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Spatial-Temporal Clustering Characteristics of Dengue in the Northern Region of Sri Lanka, 2010-2013

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***Abstract*—**Dengue outbreaks are affected by biological, ecological, socio-economic and demographic factors that vary over time and space. These factors have been examined separately and still require systematic clarification. The present study aimed to investigate the spatial-temporal clustering relationships between these factors and dengue outbreaks in the northern region of Sri Lanka. Remote sensing (RS) data gathered from a plurality of satellites were used to develop an index comprising rainfall, humidity and temperature data. RS data gathered by ALOS/AVNIR-2 were used to detect urbanization, and a digital land cover map was used to extract land cover information. Other data on relevant factors and dengue outbreaks were collected through institutions and extant databases. The analyzed RS data and databases were integrated into geographic information systems, enabling temporal analysis, spatial statistical analysis and space-time clustering analysis. Our present results showed that increases in the number of the combination of ecological factor and socio-economic and demographic factors with above the average or the presence contribute to significantly high rates of space-time dengue clusters.

***Keywords*—**ALOS/AVNIR-2, Dengue, Space-time clustering analysis, Sri Lanka.

I. Introduction

DENGUE is the most important vector-borne viral disease worldwide and a major cause of childhood fever burden in Sri Lanka, which has experienced a number of large epidemics in the past decade. Although Sri Lanka has had a history of over 40 years of dengue, since the early 2000s, progressively large epidemics have occurred at regular intervals. It remains a major public health problem in Sri Lanka where a rate of 220 per 100,000 populations, approximately a quarter of notified cases occur in children under 15 years lives in dengue transmission areas. The transmission shows significant variations in time and space [1]–[3].

Dengue outbreaks are affected by ecological and socio-economic and demographic factors that vary over time and space. Disease-promoting factors include 1) climate, such as rainfall, humidity and temperature [4]; 2) changes in land cover, particularly rapid unplanned expansion of urbanization with inadequate housing and infrastructure [5]–[11]; 3) transportation network [12]; and 4) high population density [13]. These factors have been examined separately and still require systematic clarification.

Our study aimed to investigate the impact of ecological factors (i.e., rainfall, humidity, temperature and land cover, including rapid unplanned expansion of urbanization) and socio-economic and demographic factors (i.e., transportation network and population density) on space-time dengue clusters at a division level in the northern Sri Lanka while identifying the ecological, socio-economic and demographic characteristics of space-time clusters with high rates of dengue case.

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II. Materials and Methods

A. Study Area

Dengue outbreaks in Sri Lanka are spatially heterogeneous. Investigating the spatial-temporal relationships between various factors and dengue outbreaks at the local level in Sri Lanka can help to better target surveillance and control. Our study area was the northern region of Sri Lanka, consisting of twelve Medical Officer of Health (MOH) divisions which are the health administrative divisions in Sri Lanka. Each MOH division has different geographic features—including agricultural fields, forested areas, wetlands, grassland, urban areas, etc.—as well as different socio-economic and demographic backgrounds. The climate in the region is tropical, with two monsoon seasons: namely north east monsoon from November to April, and south west monsoon from May to October.

B. Data Collection and Processing

The monthly numbers of clinically confirmed dengue cases from January 2010 through December 2013 in the twelve MOH divisions and the annual estimates of clinically confirmed dengue cases from 2007 through 2013 at the same MOH division level were obtained from the MOH divisions in Sri Lanka.

The Global Satellite Mapping of Precipitation (GSMaP) product, based on the combined MW-IR algorithm with a plurality of satellites were used for the monthly average rainfall data from January 2010 to December 2013 and the annual average rainfall data from 2007 to 2013 [14], [15]. The JAXA

Satellite Monitoring for Environmental Studies (JASMES) portal were used for the monthly average data of humidity and temperature from January 2010 to December 2013 and the annual average data of humidity and temperature from 2007 to 2013 [16]. These data were processed into TIFF image files. The ALOS/AVNIR-2 dataset was used along with an unmix method to detect and map urbanization ratio. The unmix method isolates the contribution of a specific material within a heterogeneous (mixed) pixel. For a given material, this method records pixel location and fraction of material present in the pixel. We designated eight material pixel fraction classes that report subpixel detections in material pixel fraction increments of 0.20. Pixels determined to have material pixel fractions of 20-29% belong to class 0.20-0.29, pixels with material pixel fractions of 90-100% belong to class 0.90-1.00 and so forth. The digital land cover map was used for land usage information. These data were used as ecological factors.

Vector data on transportation, such as road, railroad and airport were obtained from the ISCGM Web site [17]. Combining annual population data for the respective MOH division from 2007 to 2013 with the MOH division data for the area, we calculated the population density. These data were used as socio-economic and demographic factors.

The polygon layer which generates the twelve MOH divisions in the northern region of Sri Lanka and the TIFF image data on rainfall, humidity and temperature layer were overlaid. The values of a raster within the polygons were summarized, and the results were reported to excel tables. Similarly, the values of the urbanization raster within the polygons were summarized, and the results were reported to excel tables. We calculated the ratio of pixels with material pixel fractions of more than 50% to MOH division area. Again, the digital land cover data within the polygons were summarized and the results were reported to excel tables.

The vector data on transportation network including road, railroad and airport within the polygons were summarized and the results were reported to excel tables.

The table of polygon layer attributes was joined with the excel tables containing data on ecological, socio-economic and demographic factors. We additionally calculated the average value from a set of annual rainfall, humidity, temperature, population density at the MOH division level. This information was used for spatial statistical analysis.

More, the polygon layer which presents the twelve MOH divisions was used to calculate the coordinates of the center of gravity of each polygon. This information was used for space-time clustering analysis.

C. Temporal Analysis

To examine temporal patterns, we used data on monthly dengue cases, rainfall, humidity and temperature during the period from January 2010 through December 2013. The moving average (MA) was calculated and visualized to examine the temporal climate trend associated with outbreak of dengue. We also calculated the average monthly values from data on monthly rainfall, humidity and temperature within the period to investigate the comprehensive trend and to be used for the chi-square test. The chi-square test was used to test monthly differences in dengue cases, rainfall, humidity and temperature across the study period. The statistical significance was set at 0.05.

D. Spatial Statistical Analysis

The chi-square test was used to test the spatial association between ecological, socio-economic and demographic factors and dengue outbreak. The ecological, socio-economic and demographic factors were categorized in two ways: 1) above average and below average of factor or 2) presence or absence of factor depending on the factors. The threshold values for these levels were determined based on the average values for these factors from the results obtained with spatial analysis in GIS or categorized as two-level based on the presence or absence of these factors from the results obtained with spatial analysis in GIS.

Regarding the rainfall, humidity, temperature and urbanization data, the threshold values for the levels were categorized in two levels: above average and below average. Land cover differed among MOH divisions; with some MOH divisions showing a total absence of a given land cover type. Regarding the land cover data, the threshold values for the levels were categorized as two-level based on the presence or absence of each land cover.

Similarly, transportation such as airport and railway differed among MOH divisions, with some MOH divisions showing a total absence of a given a transportation system. Regarding the airport and railway data, the threshold values for the levels were categorized as two-level based on the presence or absence of each transportation. Regarding the road data, the threshold values for the levels were categorized in two levels: above average and below average. Likewise, as for the population density data, the threshold values for the levels were categorized in two levels: above average and below average.

The categorized data, dengue case and control (i.e., population minus dengue case) were used for the chi-square test. The statistical significance was set at 0.05.

E. Spatial-Temporal Clustering Analysis

SaTScan version 9.3 using Kulldorf method of retrospective space-time analysis and space-time permutation probability model was applied to identify geographic areas and time period of potential clusters with high rates [18]. The scan statistics did scanning gradually across time and/or space to identify the number of observed and expected observations inside the window at each location. The scanning window was an interval (in time), a circle (in space) or a cylinder with a circular base (in space-time) to which window sizes were determined, and the window with the maximum likelihood was the most likely cluster, and a p-value was assigned to this cluster [19].

In this study, the monthly dengue case from January 2010 to December 2013 in each MOH division and coordinate data from spatial analysis in GIS were used in the space-time permutation probability model. It performed geographical surveillance of the disease in order to detect space-time disease clusters and to see if they are statistically significant.

III. Results

The temporal features of monthly dengue cases, rainfall, humidity and temperature in the northern region of Sri Lanka from January 2010 through December 2013 show characteristic movement. Humidity tends to rise in early January, remaining high during the dry season, and then declining with the increase in rainfall in early September. These changes are accelerated at lower temperature. The distribution of monthly dengue cases indicated a strong seasonal pattern. Dengue case tended to increase after exponential increases or decreases in rainfall. The chi-square test results supported these tendencies. We observed significant monthly differences in dengue cases and rainfall ($p < 0.01$), while humidity and temperature were not significant.

The results of spatial statistical analysis revealed the dengue outbreak was significantly associated with ecological, socio-economic and demographic factors. Significantly more dengue cases were observed in Chankanai, Chavakachcheri, Jaffna, Karaveddy, Nallur, Point Pedro, Sandilipay and Tellipallai MOH divisions (66.7%) with average annual rainfall of >1353 mm compared to in those with average annual rainfall of <1353 mm ($\chi^2 = 112.8$; $p < 0.01$). Correspondingly, we also observed significantly more dengue cases in Chavakachcheri, Jaffna, Karaveddy, Kopay, Point Pedro Sandilipay, Tellipallai and Uduvil MOH divisions (66.7%) with average annual humidity of >39.62 mm compared to in those with average annual humidity of <39.62 mm ($\chi^2 = 55.6$; $p < 0.01$). Moreover, significantly more dengue cases occurred in Chankanai, Chavakachcheri, Karaveddy, Kopay, Sandilipay, Tellipallai and Uduvil MOH divisions (58.3%) with an average annual temperature of >31.2°C compared to in those with an average annual temperature of <31.2°C ($\chi^2 = 104.7$; $p < 0.01$).

Significantly more dengue cases were observed in Chavakachcheri, Jaffna, Karaveddy, Kayts, Point Pedro and Velanai MOH divisions (50.0%) that had the ratio of >18% to MOH division area compared to in those with the ratio of <18% to MOH division area ($\chi^2 = 40.7$; $p < 0.01$). Dengue occurrence was also significantly associated with the presence or absence of built-up area considered to represent urbanization ($\chi^2 = 264.7$; $p < 0.01$). The presence of built-up area in Karaveddy, Jaffna, Nallur and Point Pedro MOH divisions (33.3%) significantly influenced dengue occurrence.

Dengue occurrence was also significantly associated with the presence or absence of railway ($\chi^2 = 63.5$; $p < 0.01$) although the presence or absence of airport did not significantly influence dengue occurrence. The presence of railway in Chavakachcheri, Kopay, Nallur, Tellipallai and Uduvil MOH divisions (41.7%) significantly influenced dengue occurrence. We also found significantly more dengue cases in Chankanai, Kopay, Sandilipay, Tellipallai and Velanai MOH divisions (41.7%) with a road of >25 compared to those with a road of <25 ($\chi^2 = 96.4$; $p < 0.01$).

We also found significantly more dengue cases in Jaffna, Nallur, Uduvil and Sandilipay MOH divisions (33.3%) with a population density of >1150 compared to those with a population density of <1150 ($\chi^2 = 347.2$; $p < 0.01$).

Space-time clustering analysis by SaTScan indicated that four space-time clusters with significantly high rates of dengue case ($p<0.001$). Combining the result of space-time clustering analysis with the results of temporal analysis and spatial statistical analysis presents the ecological, socio-economic and demographic characteristics of space-time clusters with significantly high rates of dengue case. The most likely space-time cluster was identified in Karaveddy MOH division from 2010/6/1 to 2010/6/30. Karaveddy MOH division is urbanized land area with the relatively high rainfall, high humidity and high temperature. It supported unusually large epidemics experienced in 2004 and 2009 with the peak transmission occurring in June following the south west monsoon [3]. The second space-time cluster was identified in Jaffna MOH division from 2010/9/1 to 2011/1/31. Jaffna MOH division is urbanized land area with the relatively high rainfall, high humidity and high population density. The third space-time cluster was identified in Nallur MOH division from 2012/10/1 to 2012/11/30. Nallur MOH division is traversed by railways and urbanized land with the relatively high rainfall and high population density. The fourth space-time clusters were identified in Tellipallai and Uduvil MOH divisions from 2011/12/1 to 2012/3/31. Both Tellipallai and Uduvil MOH divisions are traversed by railways with the relatively high humidity and high temperature and either Tellipallai or Uduvil MOH division has the relatively high rainfall, high road and high population density.

IV. Discussion

From temporal points of view, the result of space-time clustering analysis correspond to the result of temporal analysis that dengue case tended to increase after exponential increases or decreases in rainfall and also when largest monthly amount of rainfall reach two hundred mm in the interval. From spatial points of view, the result of space-time clustering analysis indicates that increases in the number of the combination of ecological factor and socio-economic and demographic factors with above the average or the presence contribute to significantly high rates of space-time dengue clusters as well as high risk of dengue transmission.

Temporal analysis, spatial statistical analysis and space-time clustering analysis implemented in this study identified dengue space-time clusters which had higher dengue burden and more risks of dengue transmission while identifying what geographic areas and what time period were at the highest risk of dengue at MOH division level. These clusters and surrounding areas should be targeted for dengue prevention and control interventions.

The presently observed temporal association underlines the fact that rainfall, humidity and temperature (considered as ecological factors) can strengthen time prediction models. The spatial association found in our study highlights the fact that built-up area and urbanization (considered as ecological factors), transportation (a socio-economic and demographic factor) and higher population density (a socio-economic and demographic factor) can also strengthen spatial prediction models. The spatial-temporal association which consolidates the two kinds of associations into one can ensure more stable model for spatial-temporal forecasting. An integrated spatial-temporal prediction model at a smaller level using ecological and socio-economic and demographic factors could lead to substantial improvements in the control and prevention of dengue by allocating the right resources to the appropriate places at the right time.

Dengue transmission within Sri Lanka is spatially heterogeneous. Further research must focus on the whole island to improve the accuracy of spatial and temporal models while utilizing big data and open data.

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