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D-Moss: Dengue forecasting MOdel Satellite-based System for Vietnam

Endline case study

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Executive summary

The Dengue MOdel forecasting Satellite-based System (D-MOSS) project has developed a scalable, reliable and cost-effective dengue fever forecasting system incorporating Earth Observation (EO) data and seasonal climate forecasts to predict cases of dengue fever on a monthly basis up to six months in advance in Vietnam. The D-MOSS prototype covers the whole of Vietnam and produces dengue forecasts for each of the country's 63 provinces. The project focused on four provinces for Monitoring and Evaluation, capacity building and engagement with local-level end users and communities.

D-MOSS became operational in June 2019. Since then we have been documenting the extent to which the early warning system helps to prevent disease outbreaks and infections. The system demonstrates a clear and positive impact and added value (in terms of efficiency and reliability) with respect to existing programmes. Value adding metrics, such as the number of people reached and early evidence of a reduction of new infections in the pilot areas are included in this report. Technological, administrative and social aspects are also analysed. The operational potential and added value of the D-MOSS solution is discussed.

Established links with local/national health systems are a critical aspect of this project, and as such, evidence of appropriate cooperation with existing control programmes in the pilot areas, together with evidence of effective communication, promotion and local involvement is presented.

The forecasts of dengue outbreaks provided by D-MOSS have helped the Vietnamese Government to implement early actions at community, district and national scales, depending on the forecast lead time, as shown in Figure 1.

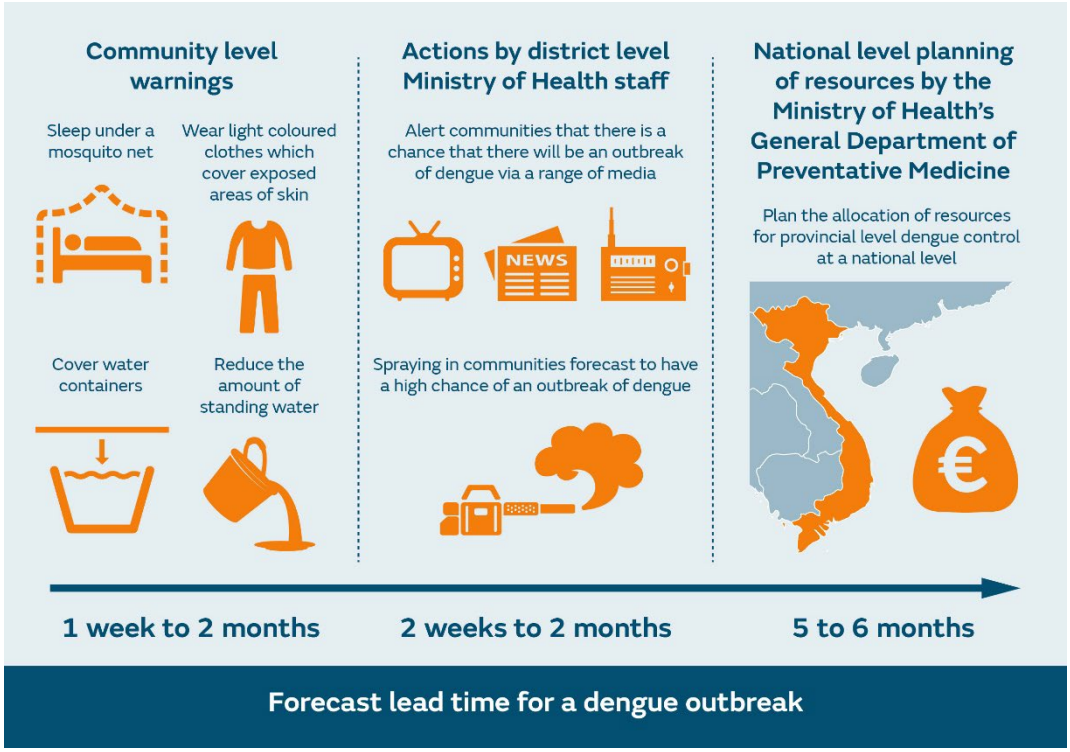

Figure 1: Early actions which can be put in place to prevent a dengue outbreak at different spatial scales for the different forecast lead times provided by D-MOSS

The key Vietnamese stakeholders (Box 1) have all expressed the need for an operational system to allow them to forecast dengue outbreaks as many months in advance as possible, allowing them and communities to proactively plan in advance for dengue outbreaks. D-MOSS has helped to fill this gap.

Box 1 Key stakeholders in Vietnam

The General Department of Preventative Medicine (GDPM) is the Vietnamese Ministry of Health department that is responsible for prevention and control of communicable and non-communicable diseases. GDPM is responsible for dengue surveillance and control in Vietnam.

Under GDPM, the four following institutes oversee the prevention and control of dengue fever in different regions of Vietnam: **the National Institute of Hygiene and Epidemiology (NIHE); the Tay Nguyen Institute of Hygiene and Epidemiology (TIHE); the Pasteur Institute in Ho Chi Minh City (PIHCMC); and the Pasteur Institute in Nha Trang (PINT).** These four institutes also lead the community data collection activities for dengue in different parts of Vietnam and are key partners for testing D-MOSS, as well as ensuring the key stakeholder requirements are met.

D-MOSS is piloted in four provinces (Hanoi, Khanh Hoa, Dak Lak and Dong Nai). Key stakeholders from the pilot provinces include Dengue prevention and control officials from the **Centres of Disease Control (CDC)** and officials from the **Provincial Departments of Health**.

Value adding metrics

Table 1 presents a summary of some key value adding metrics.

Table 1: Comparison of the agreed M&E indicators between March 2018 and November 2021

Indicator	Baseline in March 2018	Result at review November 202`
Number of trained government officials with improved understanding of the drivers of dengue outbreaks	0	65
Number of knowledge sharing products accessed and downloaded from a project or related website	0	102
Number of people within government health authorities accessing forecasts on the portal	0	65
Number of dengue forecasts produced to support prevention of dengue outbreaks	0	30
Number of organizations with staff members trained	0	13
National dengue guidelines revised to include D-MOSS as a dengue control tool	Not applicable	Yes

Whist it is difficult to assess the impact on dengue incidence over the project timescales and rigorous scientific justification is required, the dengue incidence observations in Table 2 have been made in the pilot provinces which may provide an early indication that D-MOSS is having an impact.

Table 2: Comparison of incidence rates in pilot provinces

Pilot province	Incidence rate (average of 2011 to 2015)	Incidence rate November 2021
Dak Lak	105.2	35.2
Dong Nai	191.6	127.5
Hanoi	7.3	7.2
Khanh Hoa	392.0	192.7

Proven use of results

D-MOSS is now supporting budget planning processes and dengue prevention and control: Since D-MOSS became operational in June 2019, stakeholders have reported that "*D-MOSS helps us to proactively develop action plans, develop budget estimates, and prepare chemicals and equipment needed to address dengue outbreaks"* (**CDC Khanh Hoa**) and that it "*provides us with more information to advise disease prevention and control committees at various levels. It informs our annual disease prevention and control plans"* (**CDC Hanoi).**

D-MOSS has changed Vietnam's reactive approach to dengue prevention to a more proactive one: Historically, the management of dengue in Vietnam has been largely reactive. A response to dengue was triggered when there was a high chance of outbreaks and was tied to the number of reported cases. Since D-MOSS became operational, stakeholders have reported that "*the D-MOSS forecast informs prevention and control plans and interventions in advance, before outbreaks happen or dengue fever cases increase*" (**CDC Khanh Hoa).** The **Pasteur Institute Nha Trang** has stated that "*D-MOSS provides scientific information to inform dengue prevention and control plans and budget estimates, so these plans can become more practical and feasible*." **CDC Dong Nai** stated that the "*D-MOSS system helps Dong Nai CDC to predict dengue situation in the province and nationwide in advance. It helps Dong Nai CDC to prepare and be ready to implement dengue prevention measures*".

Conclusions

Proactive approaches to dengue control are commonly underfunded and as a result poorly executed. The use of accurate and affordable early warning systems for dengue, such as D-MOSS, helps to engender proactive approaches from national government to community levels.

The application of D-MOSS in Vietnam has confirmed that it provides suitably accurate forecasts of dengue, (i.e. 90% accuracy for an outbreak one month in advance and 70% accuracy for an outbreak six months in advance), and is a reliable and cost-effective solution to help stakeholders take early actions.

D-MOSS's architecture and modular design help to ensure it can be replicated in other countries and at a range of scales, be that in South-East Asia or other countries around the world. Owing to its success in Vietnam, prototype D-MOSS systems are being implemented in Malaysia and Sri Lanka.

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1 Introduction

1.1 Description of the problem

Dengue is a mosquito-borne viral disease that has rapidly spread in recent years. In 1970 only nine countries suffered dengue epidemics. Today over 140 countries in Africa, America, Eastern Mediterranean, South-East Asia, and Western Pacific have experienced dengue epidemics. A modelling study based on cartographic approaches estimates that 3.9 billion people are at risk of infection with dengue viruses and that 70% of the actual burden of the disease is in Asia. Globally, ~390 million people are estimated to be infected, with ~40,000 people dying each year. Recovery from infection is believed to provide lifelong immunity against that serotype. Symptoms include severe headaches, high fever, nausea, vomiting and full body aches, as shown in Figure 2. Dengue has been classified as a neglected tropical disease, so called because it generally afflicts the world's poor and historically has not received as much attention as other diseases.

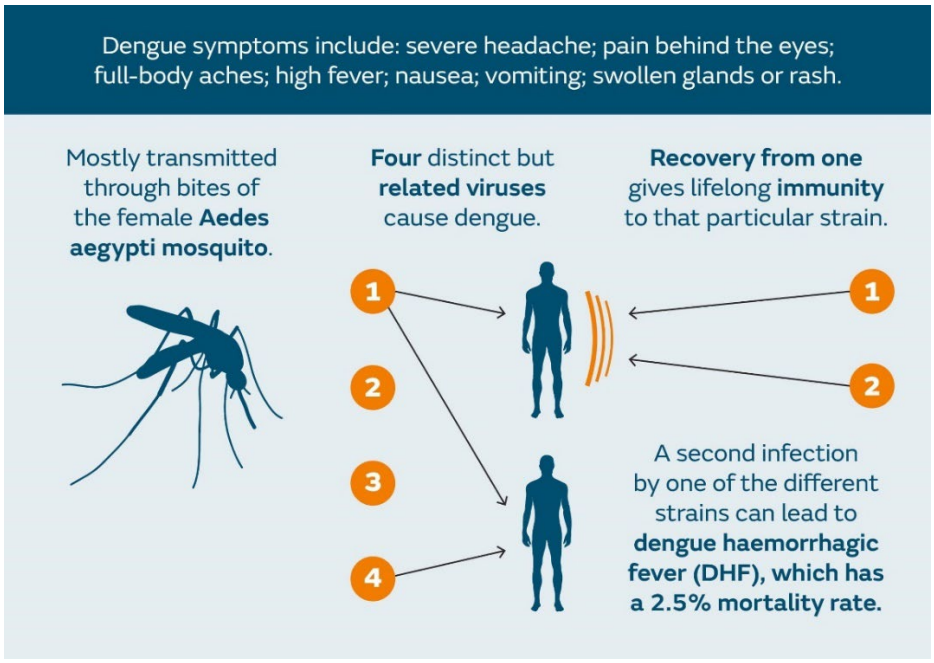

Figure 1.1: Dengue fever symptoms and related viruses

There is no specific antiviral treatment for dengue, and vaccination is restricted to seropositive individuals[1]. Dengue prevention relies on mosquito control measures, which are primarily insecticide-based[2]. The increasing resistance to insecticides highlights the need for targeted and effective interventions[3].

The total global annual cost of dengue fever has been estimated to be almost US$9 billion per year, which exceeds the estimated global annual cost of US$3 billion for cholera and US$2 billion for gastroenteritis[4]. Dengue has been hyperendemic in South-East Asia for decades. Vietnam is particularly affected by dengue with an estimated burden of about two million yearly infections[5]. On average, around 90,000 cases are reported annually to the Vietnamese Ministry of Health, causing a substantial health and economic burden.

[1] World Health Organization, 2018. Background Paper on dengue vaccines. Geneva, Switzerland
[2] Dusfour I, et al. 2019. Management of insecticide resistance in the major Aedes vectors of arboviruses: Advances and challenges. PLoS Negl Trop Dis.; 13:e0007615.
[3] Moyes CL, et al. 2017. Contemporary status of insecticide resistance in the major Aedes vectors of arboviruses infecting humans. PLoS Negl Trop Dis.; 11:e0005625.
[4] Shepard D, et al. 2016. The global economic burden of dengue: a systematic analysis. The Lancet Inf Dis.; 16:935–941.
[5] Bhatt S, et al. 2013. The global distribution and burden of dengue. Nature; 496(7446):504–507.

The most recent studies have estimated that it is responsible for ~40,000 disability-adjusted life years annually, representing an economic burden of ~US$95 million per year (in 2016 prices)[6].

Dengue is endemic in Vietnam, with epidemic cycles that are associated with social determinants such as rapid urbanisation, limited access to basic services, the rapid movement of people and goods, and climate variability and change. Dengue is characterized by strong seasonality and substantial inter-annual and spatial variability. Climatic conditions significantly influence the ecology of dengue. Temperature, for example, regulates the survival, behaviour and distribution of the principal mosquito vector in Vietnam, *Aedes aegypti*[7].

1.2 Community needs

According to a World Health Organization (WHO) report on Dengue Prevention and Control in 2016[8], although significant progress has been made in strengthening regional and country capacities to detect, assess, report and respond to dengue, the Asia Pacific Region has not seen the degree of success expected from the "Dengue Strategic Plan for the Asia Pacific Region 2008-2015"[9]. Limited tools and resources have made it difficult to control dengue and its burden continues to increase. According to the same report, early adoption of new tools, investing in and undertaking the development of new methods and making better use of available interventions (e.g. spraying, community based initiatives such as using mosquito nets) will contribute to mitigating the challenge of dengue.

The existing dengue surveillance system in Vietnam is mostly passive, relying on clinical cases reported by patients seeking healthcare[10]. The reactive nature of dengue control measures means they take place after outbreaks have occurred, hampering the ability of public health professionals to reduce the magnitude and severity of outbreaks. Public health officials and communities need as much advance notice as possible about the likelihood of a disease outbreak in a particular location to widen their range of feasible responses. The needs of key stakeholders and communities in Vietnam are provided in Box 2. For a dengue fever forecasting system to meet the communities' needs, it is important that the system is co-produced with the key stakeholders. In June 2017, before technical work commenced on D-MOSS, two weeks of meetings and workshops were held within Vietnam. The objective was to ensure that the key stakeholders were involved in the co-production of D-MOSS and that the community needs for a dengue forecasting tool in Vietnam were documented and met. Engagement with some 40 key stakeholders including General Department of Preventative Medicine (GDPM), National Institute of Hygiene and Epidemiology (NIHE), Tay Nguyen Institute of Hygiene and Epidemiology (TIHE), Pasteur Institute in Nha Trang (PINT), Pasteur Institute in Ho Chi Minh City (PIHCMC) and WHO indicated that the co-production of a dengue forecasting system, such as D-MOSS, would greatly assist to put timely dengue control and prevention measures in place at a range of spatial and temporal scales, which would significantly help to minimize the burden of the disease.

According to the Vietnamese Ministry of Health, "*global warming, El Niño, uncontrolled urbanisation and migration have hampered dengue prevention efforts*"[11]. WHO has called for a more proactive approach to tackle the disease rather than a response-driven one[12]. Vietnam needs to put appropriate measures in place for preparing in advance for a dengue outbreak. In response to this need, the D-MOSS dengue forecasting

[6] Trinh Manh Hung, et al. 2018. The Estimates of the Health and Economic Burden of Dengue in Vietnam. Trends Parasitol. Oct; 34(10): 904–918. doi: 10.1016/j.pt.2018.07.007
[7] Mordecai, E et al. 2017. Detecting the impact of temperature on transmission of Zika, dengue, and chikungunya using mechanistic models PLoS Negl Trop Dis 11(4): e0005568. https://doi.org/10.1371/journal.pntd.0005568
[8] http://iris.wpro.who.int/bitstream/handle/10665.1/13599/9789290618256-eng.pdf?ua=1.
[9] http://www.wpro.who.int/mvp/Dengue_Strategic_Plan.pdf
[10] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3713821/
[11] http://english.vietnamnet.vn/fms/society/180386/health-ministry-urges-proactive-prevention-of-dengue-fever.html
[12] https://iris.wpro.who.int/handle/10665.1/5528

system prototype developed by this project is already significantly contributing to the country's efforts towards proactively using resources to eliminate the health and socio-economic impacts of dengue.

A need for capacity building was identified by key Vietnamese stakeholders, leading to the extensive knowledge-sharing activities which form an important component of this project. Prior to the project, GDPM in Vietnam have operated a disease early warning centre based on surveillance but ***not*** forecast information. They stated at a meeting in July 2017 that they would be prepared to operate a dengue early warning system based on forecast information.

Box 2 Needs of key stakeholders and communities in Vietnam

At risk communities require information to help them prevent mosquito bites, clear breeding sites from around the home, thereby reducing ongoing transmission, and to seek treatment early to reduce the chance of developing severe disease or death. These actions all reduce ongoing transmission of the disease. Well defined actions based on D-MOSS dengue fever forecasts aid timely provision of this information to communities that require it, enabling them to take these actions proactively instead of simply responding to outbreaks when they occur.

Community and village health workers bring health care as close as possible to where people live and work and constitute the first element of the healthcare process. The forecast information from D-MOSS helps them to provide a more focused response to dengue outbreaks, by providing targeted advice to communities forecasted to be at a high risk.

Local government and health authorities in Vietnam have a responsibility to approve budgets for dengue control measures and to implement measures to control mosquitos. D-MOSS provides these stakeholders with information which assists local authorities to increase the efficiency of their response and target limited resources to those areas most at risk. In addition to making the best use of limited resources, the forecast-driven targeted actions also help reduce overuse of insecticides, maximising effectiveness when they are used.

The WHO, GDPM, PIHCMC, NIHE, TIHE, PINT use the probabilistic dengue forecasting tool, to facilitate the public health response to moderate impending outbreaks in Vietnam. In addition, WHO could facilitate future implementations of D-MOSS in other dengue affected countries worldwide, to also aid longer term planning and budgeting, which is particularly important at this level.

1.3 Targeted geographic areas and their justification

Vietnam covers an area of approximately 331,200 km^2 and has a population of around 95.5 million people. The country is divided up into 63 provinces. The D-MOSS prototype covers the whole of Vietnam and produces dengue forecasts for each of the country's 63 provinces providing the predicted number of dengue cases for each month and for six months into the future. Although D-MOSS produces forecasts for the entire country, the project focused on four provinces for Monitoring and Evaluation, capacity building and engagement with local-level end users and communities. These four pilot areas, see Figure 3 and Box 3, were selected by the Vietnamese Ministry of Health based on their contrasting geographical, climatic, demographic and epidemiological conditions. All four areas are characterised by a high prevalence of dengue cases for their region, good surveillance and case reporting systems.

Figure 1.2: Details of the four pilot areas in Vietnam

Box 3 Brief details of the four pilot areas

Hanoi (population: 8 million), in Northern Vietnam: The municipality of Hanoi covers 3,360 km^2 and has a population density of 2,400 people per km^2. It experiences seasonal dengue outbreaks between July and December, which peak in September/October. Its climate is characterised by cold winters, hot and rainy summers, and annual temperature ranging from 16°C to 29°C. In Hanoi there is more active surveillance, easy access to the healthcare system and increased public awareness compared to the other three provinces. Hanoi is also characterised by large intermittent outbreaks of dengue every few years.

Khanh Hoa (population 1.3 million) in Central Vietnam (South Central Coast region): The annual temperature ranges between 24°C and 29°C. The western part of the province is fairly mountainous and partly as a result of this, only around 16.7% of the province's total area is used for farming. Forests cover more than half of the province. In 2019, Khanh Hoa province recorded almost 12,000 cases of dengue, which is almost twice the average number of cases recorded over the past 10 years.

Dak Lak (population: 2.1 million) in Central Vietnam (Central Highlands region): Of the four pilot areas Dak Lak is the one with the lowest population density (i.e. 160 people per km^2). It is mountainous, with an average altitude of around 600 m above sea level. It is mostly rural in nature. Owing to the higher altitude, temperatures in Dak Lak are lower than the other provinces. Winters are dry, while summers are characterized by high rainfall. The average annual temperature ranges from 21°C to 23°C. A dengue study for Dak Lak found that dengue outbreaks are associated with high temperature, and high relative humidity[13].

[13] https://bmcinfectdis.biomedcentral.com/articles/10.1186/1471-2334-11-172

Dong Nai (population: 3.1 million) in Southern Vietnam: The climate in Dong Nai is strongly influenced by the southwest monsoon, characterized by high temperatures year-round. Mean annual temperatures are around 27°C with little difference between the coldest and hottest months of the year. Dong Nai has a high number of dengue cases every year. Dong Nai suffers regular outbreaks of dengue; however, in 2019 almost 20,000 cases were recorded, which is three times the 10 year average number of cases for the province.

2 D-MOSS implementation in Vietnam

2.1 Demonstrated impacts

The D-MOSS system has been producing dengue forecasts for the whole of Vietnam and is being piloted in four high-risk yet contrasting provinces of Vietnam since June 2019. The four pilot provinces are Hanoi, Khanh Hoa, Dak Lak and Dong Nai. During the prototype field trials, the project team has engaged with key stakeholders from the four pilot provinces, and with national-level stakeholders including the following:

- Dengue prevention and control officials from the Centres of Disease Control (CDC) in the four provinces;
- Officials from the Provincial Departments of Health of the four provinces;
- National Institute of Hygiene and Epidemiology (NIHE), responsible for dengue control in the North of Vietnam;
- Pasteur Institute Ho Chi Minh City (PIHCMC), responsible for dengue control in the South of Vietnam;
- Pasteur Institute Nha Trang (PINT), responsible for dengue control in Central Vietnam;
- Tay Nguyen Institute of Hygiene and Epidemiology (TIHE), responsible for dengue control in the Central Highlands of Vietnam;
- The General Department of Preventive Medicine (GDPM) of the Ministry of Health.

The web-based, prototype D-MOSS early warning system allows beneficiaries, such as the Vietnamese Ministry of Health, to issue regular warnings of likely outbreaks of dengue fever and improve their prevention and control plans. The forecasts of dengue outbreaks provided by D-MOSS have helped the Vietnamese Government to implement early actions at community, district and national scales, depending on the forecast lead time, as shown in Figure 2.1.

2.1.1 Proven use of results

The results of D-MOSS are being used in a number of ways as summarised below.

D-MOSS is now supporting budget planning processes and dengue prevention and control: Budget allocation for dengue control and response in Vietnam is centred around medium term (i.e. five-year) and annual sectoral plans, which are currently based on the likely disease burden for the following years. Data on dengue incidence are collected and analysed as part of this planning process. At sub-national level, the provincial departments of health develop their annual plans, which are submitted to the Provincial People's Committee (i.e. the local Government) and the Provincial People's Council for budget allocation. There is also an additional emergency contingency fund for dengue at the national level. With an increase in dengue cases in 2019 and 2020, district level authorities have had to increasingly request additional resources from the provincial level authorities. According to stakeholders, "*the time required to get additional budget agreed means dengue spreads*". D-MOSS is assisting stakeholders with budget planning, by providing them with long-term dengue forecasts (up to six months in advance). Since D-MOSS became operational in June 2019, stakeholders have reported that "*D-MOSS helps us to proactively develop action plans, develop budget estimates, and prepare chemicals and equipment needed to address dengue outbreaks*" (***CDC***

Khanh Hoa) and that it "*provides us with more information to advise disease prevention and control committees at various levels. It informs our annual disease prevention and control plans" (**CDC Hanoi).***

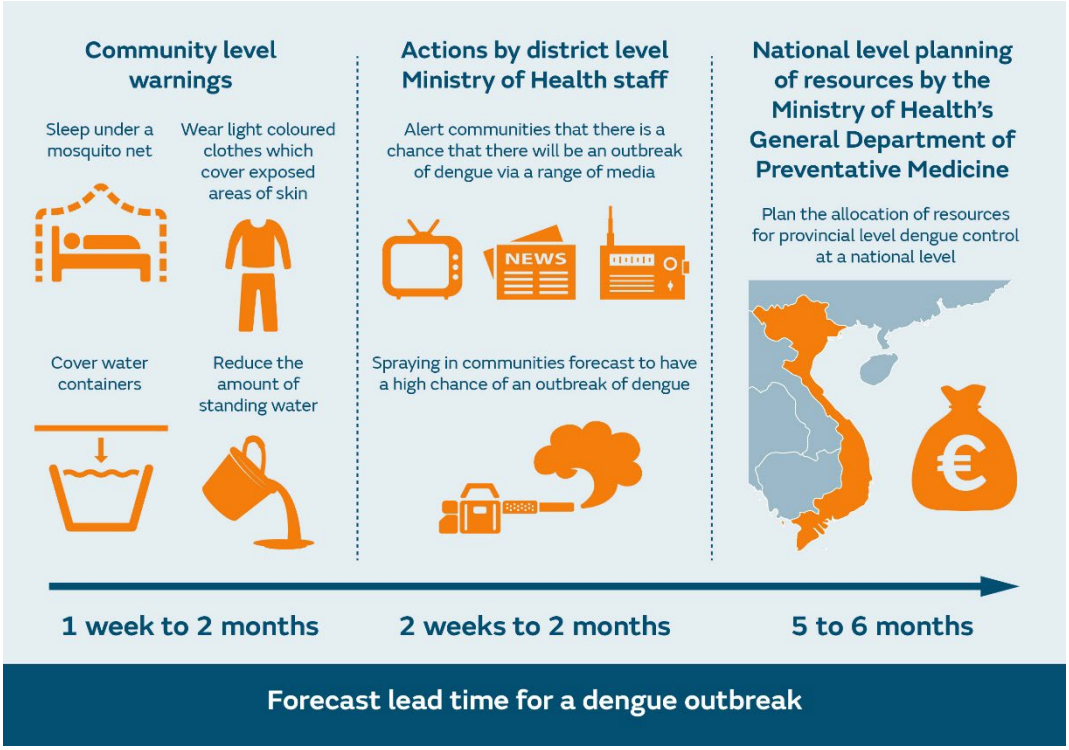

Figure 2.1: Early actions which can be put in place to prevent a dengue outbreak at different spatial scales for the different forecast lead times provided by D-MOSS

D-MOSS has changed Vietnam's reactive approach to dengue prevention to a more proactive one: Prior to D-MOSS becoming operational, and according to the national dengue guidelines, a response to dengue was triggered when there was a high chance of outbreaks and was tied to the number of reported cases. These guidelines do not cover preventive action in high-risk areas. The main approach to forecasting employed by the authorities was to look at risk factors to inform expectations concerning likely outbreaks. Historical data on incidence from recent years' outbreaks and cyclical patterns, and data generated by vector and virus surveillance activities were used to inform expectations concerning outbreaks during the next period. During a series of interviews and workshops held in 2017 and 2018, stakeholders noted that the dengue surveillance system they had in place did not forecast outbreaks or epidemics. Because of the delays between a person being infectious and being correctly diagnosed and reported, these reactive responses were frequently too late to prevent onwards transmission and therefore often insufficient to prevent an outbreak. **Historically, the management of dengue in Vietnam has been largely reactive**.

Since D-MOSS became operational, stakeholders have reported that "the D-MOSS forecast informs prevention and control plans and interventions in advance, before outbreaks happen or dengue fever cases increase" (**CDC Khanh Hoa).** The Pasteur Institute Nha Trang has stated that "D-MOSS provides scientific information to inform dengue prevention and control plans and budget estimates, so these plans can become more practical and feasible." CDC Dong Nai stated that the "D-MOSS system helps Dong Nai CDC to predict dengue situation in the province and nationwide in advance. It helps Dong Nai CDC to prepare and be ready to implement dengue prevention measures".

D-MOSS is helping the Vietnamese Ministry of Health to meet Sustainable Development Targets: Vietnam's Sustainable Development Strategy for 2011-2020[14] aimed to "timely and effectively control

[14] http://dsi.mpi.gov.vn/vietnam2035/en/3/50.html

epidemic diseases, early detect and timely cure diseases". One of the major tasks identified in Vietnam's five-year health sector development plan (2016-2020)[15], issued by the Ministry of Health, was "To actively prevent epidemics; to forecast, detect early and prevent the occurrence of epidemics, especially major ones". One of the key tasks identified in Vietnam's previous health sector development plan (2011-2015)[16], was "to develop an early warning system, rapid response; active epidemiological surveillance to prevent epidemic outbreaks". In terms of dengue fever, this target was not achieved on time but the D-MOSS project has contributed significantly towards its realisation.

To capture the extent to which D-MOSS is helping to prevent dengue outbreaks in Vietnam, a number of surveys and workshops were undertaken with key stakeholders. The surveys were internet-based and distributed via the Ministry of Health. Stakeholders' responses were anonymised and they could respond in Vietnamese. Stakeholder responses to-date have clearly demonstrated the impacts D-MOSS has had and how the D-MOSS forecast results have been used to help prevent disease outbreaks and infections. Some of the key messages received by stakeholders are shown in Table 2.1 below.

Table 2.1: Responses to "how does the D-MOSS forecast help you control dengue fever?"

How does the D-MOSS forecast help you control dengue fever?
CDC Dak Lak: *It helps us to proactively develop action plans, provide specific and accurate advices to local authorities and implement preventive measures.*
CDC Khanh Hoa: *The forecast informs prevention and control plans and interventions in advance, before outbreaks happen or dengue fever cases increase. The system helps localities to keep up with the development of the dengue fever situation, to proactively develop prevention and control plans (on required chemicals, equipment, and budget), and to implement the necessary measures to prevent dengue outbreaks (for example, by increasing the frequency of vector control and chemical spraying).*
CDC Dong Nai: *The D-MOSS system helps the Dong Nai CDC to predict the dengue situation in the province (and nationwide) in advance. It helps the Dong Nai CDC to prepare and be ready to implement dengue prevention measures.*
CDC Hanoi: *It provides us with more information to advise disease prevention and control committees at various levels. It also informs our annual disease prevention and control plans.*
National Institute of Hygiene and Epidemiology: *We use the D-MOSS forecasts to identify areas that need to be prioritized and take action to reduce the number of cases and prevent outbreaks. D-MOSS forecasts help us not waste resources for provinces with low predicted cases.*
Tay Nguyen Institute of Hygiene and Epidemiology: *The forecast helps to identify high risk areas for dengue outbreak and to guide our response plans in those high risk areas.*
Pasteur Institute Nha Trang: *D-MOSS provides scientific information to inform our dengue prevention and control plans and budget estimates, so these plans can become more practical and feasible. We receive the forecast information and study the predicted number of cases suggested by the forecasts. We send warnings to relevant areas so that they can proactively develop plans, including mosquito control plans and surveillance plans. We can now predict and compare the number of dengue cases across provinces. We can proactively strengthen our surveillance activities. We can proactively prepare resources and D-MOSS informs our response plans.*
Pasteur Institute Ho Chi Minh: *The forecast helps to proactively implement interventions in high-risk areas.*

During the prototype field trials we documented the extent to which the D-MOSS early warning system helps to prevent dengue outbreaks. Four case study field trial briefs (from the North, South, Central Highlands and Central Vietnam) summarize the impacts and prove the use of results from the early warning system. These field trial briefs are shown in Annex A (Figures A1, A2, A3 and A4). It is important to note that although the field trials of D-MOSS concentrated on four provinces, D-MOSS has provided forecasts of dengue cases for each of Vietnam's 63 provinces since June 2019, so there is potential for the dengue forecasts to impact the entire population (~95.5 million people).

[15] http://www.euhf.vn/upload/Strategic%20documents/82.%20MOH%205-year%20plan%20(Eng).pdf
[16] https://www.uhc2030.org/fileadmin/uploads/ihp/Documents/Country_Pages/Vietnam/VietnamHealthPlan2011-2015.pdf

2.1.2 Value adding metrics

As part of the implementation of D-MOSS, independent Monitoring and Evaluation (M&E) of the work was carried out by M&E experts at OPM. As part of the M&E, OPM carried out a baseline M&E study in March 2018 and then a review of the project in the period September 2020 to November 2020. At the outset of the work, a Logical Framework (logframe) was put in place. A logframe is a planning tool consisting of a matrix which provides an overview of a project's goal, activities and anticipated results. It provides a structure to help specify the components of a project and its activities and for relating them to one another. As part of the review carried out by OPM, data collection activities focused on measuring progress against a number of logframe indicators, using a combination of secondary sources when pertinent and available, as well as primary data collected during field missions to Vietnam and by Vietnamese M&E experts employed by OPM to carry out this task. Table 2.2 presents a summary of some key value adding metrics.

Table 2.2: Comparison of the agreed M&E indicators between March 2018 and 30 November 2021

Indicator	Baseline in March 2018	Result at review November 2021
Number of trained government officials with improved understanding of the drivers of dengue outbreaks	0	65
Number of knowledge sharing products accessed and downloaded from a project or related website	0	102
Number of people within government health authorities accessing forecasts on the portal	0	65
Number of dengue forecasts produced to support prevention of dengue outbreaks	0	30
Number of organizations with staff members trained	0	13
National dengue guidelines revised to include D-MOSS as a dengue control tool	Not applicable	Yes

Whist it is difficult to assess the impact on dengue incidence over the project timescales and rigorous scientific justification is required, the dengue incidence observations in Table 2.3 have been made in the pilot provinces which may provide an early indication that D-MOSS is having an impact.

Table 2.3: Comparison of incidence rates in pilot provinces

Pilot province	Incidence rate (average of 2011 to 2015)	Incidence rate November 2021
Dak Lak	105.2	35.2
Dong Nai	191.6	127.5
Hanoi	7.3	7.2
Khanh Hoa	392.0	192.7

2.2 Level of cooperation with existing control programmes

2.2.1 Evidence of appropriate cooperation with existing control programmes in the demonstration areas

Overview of the existing control programmes in the four pilot areas

Vietnam's National Dengue Control Programme was established in 1999, and the Vietnamese Government funds allocated for this programme range from US$1 million to US$5 million per year, excluding the contributions made by local governments. In 2016, governments of the WHO's Western Pacific Region, including Vietnam, adopted an action plan for dengue prevention and control that provides strategic guidance to transition from containment of outbreaks to reducing the impact of dengue on communities and health systems. In Vietnam, dengue surveillance and response activities are guided by the *National*

Guideline on Dengue Surveillance, Prevention and Control, which was issued in 2014, and is aligned with the WHO regional plan.

Participation in coordinated local community organisations is popular in many parts of Vietnam. The local dengue control programmes are carried out by communal health workers, paid health-collaborators, and school teachers and pupils who carry out dengue control initiatives such as inspecting houses and collecting discarded water containers which can act as mosquito breeding sites. No national action plans have been made yet for dengue prevention and control since 2016. In addition, little involvement of other sectors regarding dengue control takes place in Vietnam. This is highly needed considering that the 2017 outbreak showed a lack of resource and human capacity, low efficiency, lack of management and leadership at lower levels and lack of maintaining regular and continual epidemic control activities.

Demonstration of D-MOSS cooperation with existing control programmes

D-MOSS is being integrated into existing surveillance activities: In line with the WHO "Regional Action Plan on Dengue Prevention and Control for the Western Pacific", D-MOSS has enabled WHO to support the surveillance of adult mosquitoes by using Gravid *Aedes* Traps (GAT) and other methods as part of a citizen science initiative. GATs have been distributed to selected households in the four provinces where D-MOSS is piloted, and mosquito density is monitored on a weekly basis. This activity has been supported by Government implementing partners (NIHE, TIHE, and the two Pasteur Institutes). Field information is also collected on dengue virus subtypes, to optimize the forecasting capacity of dengue outbreaks and associated morbidity, and to serve for monitoring and evaluation of the early warning system. Whilst the GAT vector monitoring system is separate from D-MOSS, once sufficient data is collected (over a period of five years), results from the adult mosquito surveillance programme will be used as an additional input to the model. Collection of GAT trap data is shown in Figure 5.

Prior to D-MOSS, dengue officers from the four pilot provinces had to determine the level of dengue risk themselves, but now each Provincial Health Official can quickly see the risk profile of their area for each month, up to six months in advance using results from the D-MOSS forecasts. If D-MOSS indicates a high risk then they use this as a reference guide to conduct an official risk assessment based on the Ministry of Health framework to identify the hotspots of outbreaks at district and commune levels. This highlights both D-MOSS's relevance and practical use to help to target critical resources and to facilitate early action to control and manage dengue outbreaks.

Figure 2.2: WHO and Dong Nai CDC staff supervising the collection of dengue data from GAT traps during a visit to Dong Nai province as part of a citizen science initiative

D-MOSS is helping address key challenges of dengue prevention and control: During the project's Monitoring and Evaluation (M&E) baseline survey of 2018, stakeholders reported a number of challenges including the difficulties in predicting dengue outbreaks, the scale of dengue outbreaks and the fact that existing dengue control systems are reactive rather than proactive. D-MOSS is now helping alleviate some of these challenges, as according to the Tay Nguyen Institute of Hygiene and Epidemiology it helps stakeholders to *"identify dengue outbreak prone areas, prepare resources for proactive responses and guide response plans in those high risk areas."* The National Institute of Hygiene and Epidemiology is reporting that *"having access to the predicted number of cases for 3 months and 6 months ahead, helps inform short-term and long-term plans. Forecasts generated for each province are also very helpful for managing activities."*

2.3 Level of communication, promotion and involvement at local level

D-MOSS was co-produced in partnership with a number of key stakeholders who are responsible for dengue control and prevention in Vietnam. Partners who are key to local-level communication, promotion and engagement in different regions of Vietnam are shown in Box 1 (Executive Summary).

User engagement has been a priority from the outset and critical in the successful co-development of a demand-driven prototype D-MOSS system. The Vietnamese Ministry of Health in partnership with WHO and UNDP led this engagement which took the form of workshops, semi-structured interviews and surveys at regular intervals.

The level of communication, promotion and involvement of local level stakeholders in the project was assessed by an independent "endline" Monitoring and Evaluation (M&E) exercise which was carried out by Oxford Policy Management which was completed in December 2021. As part of this endline M&E exercise, local-level stakeholders were interviewed and asked to provide feedback on the D-MOSS performance and their involvement in the project to date. To collect this information, key informant interviews and focal group discussions were conducted in Vietnam with various National, Provincial and District Ministry of Health staff, communities, regional research institutes and international partners. An overview of some of the endline M&E feedback are provided in Table 6, and in the following paragraphs of this section.

Table 2.4: Responses to the relevance of the information presented on the D-MOSS interface

Responses from different levels of stakeholders
National authorities and end users: All of the respondents to the endline M&E evaluation were impressed and happy with the D-mOSS web interface. In its current form it provided the right amount of information that can easily be interpreted by trained technical staff at both Provincial and District level. Specific feedback included "*The model is easy to use, the website is not complicated, see how many cases are coming next month, the data is intuitive, vivid… It is easy to access, access on many tools such as computers, tablets, phones..., tools are diverse, easy access, fast speed, just need to have internet to open', whilst 'the dashboard also makes it easy for viewers to follow. Maps and charts with forecast data presented in the form of data tables also help to have more specific bases for forecasts. The software has more instructions and definitions of specific variables, so it is convenient to look up and interpret the forecast results obtained by the software on the Technical Information tab*".
Provincial authorities: Positive feedback was provided about the interface, especially the colour coding, which simplifies that forecasted prevalence of the Province; blue districts (no epidemic), orange districts (average epidemic), and red districts (outbreaks). The new version (2021) for the provincial level was reported to be much better than the old one, being more intuitive, vivid in colour, whilst giving percentile lines that were quite close to reality. The new version was also said to be more streamlined and more convenient to use, having to just click on the top bar to check any information they required.
District level authorities: Overall, the districts interviewed reported that they are not currently using the D-MOSS website.

Endline M&E activities looked at how D-MOSS had strengthened the capacity of different stakeholders to forecast and respond to dengue outbreaks. A summary of the responses from the endline M&E report is provided below.

National level authorities and end users:

D-MOSS has led to an improved capacity to forecast dengue incidence, as well as the capacity to monitoring for mosquitos. Regional Institutes said that for those districts selected as pilots to deploy vector monitoring as part of the D-MOSS project, the quality of vector monitoring has improved. Whilst, furthermore, Provincial leaders within the health sector are paying more attention to the quality of vector monitoring data in terms of staff training and the quality of mosquito catching equipment. The leaders of these authorities are also paying more attention to dengue forecasts, and that their response to dengue prevention and control has also improved.

Authorities said that budget planning has improved because of the six month forecasts provided by D-MOSS, strengthening their capacity to effectively allocate resources. Examples of this included the regional and national health institutes (e.g.; Pasteur Institutes, NIHE & TIHE) responding to the D-MOSS forecasts with advanced preparation of funds and purchase of chemicals for spraying, as well as sending teams to Provinces with high percentile forecasts to monitor for signs of the disease. Health authorities are no longer dependent upon assessing historical prevalence of cases to define hotspots for dengue, but can now plan ahead based upon D-MOSS forecasts.

Regional Institutes said that the ability to access forecasts directly from D-MOSS and assess the risks of an outbreak using the interfaces graphs and diagrams reduced the need for them to have to undertake extensive manual calculations to assess risk factors, and improved their capacity to communicate these risks.

Provincial level authorities and end users:

The Provincial leaders in the endline M&E all highlighted how D-MOSS had been used at the CDC to support prevention and control activities, specially to make a response plan and present evidence to the Peoples Committee for budget allocation. Leaders also stated that budget allocation was more efficient using D-MOSS that the under the national program without D-MOSS. These comments referred to the targeted use of human and resources to undertake prevention and control activities in advance of outbreaks as a response to D-MOSS forecasts.

Technical officers from all four provinces referenced the use of D-MOSS in their improved capacity to forecast dengue outbreaks and more importantly, the use of D-MOSS forecasts in influencing the decisions of provincial and district leaders to undertake preventative action and control the spread of mosquitoes and larvae through focused spraying. D-MOSS forecasts and integrated into monthly presentations to Provincial and District leaders alongside the use of monthly data from existing software to corroborate the accuracy of the previous Dengue forecasts.

Regarding data quality, technical officers said that D-MOSS had also helped them to identify shortcomings in the province's M&E systems highlighting the need to collect more accurate information, and systematically store for use when needed.

3 Conclusions

The WHO currently classifies 20 diseases and conditions as Neglected Tropical Diseases (NTDs). Dengue is one of only three mosquito-borne diseases classified by the WHO as NTDs. On 28 January 2021 WHO launched its road map for NTDs entitled ‘Ending the neglect to attain the Sustainable Development Goals: a road map for neglected tropical diseases 2021–2030’. In this document, dengue is targeted as a NTD which

needs to be controlled with an aim of reducing the disease's fatality rate to 0% by the year 2030. Historically work on dengue has been under-funded[17].

Climate change alters the epidemiology of vector-borne diseases and the spread of NTDs. In addition, insecticide resistance is an emerging threat for dengue, especially in view of the widespread use of insecticides for vector control. These challenges highlight the importance of new and innovative approaches to NTDs, such as dengue. Proactive approaches to dengue control are commonly underfunded and as a result poorly executed. The use of accurate and affordable early warning systems for dengue, such as D-MOSS, helps to engender proactive approaches from national government to community levels.

The application of D-MOSS in Vietnam has confirmed that it provides suitably accurate forecasts of dengue, (i.e. 90% accuracy for an outbreak one month in advance and 70% accuracy for an outbreak six months in advance), and is a reliable and cost-effective solution to help stakeholders take early actions. The endline M&E report found that D-MOSS was very relevant to the needs of National authorities and end users in Vietnam and that its relevance grew over the life of the project. The report also found that there has been a positive impact from the use of D-MOSS forecasts informing dengue preventive actions and budget planning at provincial level in all provinces. In addition, there has been significant potential and positive impact of D-MOSS on national policy and plans for dengue prevention and control in Vietnam.

D-MOSS is now being rolled out across all 63 provinces in Vietnam and at the same time, district-level forecasts are introduced into 62 districts of four pilot provinces. The national dengue guidelines have been updated to recommend usage of D-MOSS for dengue prevention and control, which is a big step towards sustainability.

Scalability and replicability considerations have been incorporated from the outset of the project. D-MOSS's architecture and modular design help to ensure it can be replicated in other countries and at a range of scales, be that in South-East Asia or other countries around the world. Owing to its success in Vietnam, prototype D-MOSS systems are being implemented in Malaysia and Sri Lanka.

[17] Warkentien, T. & Pavlicek, R. Dengue fever: Historical perspective and the global response, J Infect Dis Epidemiol 2016, 2:015 Volume 2 Issue 2

Appendices

A Case study briefs

Why D-MOSS works for me

D-MOSS

Name: Dr Vu Trong Duoc

Position: Deputy Director of the Department of Medical Entomology and Zoology, National Institute of Hygiene and Epidemiology (NIHE), Vietnam.

Role description: As secretary of the Dengue Prevention and Control Programme for the Northern region of Vietnam, I am in charge of planning and executing dengue prevention and control activities.

D-MOSS end users at the NIHE

How do I use D-MOSS?

At NIHE, we use D-MOSS as an early warning system and its forecasts as a reference for early prevention and control activities against dengue outbreaks.

"D-MOSS has helped policy-making officials to develop dengue prevention and control strategies in advance of an outbreak."

How has D-MOSS made a difference?

Policy making
We are beginning to see that D-MOSS has helped policy-making officials to develop dengue prevention and control strategies in advance of an outbreak, and to contribute to reducing dengue cases and mortality rate.

Coordination
D-MOSS is useful in discussions with relevant officials in charge of dengue prevention and control. NIHE, together with the Centre of Disease Control and Prevention in Nghe An and a spraying equipment company have used the results of D-MOSS to improve their cooperation and to implement dengue prevention activities.

Localised response
We recently used D-MOSS to support the prediction of the dengue situation in the Nghe An province. The model told us that there was a higher probability of dengue outbreaks, compared to that of other provinces. This meant we were able to take the appropriate responses such as larvae killing, environmental cleaning and chemical spraying. We also encouraged strong participation of local governments and allocated more chemicals for the area.

Future planning
D-MOSS also showed a high probability of dengue outbreaks in July, August and September 2020 in Nghe An. Accordingly, we are going to organise training on entomological surveillance and use of spraying equipment for district officials.

"D-MOSS is useful in discussions with relevant officials in charge of dengue prevention and control."

How will I use D-MOSS in the future?

We are looking forward to using the forecasts in the next version of D-MOSS as a reference for dengue early prevention and control efforts.

BE-107-1 R1

Figure A.1: How D-MOSS helps to prevent dengue outbreaks in the North of Vietnam, field trial brief from the National Institute of Hygiene and Epidemiology

Why D-MOSS works for me

D-MOSS

Name: Dr Do Kien Quoc

Position: Dengue control officer, Disease Prevention and Control Department, Pasteur Institute of Ho Chi Minh City, Vietnam.

Role description: I prepare the data used by D-MOSS, track forecasts and help make dengue control plans.

D-MOSS end users in Ho Chi Minh City

How do I use D-MOSS?

I collect data from the case surveillance system and from the field, clean the data and undertake statistical analysis, before the information is uploaded to D-MOSS. When the D-MOSS forecasts are produced, I send warnings to areas with high dengue risks.

"D-MOSS is easy to use and has a user-friendly interface."

How has D-MOSS made a difference?

Usability

D-MOSS is easy to use has a user-friendly interface and it's really simple to prepare data for D-MOSS, making data collection trouble-free at all levels.

Proactivity

Thanks to D-MOSS forecasts, which are issued up to six months in advance of an outbreak, provinces were able to proactively prepare comprehensive and meaningful actions, responses and interventions.

Graphics

Maps allow us to see the distribution of dengue and anticipate the risk of the disease spreading to other provinces. Charts help us to anticipate dengue cases by month and by province in the next six months.

"D-MOSS enables provinces to proactively prepare comprehensive and meaningful actions, responses and interventions."

BE-107-2 R1

Figure A.2: How D-MOSS helps to prevent dengue outbreaks in the South of Vietnam, field trial brief by the Pasteur Institute Ho Chi Minh City

Why D-MOSS works for me

D-MOSS

Name: Dr Pham Ngoc Thanh

Position: Deputy Director of the epidemiology department, Tay Nguyen Institute of Hygiene and Epidemiology (TIHE), Vietnam.

Role description: I plan and direct dengue response activities in the Central Highland region of Vietnam.

D-MOSS end users at TIHE

How do I use D-MOSS?

We use the D-MOSS dengue forecasts and early warnings to help develop relevant and effective dengue response plans and actions.

"Using D-MOSS has… helped reduce the number of dengue cases and mortality rate."

How has D-MOSS made a difference?

Reducing cases and mortality

Using D-MOSS to help develop action plans, take dengue response actions, make recommendations and issue warnings has helped to reduce the number of dengue cases and mortality rate.

Usability

The system includes graphics that allow us to track the trends in our area and there is a map to help us to understand the situation in neighbouring provinces.

Coordination

D-MOSS improves coordination and timely decision making at regional and provincial level.

Integration

We have combined D-MOSS outputs with information collected by our existing procedures for dengue control.

Taking action

We are beginning to see D-MOSS supporting us to bridge the gap between early warning and early action. D-MOSS helps by engaging health officials and decision makers on a shared platform that is linked to follow-up action.

"D-MOSS is helping bridge the gap between early warning and early action."

BE-107-3 R1

Figure A.3: How D-MOSS helps to prevent dengue outbreaks in the Central Highlands of Vietnam, field trial brief from the Tay Nguyen Institute of Hygiene and Epidemiology

Why D-MOSS works for me

D-MOSS

Name: Dr Nguyen Thanh Dong

Position: Head of Dengue office, Pasteur Institute of Nha Trang.

Role description: Heading up the Department for Entomology and Quarantine, at the Pasteur Institute of Nha Trang, I am responsible for planning, research and assessment of dengue, zika and vector-borne diseases in 11 provinces in the central region of Vietnam.

End users at the Pasteur Institute of Nha Trang

How do I use D-MOSS?

We analyse and evaluate the differences between the data from D-MOSS forecasts with actual data retrieved from the electronic Communicable Disease Surveillance software.

This allows us to predict cases up to six months in advance and report forecasts to different cities and provinces. D-MOSS also helps us implement surveillance and response activities.

"D-MOSS's accurate forecasts have helped us to save resources."

How has D-MOSS made a difference?

Case monitoring

We can now be proactive in our management of dengue. We have been able to identify districts and towns with potentially high numbers and increased case monitoring by escalating surveillance in hospitals and communities.

Resource allocation

D-MOSS's accurate forecasts have helped us to save resources. It allows us to order the right levels of chemicals and equipment in advance with more certainty and we can now make requests to the Pasteur Institute months in advance.

Communications

Communications campaigns at a community level are also important to reduce dengue and we can now plan these in advance.

Budgeting

We can now ask for budget allocation based on the number of predicted cases.

Coordination

D-MOSS improves the coordination and monitoring of dengue outbreaks and incidence between different levels (national and provincial level).

Accuracy

Using the forecasts since January 2020, we have found that D-MOSS forecasts are fairly accurate. The forecasts for Binh Thuan, Ninh Thuan and Quang Tri provinces are very accurate.

D-MOSS's accurate forecasts have helped us to save resources in some areas (for example in Ninh Thuan Province). This evidence-based decision-making on resource allocation and dengue prevention, which is underpinned by D-MOSS, is very valuable for staff working in areas with high dengue risk.

BE-107-4 R1

Figure A.4: How D-MOSS helps to prevent dengue outbreaks in Central Vietnam, field trial brief from Pasteur Institute Nha Trang

B The D-MOSS early warning system

B.1 Objectives

The objectives of the D-MOSS system were to:

- Produce a fully integrated, operational, reliable, scalable dengue fever forecasting system incorporating EO data, seasonal climate forecasts and in-situ data, to issue forecasts every month up to six months in advance covering each of Vietnam's 63 provinces;
- Meet the needs of communities and key stakeholders in Vietnam (see Box 1), by providing warnings of likely dengue outbreaks up to six months in advance;
- Play a part in reducing the overall disease burden caused by dengue in Vietnam.

B.2 Overview of the concept used in D-MOSS

Overarching concept

The effect of climate fluctuations on dengue vector populations and vector-virus interactions can lead directly to variations in the intensity of dengue transmission. These climate-driven variations in risk interact with other factors such as demographic and socio-economic conditions that can alter the local disease prevalence significantly. If these factors can be monitored and predicted then this allows outbreaks of dengue to be forecasted[18].

D-MOSS comprises a climate-driven dengue forecasting system, co-designed with stakeholders from the Vietnamese Ministry of Health, WHO and UNDP. The D-MOSS system provides probabilistic monthly forecasts of the number of dengue cases for the whole of Vietnam at a provincial level using Bayesian statistical models, which utilise seasonal climate forecasts and big EO data on meteorology and socio-economic factors.

Relationship between climate variables and dengue

Weather conditions strongly influence the abundance of the dengue virus mosquito vector[19]. The effects of climate upon dengue can be either immediate (e.g. increases in temperature result in higher biting rates) [20], or delayed (e.g. rainfall creates new egg-laying habitat that increases the size of the mosquito population two to three weeks later). Hence, when modelling dengue, the time lag between changes in the climate system and elements of the ecology of the disease, which lead to dengue, should be considered[21].

Relationship between socio-economic factors and dengue

Increasing urbanisation is thought to have contributed significantly to increases in dengue incidence. Urban areas contain higher densities of susceptible human hosts, the built environment creates favourable breeding habitats for *Aedes aegypti*, and increasing population connectivity in cities can facilitate the spread of dengue[22]. Furthermore, unplanned urban development is usually accompanied by overburdened water

[18] Lowe, R. et al. 2017. Climate services for health: predicting the evolution of the 2016 dengue season in Machala, Ecuador, Lancet Planetary Health, Vol 1 Issue 4.
[19] Moreno-Madriñán, M. et al. 2014. Correlating remote sensing data with the abundance of pupae of the dengue virus mosquito vector, Aedes aegypti, in central Mexico. ISPRS Int. J. Geo-Inf. 3, 732–749
[20] Kraemer, M.U.G., et al. 2019. Past and future spread of the arbovirus vectors Aedes aegypti and Aedes albopictus. Nat Microbiol 4, 854–863. https://doi.org/10.1038/s41564-019-0376-y
[21] R. Lowe et al. 2018. Nonlinear and delayed impacts of climate on dengue risk in Barbados: A modelling study. PLoS Med, 15:e1002613.
[22] Salje H, et al. 2017. Dengue diversity across spatial and temporal scales: Local structure and the effect of host population size. Science. 24;355(6331):1302-1306. doi: 10.1126/science.aaj9384. PMID: 28336667; PMCID: PMC5777672.

and sanitation systems that may lead to increased domestic or peri-domestic water storage, providing potential breeding sites for mosquitoes.

Use of big EO data sets

In many countries, including Vietnam, there is paucity of coherent historical ground-based meteorological and other data at a suitable spatial scale, over a sufficiently long period of time, to allow a relationship between these variables and cases of dengue to be formulated. Over the past 20 years, advances in satellite-based technology have created more accessible big data repositories and improved the monitoring of meteorological variables, as well as land use, vegetation and soil indicators. The use of these big EO data time series makes it possible to develop relationships between them and dengue cases, where coherent long-term records of dengue cases are collected, as in Vietnam.

Use of seasonal climate forecasts

Seasonal climate forecasts, which predict meteorological variables from one to six months ahead, can be used to drive dengue forecasting models. The prediction of dengue outbreaks several months in advance can help to reduce the impacts of the disease by improving decision making with regards to the allocation of resources, interventions and advice to communities at risk. Using seasonal climate forecasts and big EO data with patio-temporal statistical models provides a means of quantifying the probability that a future dengue outbreak may occur across times and space up to six months ahead, allowing health professionals and communities to proactively intervene.

B.3 Justification for the methodology

The links between meteorological and socio-economic variables with infectious diseases highlight the potential for developing early warning systems for epidemics, so proactive measures can be put in place to help to prevent or reduce outbreaks of diseases such as dengue. The WHO, the World Meteorological Organization (WMO) and others have encouraged the use of seasonal climate forecasts to manage the increasing burden of dengue as part of comprehensive early warning and response systems for epidemic control and disaster preparedness[23] [24]. Multiple studies have highlighted the potential usefulness of climate-driven epidemiological surveillance for decision-making and planning[25] [26] [27], although there has been limited progress in using seasonal climate forecasting to compute disease forecasts on a routine, operational basis.

There have been a number of dengue forecasting models set up in the past. For example, in Malaysia, Sri Lanka and Colombia multiple time series regression and Auto-Regressive Integrative Moving Average[28] approaches, based on climate variables have been used to develop dengue forecasting models.

The methodology employed by D-MOSS improves on those of other dengue early warning systems by:

- Providing forecasts of dengue for every month up to six months in advance. This was achieved by using seasonal climate forecasts which provide predictions of meteorological parameters with a six month lead time. Many existing dengue models rely on either observed climate data only, or relatively short-term weather forecasts (i.e. less than three months in advance).

[23] Kovats, R. S., et al. 2003. El Niño and health. The Lancet, 362(9394), 1481-1489.
[24] World Health Organization 2005. Using climate to predict infectious disease epidemics.
[25] Lowe R, et al. 2014. Dengue outlook for the World Cup in Brazil: an early warning model framework driven by real-time seasonal climate forecasts. Lancet Plan Health; 14:619–626.
[26] Lauer S, et al. 2018. Prospective forecasts of annual dengue haemorrhagic fever incidence in 591 Thailand, 2010–2014. Proc Natl Acad Sci U S A.; 115::E2175–E2182.
[27] Tompkins A, Di Giuseppe F. 2015. Potential Predictability of Malaria in Africa Using ECMWF Monthly and Seasonal Climate Forecasts. J Appl Meteor Climatol.; 54:521–540.
[28] Eastin M, et al. 2014. Intra- and interseasonal autoregressive prediction of dengue outbreaks using local weather and regional climate for a tropical environment in Colombia. Am J Trop Med Hyg.; 91:598–610.

- Incorporating multiple statistical modelling parametrisations into a “superensemble” within a Bayesian framework. This Bayesian framework allows uncertainty in the probability of a dengue outbreak to be accurately measured when fitting models, and propagated when making future outbreak predictions. Inclusion of multiple statistical models within this Bayesian ensemble framework improves the model’s flexibility and allows it to predict outbreaks with a variety of different causes in different places, and at different times. Public health officials can be more inclined to take action if the probability of observing a dengue outbreak exceeds a certain threshold value[29].
- Including a water availability model which provides predictions of soil moisture and runoff, which are fed into the dengue model. Runoff and soil moisture affect mosquito breeding sites and thus mosquito population size, and ultimately the number of dengue cases.
- Undertaking a rigorous, retrospective and prospective validation procedure that fully quantifies the model’s predictive ability across all provinces of Vietnam, using over 20 years of dengue dynamics.
- Developing the early warning system in partnership with key stakeholders and end users in Vietnam so that it meets the planning and response requirements of the beneficiaries.
- Using software architecture which is modular, meaning that it can be replicated in other countries and at different spatial scales.
- Using a web-based, secure user interface which allows a range of public health staff from national to community level to access and download the dengue forecasts to inform public health decision making.

[29]Lowe R., et al. 2016. Evaluating probabilistic dengue risk forecasts from a prototype early warning system for Brazil. eLife; 5:e11285.

C D-MOSS implementation in Vietnam

C.1 Events organised to showcase the results and impact of D-MOSS

There have been numerous events held both in Vietnam and internationally to showcase D-MOSS. The events specifically targeting the epidemics and vector borne diseases communities are briefly summarised below. Events that target a wider stakeholder community are summarised in Section 3.2.

Events held in Vietnam

July 2019 - D-MOSS Release 1: The first release of D-MOSS was available from June 2019. Following the first release, a series of events were organised by the D-MOSS team. The main objective was to showcase the results of D-MOSS to key national and pilot area beneficiaries on the D-MOSS internet-based platform and to obtain feedback on how D-MOSS could be improved.

November 2019 - D-MOSS Release 1 follow-up events: Additional events were organised in the four pilot provinces in November 2019, to showcase the results and initial impact of D-MOSS. During these workshops, the D-MOSS end users were introduced to the use and limitations of seasonal dengue forecasts and to making decisions under uncertainty. Training was also provided on the D-MOSS software itself; the underpinning science and algorithms; and how to use and interpret the probabilistic dengue forecasts.

January 2020 to April 2020 - D-MOSS Release 2: Following feedback from the pilot provinces and the Ministry of Health, a second release of the prototype was produced in January 2020. This was to be followed by further visits to the pilot provinces, which were moved to online meetings owing to the travel restrictions imposed to combat the COVID-19 pandemic. A series of meetings and surveys, including an online workshop in April 2020, took place with stakeholders to showcase the results and impact of D-MOSS. The online workshop also identified the best way to further translate the produced forecasts into indicators of disease risk, in order to detect the most vulnerable areas and enhance the way forecast impacts can be communicated to society.

International events

A two-day international workshop was organised in November 2019 in Hanoi, on the 18th and 19th November 2019, to showcase the D-MOSS system to Ministry of Health officials and health experts from the vector-borne disease and epidemics community from eight Asian countries. Representatives from Cambodia, Laos, Malaysia, the Philippines, Sri Lanka, Thailand, Bangladesh and Vietnam attended.

In a press release issued by the United Nations Development Programme (UNDP), and the WHO following the workshop, Dr Dang Quang Tan, the Director General of the Vietnamese Ministry of Health's General Department of Preventive Medicine said "*The Ministry of Health highly appreciates this initiative and the technical support that the project is expected to bring. This is the first initiative to be developed and tested in the world combining scientific intelligence from many international and national organizations. The information shared by these countries plays an important role in the region's overall efforts to respond to dengue fever when the disease has no geographical borders*".

Speaking at the workshop, Sitara Syed, the UNDP Deputy Resident Representative in Vietnam remarked that "*Fighting dengue fever requires common efforts across countries and regional cooperation to ensure that the best information, experiences and innovative tools are shared in a timely manner. Dengue fever is becoming more prevalent as the result of climate change. In any given country, existing tools need to be complemented by innovative forecasting systems to help control and minimize further expansion of this disease*".

The scientific innovations and results of the D-MOSS system have also been published in peer reviewed journals and conference articles, magazines, as well as presented through invited talks in workshops, or conferences. These include:

- Annual meeting of the American Society of Hygiene and Tropical Medicine (ASHTM), 2020;
- Colón-González F.J., et al., 2021. Probabilistic seasonal dengue forecasting in Vietnam: A modelling study using superensembles. PLoS medicine. 2021 Mar 4;18(3):e1003542;
- Tsarouchi G. Forecasting dengue fever outbreaks from space. ROOM Space Journal, March 2021;
- Tsarouchi G., et al., 2019. D-MOSS: An integrated dengue early warning system driven by earth observations in Vietnam. Proc. of the 2019 conference on Big Data from Space (BiDS'2019), doi:10.2760/848593, 2019;
- Changing the landscape of dengue fever, GeoConnexion, 29 October 2020;
- D-MOSS: an integrated dengue virus early warning system, Issue 8 of Health Europa Quarterly, February 2019;
- International Environmental Modelling and Software Society (iEMSs) conference, USA (2018), online (2020);
- UK National Earth Observation Conference, UK (2018, 2019);
- Infectious Disease Dynamics conference, UK (2019);
- European Geosciences Union, Vienna, Austria (2019, 2020);
- American Geosciences Union, San Francisco, USA (2019, 2020);
- Big Data from Space, UK (2019);
- European Space Agency (ESA), Living planet symposium, Milan Italy (2019);
- Vietnam Water Cooperation Initiative, Hanoi, Vietnam (2019);
- Free and Open Source Software for Geoinformatics (FOSS4G), Annual gathering, UK (2019);
- UK Space Conference, Cardiff, UK (2019);
- Multidisciplinary research on epidemic preparedness and response, London, UK (2019).

C.2 Relevance of the targeted environment and choice of pilot demonstration areas

As mentioned in Section 1.3, D-MOSS produces forecasts for all 63 provinces across Vietnam; however, four pilot demonstration areas were selected by the Vietnamese Ministry of Health to carry out a detailed evaluation of D-MOSS. The four D-MOSS pilot demonstration areas, shown in Figure 3, were selected owing to their contrasting geographical, climatic, demographic and epidemiological conditions. All four areas are characterised by a relatively high prevalence of dengue cases for their region, good surveillance and case reporting systems. Brief details of the four pilot areas are provided in Section 1.3 (see Box 3).

The pilot areas typify the regional variations in the seasonality of dengue epidemiology in Vietnam. Dengue is highly endemic in southern Vietnam, while increasingly large seasonal epidemics have occurred in northern Vietnam over the last decade[30]. In the Northern and Central Highland regions, dengue notifications are low during the winter time from December to March, while in the southern regions, dengue transmission occurs throughout the year, with sharp increases during the rainy season from July to September. Given that dengue is a vector-borne disease and that mosquito population dynamics are strongly dependent on climatic factors, the diversity of climates in Vietnam (the north-south elongation of the country means it straddles many climatic zones) may explain the observed diversity of dengue epidemiological dynamics. The central

[30] https://journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0002581

and southern regions experience humid conditions throughout the year which favours many infectious agents and vectors such as mosquitoes. Provinces in the southern parts of the country have higher reported cases compared to those from central and northern regions.

C.3 Technological, administrative and social aspects

Vietnamese stakeholders in the health sector are unaccustomed to using forecasting tools. The need for capacity building, to support a cultural shift to the use of probabilistic forecast of mosquito borne diseases, such as dengue was made clear by all the beneficiaries and stakeholders from the commencement of the work. When using any mosquito-borne disease forecasting system, end users will be reluctant to expend resources on prevention of an outbreak (e.g. spraying, community awareness) unless the forecasts are sufficiently accurate and at a suitable spatial resolution. From the start of the D-MOSS project, a series of capacity building and training exercises have been run to help stakeholders understand the usefulness of probabilistic forecasts. A series of training workshops was delivered in the four pilot provinces during the summer and autumn of 2019, to engender a technical and cultural shift in understanding of what is feasible with early warning systems. During these workshops, the D-MOSS end users were introduced to the use and limitations of seasonal forecasts and making decisions under uncertainty.

Figure C.1: Photograph from the “paying for predictions” game which was used in a number of workshops to demonstrate the usefulness of probabilistic dengue fever forecasts

A seasonal forecasting game, called “paying for predictions”, initially developed by the International Federation of the Red Cross and Red Crescent Climate Centre, was adapted into a dengue fever forecasting game. The objective of the game was to help to show stakeholders the value of the probabilistic dengue forecasts produced by D-MOSS, and to help to breakdown some of the barriers to their effective use. During this game, D-MOSS end users were presented with a probabilistic forecast, for example: there is 40% chance that there will be a dengue fever outbreak in your province in two months’ time. Players had to make decisions based on this information and saw the consequences of their decisions. The goal was to see how well each health official can adjust their decisions based on probabilistic seasonal forecasts. Participants playing the dengue fever forecasting game have to roll a dice which determines if their province will suffer from an outbreak of dengue. They then have to decide if they want to invest in obtaining a probabilistic forecast which will help them decide whether to take pre-emptive action to prevent the outbreak. Photographs from one of the workshops where this game was used are shown in Figure C1. At the end of

the game, participants understood the possible uses and limitations of these forecasts, their personal risk-taking preferences and how seasonal forecasts can affect health decisions.

At present, there is an absence of national guidance on how the Vietnamese stakeholders should use the dengue forecasts. This needs to be reflected in national guidelines on dengue prevention and control but requires political buy in. The D-MOSS team is in the process of engaging with WHO and the Ministry of Health to update these national guidelines, and the intention is that the guidelines recommend the usage of D-MOSS. D-MOSS needs to be used by multiple levels of government and health authorities and thus it is important that stakeholders at all these levels understand the system and can access the data appropriate to them.

C.4 Measures required to use the results in an operational context

The D-MOSS results have been used in an operational context by the provincial level Ministry of Health offices in the four pilot provinces and the four research institutes responsible for dengue control in Vietnam (NIHE, TIHE, PIHCMC, PINT) since June 2019. However, in the South of Vietnam, PIHCMC has already started to train officials from 20 additional provinces in using D-MOSS. PINT has also completed a first round of training activities with officials from an additional 11 provinces in Central Vietnam. To further expand the usage of D-MOSS operationally to the remaining provinces in Vietnam, the following steps are required:

- Training of officials from the remaining provinces that have not been introduced to D-MOSS yet;
- Creation of login credentials to access the D-MOSS website;
- Update of the national dengue guidelines to recommend usage of D-MOSS for dengue prevention and control.

C.5 Local capacity building

The process of making D-MOSS sustainable in Vietnam has been supported by substantial in-country capacity-building, through increasing the skill base of the beneficiaries. Capacity building and training activities have been critical to ensure on-going maintenance and evolution of the system. The capacity of Vietnamese government staff has been strengthened to allow the dengue forecasting tool to be successfully adopted by the Ministry of Health.

Over the course of the project to-date, the key Ministry of Health stakeholders detailed in Section 3.2 have been engaged, not only to help co-produce the D-MOSS dengue fever forecasting system, but also to identify specific gaps in capacity that can be addressed by the project. Five main capacity building areas were identified as follows:

- Collation of data used by the D-MOSS system, (e.g. EO data, dengue fever cases, hydro-meteorological data);
- Using the D-MOSS user interface (capacity to interpret and use probabilistic forecasts and to communicate them effectively to other stakeholders);
- The underpinning science, statistical models and algorithms that the D-MOSS forecasts are based on;
- The interpretation of uncertainty in the dengue fever forecasts;
- The use of the dengue forecasts as part of various Ministry of Health organisations' procedures, and how they relate to thresholds and historical outbreaks of dengue.

Development of training materials: As part of the D-MOSS capacity building activities, training materials have been developed throughout the course of the project taking into account the following principles:

- Direct relevance to the learning objectives;
- As much hands-on practice, games and simulations as possible;

- Use of “blended learning” approaches that include training in several different formats (e.g. computer-based, exercise-based and trainer-led).

Figure C2 shows how the training of provincial-level health staff in provinces outside the four pilot areas has been achieved, by training the trainers: staff from the WHO, UNDP in Vietnam supported by HR Wallingford, the London School of Hygiene and Tropical Medicine and the UK Met Office have trained trainers at Vietnamese organisations responsible for dengue control and surveillance (e.g. GDPM, NIHE, TIHE, Pasteur institutes). These trainers have then trained provincial-level health workers, outside the four pilot provinces, on how to use D-MOSS and to interpret its forecasts. In the South of Vietnam, PIHCMC has already trained officials from 20 provinces in using D-MOSS. PINT has also completed a first round of training activities with officials from 11 provinces in Central Vietnam.

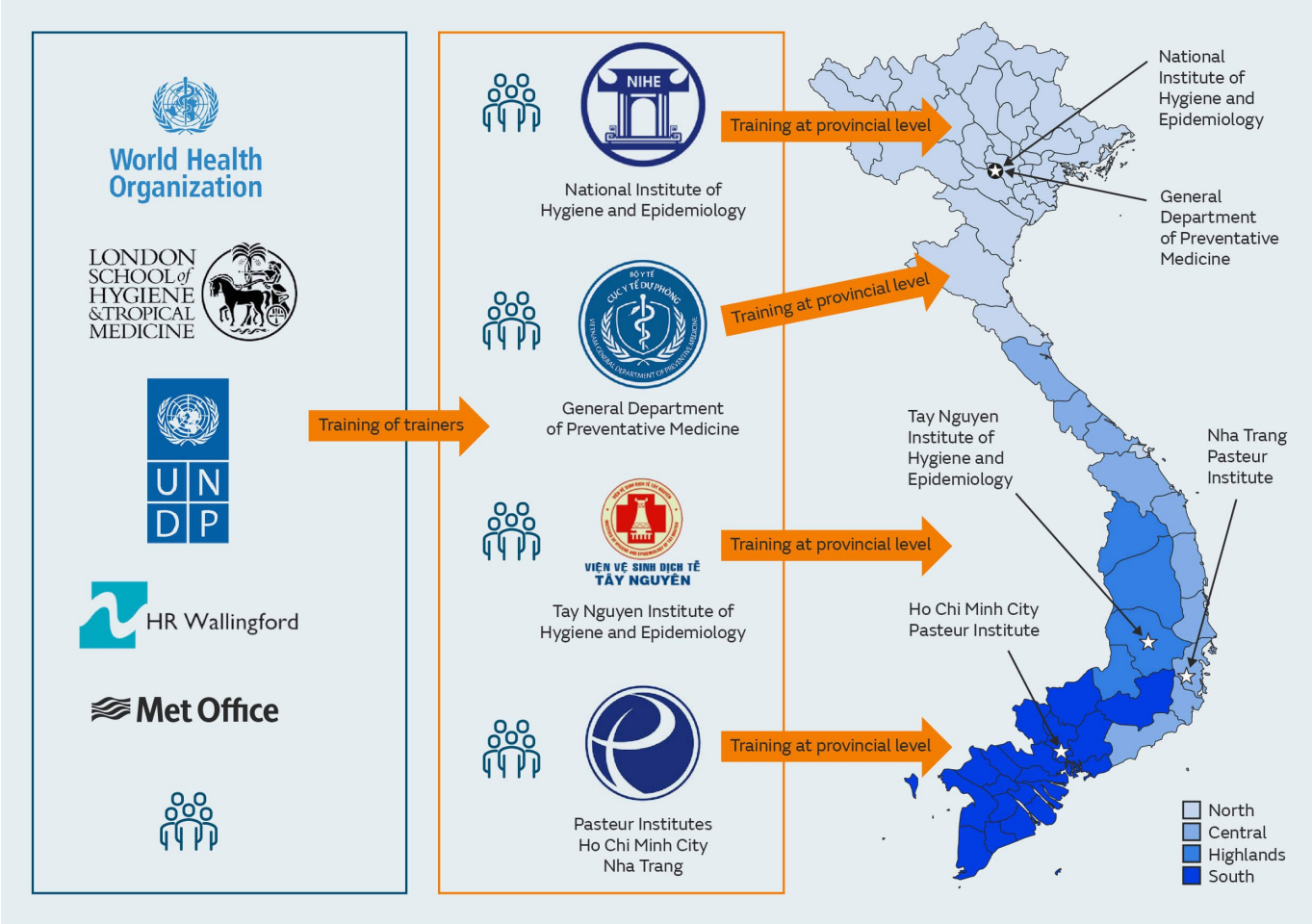

Figure C.2: Scaling up of training in the use of D-MOSS via the training of trainers including the General Department of Preventative Medicine, National Institute of Hygiene and Epidemiology and the Pasteur Institutes

Implementation: The training and capacity building has been implemented through a variety of tools and techniques:

- *Hands-on use of the D-MOSS software:* Face-to-face, hands-on training sessions follow each release of the D-MOSS system with users having access to the web-platform via individual laptops and being given time to explore the system, as well as to interpret dengue forecasts. The Vietnamese language D-MOSS user manual is available to the users in hard copy form and is accessible from the user interface (together with the English language version). This is revised following feedback from each training session.

- *Training of trainers:* Members of staff at the Ministry of Health's GDPM, the two Pasteur Institutes and the National Institute of Hygiene and Epidemiology have been training provincial level members of staff throughout Vietnam i.e. in provinces outside the pilot areas. Training in the use of D-MOSS has already taken place in almost half of Vietnam's 63 provinces. This is helping to scale up the use of D-MOSS in the North, Central, Highlands and South regions of Vietnam.
- *Participatory games and simulations:* Other hands-on activities such as games and simulations are employed to help users understand the use and advantages of probabilistic dengue fever forecasts. Experience has shown participatory decision games can be an effective vehicle for learning at all levels from communities to disaster management staff, policy-makers and donors (IFRC, 2012[31]). The games include the adapted International Federation of the Red Cross and Red Crescent 'Paying for Predictions' game[32], discussed earlier and a bespoke scenario simulation designed to assess response and understanding of different methods of portraying D-MOSS results.
- *Technical presentations:* Certain stakeholders require an understanding of the underlying science and technology behind D-MOSS. This has been articulated through face-to-face technical presentations, as well as technical information presented as part of the user interface for these users, covering topics such as use of EO data, interpreting probabilistic forecasts, and forecast skill.
- *Secondments:* HR Wallingford regularly hosts practitioners and researchers on secondments lasting from a few weeks to several months. As part of the project, HR Wallingford has hosted staff from the Institute of Meteorology, Hydrology and Climate Change (IMHEN).

The training was evaluated via a range of feedback mechanisms including individual, anonymous evaluation forms that are compiled after each event, as well as in some cases internet-based surveys. This information is used to shape future capacity building through direct input and indirect assessment of success.

Capacity building pathway: To track progress, a clear capacity building pathway has been developed, that describes for each area of need the objectives, evidence for success and activities required to meet the objectives. The capacity building pathway for Ministry of Health staff is provided in Table C.1.

Table C.1: Ministry of Health and related organisations' capacity building progress tracking

Objectives	Evidence of achievement	Activities
An understanding of the type, importance and format of data used by D-MOSS to forecast dengue fever.	Participants can demonstrate that they understand the provenance and importance of the formats of the data that D-MOSS uses.	Technical presentations by key members of the project team.
An ability to use the D-MOSS system to understand the monthly forecasts of dengue fever.	Ministry of Health staff are able to describe the monthly dengue fever forecast after navigating the web-based user interface.	Hands on training in the D-MOSS software following each release. Production of D-MOSS user manual in Vietnamese. Technical presentations in Vietnamese. Feedback from participants on the D-MOSS software so that after each release it can updated accordingly.
Capacity to interpret and use probabilistic forecasts and to	Ministry of Health staff use monthly, probabilistic forecasts in their day-to-day work and are	Use of a mix of activities including scenario-based

[31] International Federation of Red Cross and Red Crescent Societies (IFRC) (2012) Community early warning systems: Guiding principles
[32] https://www.climatecentre.org/resources-and-games/games/2/paying-for-predictions

Objectives	Evidence of achievement	Activities
communicate them effectively to other stakeholders.	able to communicate these to a range of stakeholders, who provide evidence of taking appropriate actions.	games, presentations and quizzes.
Comprehension of the probabilistic dengue forecasts and thresholds used in different parts of Vietnam to identify an outbreak.	Questionnaires to demonstrate that participants' knowledge related to understanding probabilistic forecasts in relation to different threshold levels has improved.	Use of a mix of activities including scenario-based games, presentations and quizzes.

Sites selected for further development: Whilst stakeholders in Vietnam acknowledge the benefits being already delivered by D-MOSS forecasts which are given at province level, this comes with expectations for improvements in the future. There is a cross sector desire to see the programme deliver forecasts at district level (each province is divided into ~10 districts). As such, over the next year, the D-MOSS team will be further developing D-MOSS to deliver district-level forecasts for the four pilot provinces. Initial research has been undertaken into establishing the feasibility of forecasting at this scale with sufficient accuracy, but further work is necessary and definite conclusions have not yet been possible. Over the next year, the D-MOSS team will be looking at heterogeneity by considering finer scale, socio-economic drivers, housing quality, access to water, sanitation and hygiene amongst other factors, to develop district-level forecasting tools.

C.6 Established links with local/national health systems

This section provides an overview of the key local and national stakeholders in dengue control in Vietnam, as well as the project's established links with the local and national health system.

Dengue control stakeholders: In Vietnam, the stakeholders in dengue control can be divided into four main categories: authorizers, approvers, advisors and implementers. Authorizers include ministries such as the Ministry of Health. Approvers include the prime minister and People's Committees. Advisors are the World Health Organization (WHO), the Centres for Disease Prevention and Control (CDC) and research institutes such as the National Institute of Hygiene and Epidemiology (NIHE), Tay Nguyen Institute of Hygiene and Epidemiology (TIHE), Pasteur Institute Nha Trang, and Pasteur Institute Ho Chi Minh City. Implementers are the Provincial Preventive Medicine Centres (PPMC), the District Health Centres (DHC) and the Commune Health Stations (CHS). These groups are not clearly defined, for example research institutes can act as implementers and in some cases the organizations at province, district and commune level can contribute both to the input and the output of the strategy and plans made at higher levels. Figure C3 shows the structure of the health system in Vietnam.

The Ministry of Health is the government ministry responsible for the governance and guidance of the health, healthcare and health industry of Vietnam. In conjunction with other ministries and the prime minister's office, the Ministry of Health is responsible for creating and promulgating long-term health policy. The Ministry of Health comprises a number of departments. The General Department of Preventative Medicine (GDPM) assists the Ministry of Health in implementing state management functions and organizing the implementation of legal regulations in the field of preventive medicine nationwide, including: prevention and control of communicable diseases, diseases of unknown cause; and prevention and control of non-communicable diseases. GDPM is responsible for dengue surveillance and control in Vietnam.

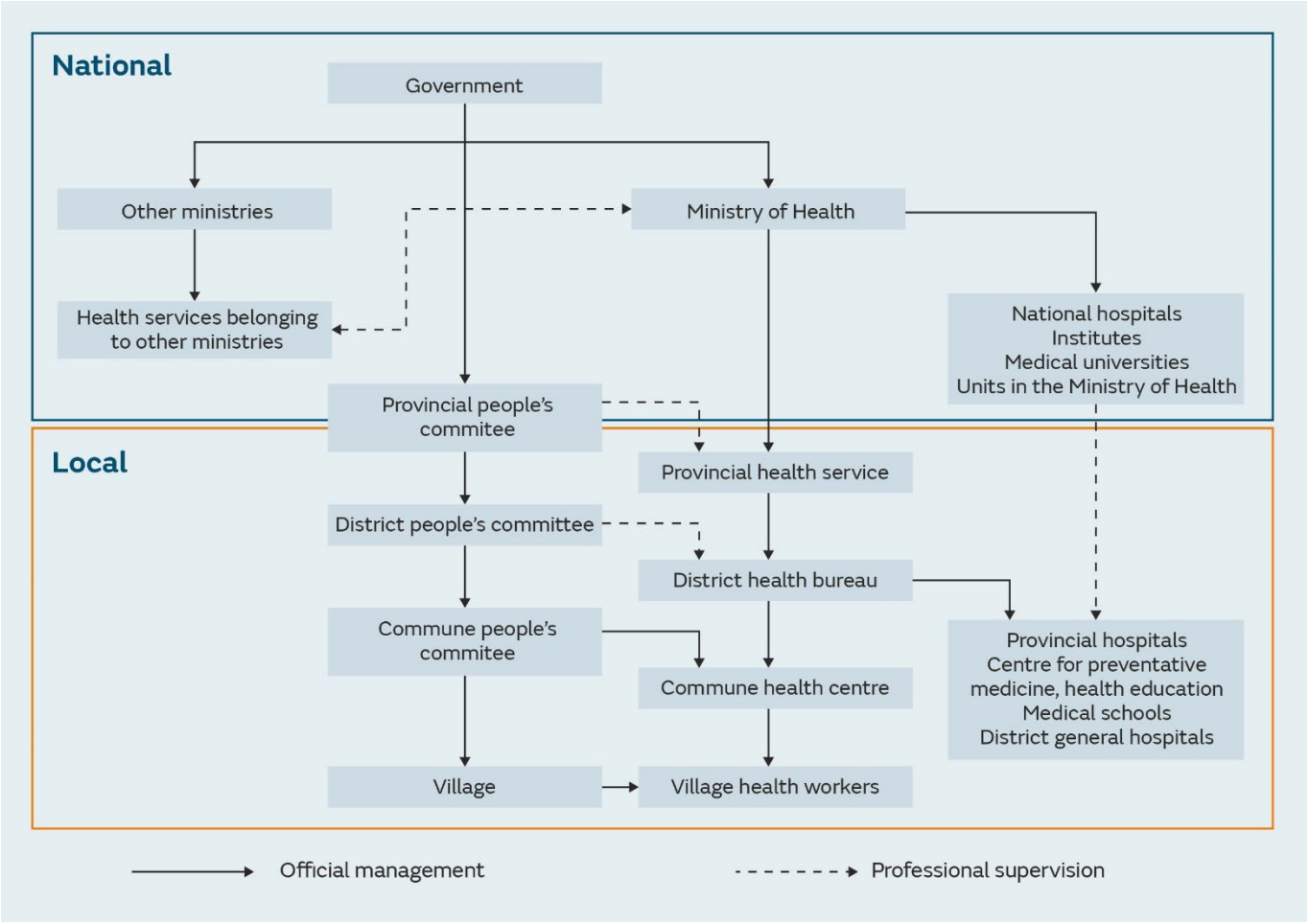

Figure C.3: Organisation of the Vietnamese health service

GDPM has established a clear power distribution among advisory institutes and between the People's Committees and medical and health centres at province, district and commune level. The D-MOSS consortium, together with GDPM, organize frequent joint meetings and activities that include stakeholders at all levels shown in Figure C3, in order to stimulate trust and mutual acquaintanceship. The key stakeholders which have been engaged with in co-producing D-MOSS, since its inception, are: GDPM, NIHE, IPHCM, IPNT, TIHE and the CDCs of the four pilot provinces.

Strong support for the D-MOSS early warning system: In June 2018, stakeholders were consulted as part of a baseline survey for the Monitoring and Evaluation (M&E). At the national level, representatives from General GDPM, responsible for dengue surveillance and control in Vietnam, together CDC representatives from the four pilot provinces and representatives of the four research institutes (NIHE, TIHE, PIHCMC, PINT) attended the baseline evaluation workshop hosted by UNDP and WHO in Hanoi. Feedback from this consultation was complemented by interviews conducted with provincial and district health workers, and commune-level focus groups during a second round of data collection. All national, regional and provincial stakeholders consulted welcomed the D-MOSS project and its ambition to create the first dengue forecasting system. Dengue forecasting was defined as very important, noting that dengue outbreaks and epidemics are very difficult to predict, making it difficult to mount an effective and timely response to outbreaks in Vietnam. Stakeholders emphasised the need to move their system towards being more proactive, rather than reactive.

Since the D-MOSS prototype became operational in June 2019, the stakeholders started reporting how the D-MOSS forecasts are used to *"get information on months with increasing cases; predict and compare number of cases across provinces; proactively strengthen and focus on surveillance activities; prepare*

*resources for proactive responses and guide response plans"(**Pasteur Institute Nha Trang).*** Stakeholders are now reporting that they *"use D-MOSS forecasts to identify prioritized areas and resources and take actions to reduce the number of cases and prevent outbreaks."* D-MOSS is helping them in *"not wasting resources for provinces with low predicted cases" (**National Institute of Hygiene and Epidemiology).***

The intensity and level of cooperation with stakeholders responsible for existing programmes at national, regional and local levels includes a long timeline of cooperation activities including:

July 2017 - Pre-project stakeholder engagement: Before the project commenced a two week visit was undertaken to Vietnam by the project team, to engage with key stakeholders including the Vietnamese Ministry of Health, WHO and UNDP to co-design the project from the outset. This was carried out via a series of workshops, semi-structured interviews and meetings. This engagement led to the initial co-development of the project plan.

February to July 2018 - Commencement of the project and development of the user requirements: The project officially commenced in February 2018. Over the first five months, the user requirements for a dengue forecasting system were co-produced with the key stakeholders and beneficiaries.

July 2018 - User requirements finalised: The user requirements were finalised and agreed with all the key stakeholders and published in Vietnamese and English.

February 2018 to March 2019 - Co-development of the D-MOSS user interface: A good user interface is important when developing any software, especially when it needs to be used to display complex results such as outputs from probabilistic forecasts. During the initial phase of the work, the user interface was co-designed with beneficiaries of the system, whilst exploring how dengue forecasts should be displayed in map, graphical and tabular formats. A series of semi-structured interviews, meetings and workshops were held to co-design the user interface. Figure C4 shows photographs from a workshop held with key stakeholders, together with some of the options for how forecasts could be displayed in D-MOSS.

March 2019 - Commencement of engagement with the four pilot areas: Following the official designation of the pilot areas by the Vietnamese Ministry of Health, engagement with provincial district and community level stakeholders commenced.

July 2019 - D-MOSS Release 1 training workshops: The first release of D-MOSS was available from June 2019. Following the first release, a series of workshops were held with key stakeholders, co-organised by the Vietnamese Ministry of Health's GDPM, WHO and UNDP. The main objective was to provide training for key national and pilot-area beneficiaries on the D-MOSS internet-based platform and to obtain feedback on how D-MOSS could be improved. Figure C5 shows photographs from one of these training workshops.

The co-production process with the users at national, province and district levels resulted in a number of specification changes to the first release of the D-MOSS system. These included the following aspects:

The dengue forecast over-emphasised the influence of surrounding provinces and needed to focus more strongly on behaviour in individual provinces.

D-MOSS needed to use several outbreak thresholds, calculated both according to WHO specifications as well as those designed for specific local circumstances.

An automatic interface needed to be built to communicate the forecast to downstream systems capable of using it, in particular a notification module under construction by local developers.

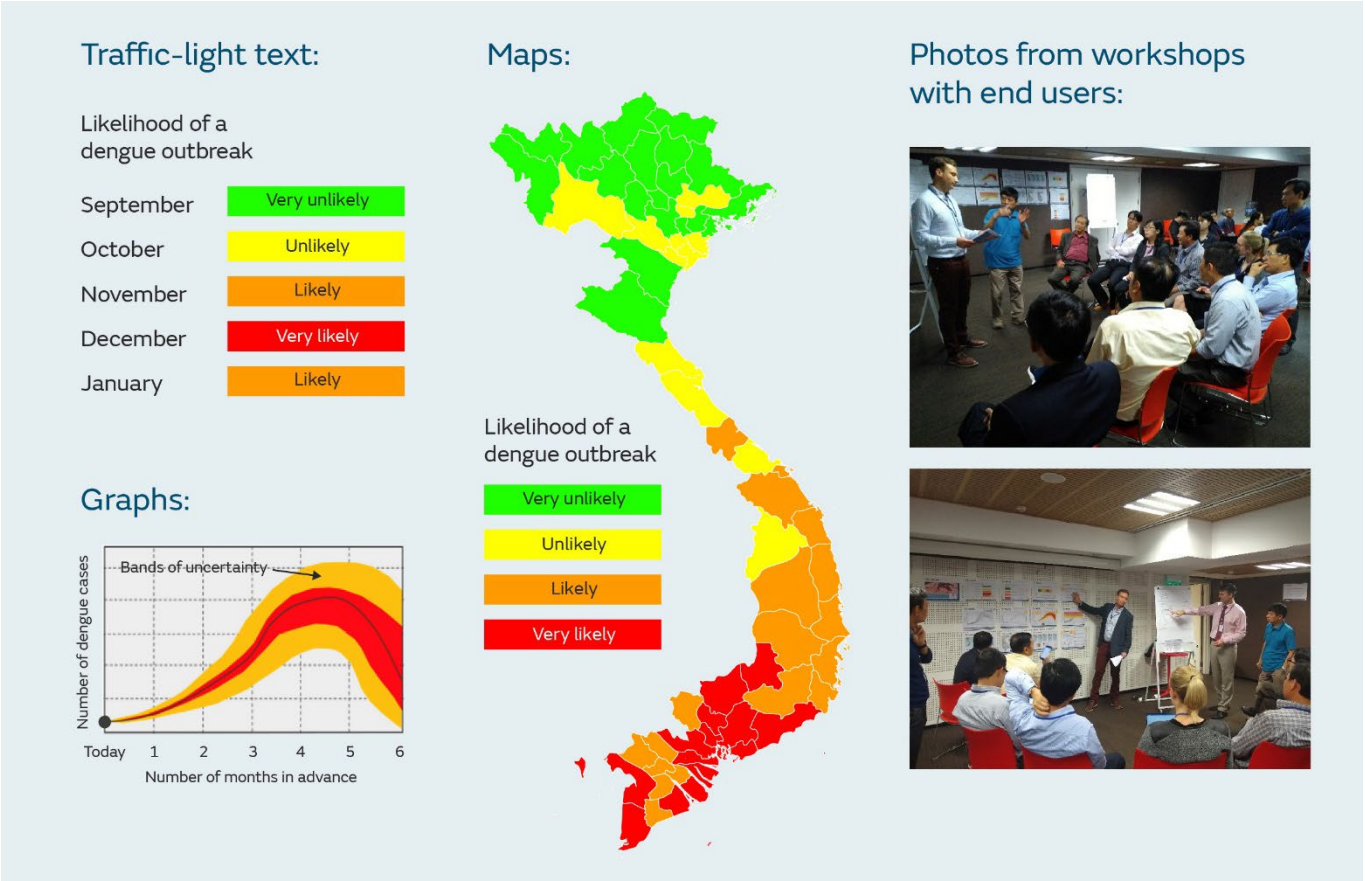

Figure C.4: Options for how dengue forecasts could be displayed in D-MOSS, together with photos from two workshops

November 2019 - Further D-MOSS Release 1 training workshops and training on the use of probabilistic forecasts: Additional training workshops were delivered in the four pilot provinces in November 2019, to check stakeholders' understanding of probabilistic forecasts and to engender a technical and cultural shift in understanding of what is feasible with early warning systems. During these workshops, the D-MOSS end users were introduced to the use and limitations of seasonal forecasts and making decisions under uncertainty, to allow the uncertainties in the forecasts to be communicated transparently using a seasonal forecasting game, named "paying for predictions" (see above). Training was also provided on the D-MOSS software itself; the underpinnings science and algorithms; how to use and interpret the dengue forecasts; and how the dengue forecasts relate to thresholds and historical outbreaks of dengue.

Figure C.5: Photographs from a training workshop which gathered feedback on Release 1 of D-MOSS

January 2020 – D-MOSS Release 2: Following feedback from the pilot provinces and the Ministry of Health, a second release of the prototype was produced in January 2020. This was to be followed by further visits to the pilot provinces, which were moved to online meetings owing to the travel restrictions imposed to combat the COVID-19 pandemic.

Prior to the Covid-19 pandemic, continual contact with the pilot provinces and the Ministry of Health was maintained with numerous in-person visits (approximately every 5 to 6 weeks). This is expected to resume when travel is possible and, in the meantime, is being supplemented with online meetings. Further updates to the user interface were released in July and November 2020.

January 2020 to April 2020 - D-MOSS Release 2 co-production: A series of meetings and surveys, including an online workshop in April 2020, took place with stakeholders to co-produce the next version of D-MOSS and to incorporate requirements to help to enable better informed decision-making on dengue prevention and control. The online workshop also identified the best way to further translate the produced forecasts into indicators of disease risk, in order to detect the most vulnerable areas and enhance the way forecast impacts can be communicated to society.

June 2020 – D-MOSS Release 2 end user assessment: A series of online workshops took place in early June 2020, with government stakeholders providing feedback on how they have been using the D-MOSS system and their early assessments of its performance. Discussions also focused on the different outbreak thresholds that the system currently provides, and their advantages and disadvantages.

July 2020 – Field visits: WHO arranged a series of field visits in the four pilot provinces, to observe how the end users are interacting with the D-MOSS system and to supervise the collection of dengue data in the sentinel sites of the four pilot provinces.

November 2020 - Budget planning engagement with Ministry of Health: An online meeting was held, with participation from WHO, GDPM (Vietnamese Ministry of Health) and HR Wallingford. In this meeting the discussion focused on the operational costs of D-MOSS and potential ways to reduce them. GDPM would like support from WHO, UNDP and HR Wallingford in putting forward a case to the Ministry of Health and Ministry of Finance for covering some of the D-MOSS costs. Prior to doing this, it is essential that the system is operated for another year, in order to gather the necessary evidence of its usefulness. In the meeting, the transfer of the system to GDPM was discussed as well as the delivery of training for rolling out the system to all 63 provinces of Vietnam.

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