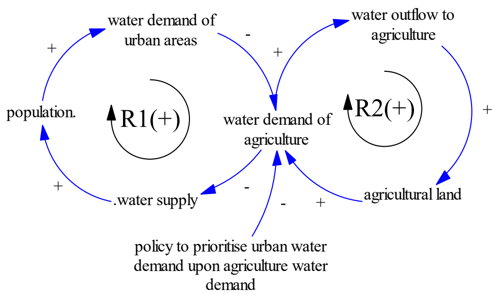


**Fig. A3.** The Success to Successful.

Relationships among water supply, agriculture and tourism are visually described in figure A3. Figure A3 reproduces a system archetype so-called the success to successful archetype. In this situation, tourism or urban areas (R1) and agriculture (R2) competes for the same critical resource: water. Because water demand for urban is prioritized, the expansion of agriculture is suspended, leading to the abandonment of farming land.

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