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Spatiotemporal Prediction of Arbovirus Outbreak Risk

– the role of weather and population mobility

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Abstract

Background. Arboviruses such as dengue and chikungunya have been a significant public health burden globally for several decades. In Indonesia, all four dengue serotypes are circulating. Considering that Indonesian children are exposed to dengue early in life, and secondary infection is more likely to cause severe dengue, the population of Indonesia is confronting a high potential risk of severe dengue. Severe complications such as hemorrhage can develop and lead to fatal outcomes. There exists no specific treatment for dengue infection, but symptomatic treatment can be effective to prevent deaths. Consequently, vector control has become a critical component for controlling dengue transmission, but it is currently often triggered as a reactive response to observed outbreak clusters. Based on disease surveillance, it thus remains challenging to implement vector control efficiently to prevent outbreaks. While meteorological conditions have shown to be predictive of dengue incidence over space and time, it has rarely been used to predict outbreaks at a fine-scale intra-urban level. Further, as the propagation of dengue outbreaks and the introduction of viruses has been found to be associated with human mobility, predictive models combining meteorological conditions with granular mobility data hold promise to provide more predictive models. The objectives in this thesis were to 1) describe the influence of temperature, rainfall, and past dengue cases, and population mobility on dengue risk; 2) develop and validate spatiotemporal models of dengue outbreak risk at fine-scale at the intra-urban level; 3) to utilize new data to assess the emergence and spread of chikungunya in an outbreak situation.

Methods. Initially, multivariate time series regression models were established to analyze the risk of dengue corresponding to monthly mean temperature, cumulative rainfall, and past dengue case. Following that, we investigated the potential use of geotagged social media data as a proxy of population mobility to estimate the effect of dengue virus importation pressure in urban villages. Subsequently, we employed distributed lag non-linear models with a Spatiotemporal Bayesian hierarchical model framework to determine the exposure-lag-response association between the risk of dengue and meteorological data while allowing the spatial covariance to be informed by mobility flows. Finally, we validated the selected best-fitted model by its predictive ability using an unseen dataset to mimic an actual situation of an early warning system in use.

Results. We found that an optimal combination of meteorology and autoregressive lag terms of past dengue cases was predictive of dengue incidence and the occurrence of dengue epidemics. Subsequently, when we integrated mobility data our results suggested that population mobility was an essential driver of the spread of dengue within cities when combined with information on the local circulation of the dengue virus. The geotagged Twitter data was found to provide important information on presumably local population mobility patterns which were predictive and can improve our understanding of the direction and the risk of spread.

Conclusions. A spatiotemporal prediction model was developed that predicted a prognosis of dengue at fine spatial and temporal resolution. Subsequently, such a prognosis can be used as the foundation for developing an early warning system to more effectively deploy vector control prior to the establishment of local outbreak clusters . These findings have implications for targeting dengue control activities at the intra-urban villages level, especially in the light of ever increasing population growth, mobility and climate change.

Keywords: arbovirus, dengue, temperature, rainfall, extreme weather, climate variability, population mobility, twitter data, social media, forecasting model, early warning, epidemic, big data, INLA, spatio-temporal model, climate services

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