Remote sensing applied to the analysis of spatial and temporal patterns of dengue incidence based on ecological and socio-economic and demographicfactors in Sri Lanka

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ABSTRACT

Dengue outbreaks are affected by biological, ecological, socio-economic and demographicfactors thatvary over time and space. These factors have been examined separately, with limited success, and still require clarification. The present study aimed to investigatethe spatial and temporal relationships between these factors and dengue outbreaks in thenorthern region ofSri Lanka, in order to clarify the disease causes and to better target surveillance and control. Remote sensing (RS) data gathered from a plurality of satellites were used to develop an index comprisingrainfall, humidityand temperature data. RS data gathered by ALOS/AVNIR-2 were used to detect urbanization,and a digital land cover map was usedto 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, enablingboth spatial association analysis and spatial statistical analysis. Our findings show that the combination of ecologicalfactors derived from RS data and socio-economic and demographic factors is suitable for predicting spatial and temporal patterns of dengue outbreaks.

Keywords:dengue, ecological and socio-economic and demographic factors, Local Moran LISA statistics, spatial and temporal analysis

1. INTRODUCTION

Since the early 1960s,dengue has been an important vector-borne viral disease and a major cause of childhood fever burdenin Sri Lanka, which has experienced a number of large epidemics over the past decade. In 2012, 44,456 dengue cases were reported, corresponding to a rate of 220 per 100,000 individuals.Approximately a quarter of reportedcases occur in children under 15 years of age (Tam et al., 2013).Dengue is now considered to be hyperendemic in Sri Lanka, with detectedco-circulation of multiple serotypes (Kanakaratne, 2009; WHO, 2011).

Dengue outbreaks are affected by biological, ecological,socio-economic and demographicfactors thatvary over time and space. Disease-promoting factors include 1) climate,such asrainfall, humidity andtemperature(Canyon, 1999);2) changes in land cover,particularly rapid unplanned expansion of urbanizationwith inadequate housing and infrastructure(Gubler, 1997;Rodhain and Rosen, 1997;Lian, et al., 2006; Ooi and Gubler, 2008;Tran, et al. 2010;Gubler, 2011; WHO, 2012);and 3) high population density(Gubler, 1998).

Previous studies have identified a large number of biological, ecological and socio-economic and demographicfactorsthat are considered to impact both susceptibility and exposure to spatial and temporaloutbreaks of dengue in Sri Lanka. However, these factors have mainly been examined separately, with limited success. Further clarification is required.

The present study aimed to investigate the spatial and temporal relationships between these factors andoutbreaks of dengueassociated with mosquito breeding sites and habitatsin northernSri Lanka, in order to clarify the causes of the disease and to better target surveillance and control in this region.

2. MATERIALANDMETHODS

2.1 Conceptual Framework

Ourconceptual framework highlightsecological factors (i.e., rainfall, humidity, temperature and land cover, including rapid unplanned expansion of urbanization) as well associo-economic and demographicfactors (i.e., population density)that impact vulnerability todengue by creating conditions of susceptibility within humancommunities, of exposure to the vector, or proximity to breeding habitats.

2.2Study Area

Dengue outbreaks in Sri Lanka are spatially heterogeneous.Investigatingthe spatial-temporalrelationships between various factorsand dengue outbreaks at the local levelin Sri Lankacan help tobetter target surveillance and control.

Our study area was thenorthern region of Sri Lanka,consisting oftwelve Medical Officer of Health(MOH) divisions which are the health administrative divisions in Sri Lanka.Each MOH divisionhas differentgeographic features—including agricultural fields, forested areas, wetlands, grassland, urban areas, etc.—as well as different social backgrounds.The climate in the region is tropical, with twomonsoonseasons:namely north east monsoon fromNovember to April, andsouth west monsoon fromMay to October.

2.3DengueData

From the MOH divisionsin Sri Lanka, we obtained the monthly numbers ofclinically confirmed dengue cases fromJanuary 2010 through December 2013 in the twelve MOH divisions,andthe annualnumbers of clinically confirmed dengue cases from 2007 through 2013in the same MOH divisions.

2.4 Rainfall, Humidity and Temperature

Rainfalldata for the regionwere obtained usingthe Global Satellite Mapping of Precipitation(GSMaP) product,based on the combined MW-IR algorithm with a plurality of satellites:TRMM TMI, Aqua AMSR-E, GCOM-W AMSR2, DMSP SSM/I, DMSP SSMIS, NOAA-19 AMSU, MetOp-A AMSU and GEO IR. The GSMap is drawn to the highest levels of precision and resolution in the world (Temporal resolution: 1 hour, Spatial resolution: Grid latitude-longitude of 0.1 degrees), and is published on a quasi-real-time basiswith an approximately 4-hour lag from the time of satellite monitoring(JAXA, 2014; RESTEC, 2014). Themonthly averagerainfallfrom January 2010 to December 2013 and the annual averagerainfallfrom 2007 to 2013 wereobtained by processing the RS data, and converting this processed data into TIFF image data for spatial analysis in geographic information systems (GIS).

Humiditydata were acquiredfrom theAqua/MODIS and Terra/MODIS data set. The MODIS instrument is operating on both the Terra and Aqua spacecraft. It has a viewing swath width of 2,330 km, and views the entire Earth's surface every one to two days. Its detectors measure 36 spectral bands between 0.405 and 14.385 μm, and it acquires data at three spatial resolutions: 250m, 500m and 1,000m (NASA, 2014).We obtained the monthlyaverage humiditylevels fromJanuary 2010 to December 2013,and the annualaverage humidity levelsfrom 2007 to 2013 by processing the RS data, and converting this processed data into TIFF image data for spatial analysis in GIS.

Temperature data were also acquiredfromthe Aqua/MODIS and Terra/MODIS data set. Weobtained the monthly averagetemperaturesfrom January 2010 to December 2013 and the annualaverage temperaturesfrom 2007 to 2013 by processing the RS data, and converting this processed data into TIFF image data for spatial analysis in GIS.

2.5 Land Cover,Including Urbanization

Apaper survey mapwas digitizedto generate detailedland cover data, and the digital land cover map of this study areawas used for spatial analysis in GIS.

The ALOS/AVNIR-2 data setwas used to detect urbanizationby conducting unmixing, whichisolates the contribution of a specific material within the mixed pixel. Thismethod identifies the locations of pixels that contain a given material, and reports the material pixel fraction, i.e., how much of the material is in each pixel.We selected eight material pixel fraction classes thatreport 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 of30–39% belong to class 0.30–0.39,and pixels with material pixel fractions of90–100% belong to class 0.90–1.00.

2.6 Population Density

We obtained annual population datafor the respective MOH divisionfrom 2007 to 2013fromthe Regional Epidemiological Unit, Jaffna. With this information combined withthe area data by MOH divisionobtainedfrom spatial analysis in GIS, we calculated the population densityas a socio-economic and demographic factor. We also calculatedthe average value froma set ofannual population density at the MOH divisionlevel to investigatethe comprehensive trend of annual population density. This was used for both spatial association analysis and spatial statistical analysis.

2.7 Incidence Rates

To examine the spatial patterns of dengue disease, epidemic curves were produced by calculating the annual dengue incidence rate during the period 2007–2013. Annualincidence rates for each MOH division were calculated from the number of annualconfirmed dengue cases, divided by the total population-years and then multiplied by 10,000.These rates were expressed as annualconfirmed dengue casesdivided by total population*10,000people.The average annual incidence at the MOH divisionlevel was also calculated to determine the comprehensive trend of annual incidence. This was used for both spatial association analysis and spatial statistical analysis.

2.8Spatial Analysisin GIS

A polygon layerthatgeneratesthe twelve MOH divisions inthe northern region of Sri Lankawas used for spatial analysis in GIS. TIFF image data on rainfall, humidity and temperaturewere integrated into GIS, and the pixel (i.e., raster) size was changed from0.05 to0.01.Thepolygon layer and the processed raster layer wereoverlaid. The values of a raster within the polygonswere summarized, and the results were reported to excel tables.

The digital land cover map was integrated into GIS. Thepolygon layer and the digital land cover map layer were overlaid. Theland cover data within the polygonswere summarized and the results were reported to excel tables.The raster data on urbanization were integrated into GIS. Thepolygon layer and the rasterlayer were overlaid. Again, the values of a raster within the polygonswere summarized, and the results were reported to excel tables.

The table of polygon layer attributeswas joined with the excel tables containing dataon ecological,socio-economic and demographic factors. This information was used for spatial association analysis and spatial statistical analysis.

We additionally calculated the average valuesfromdata on annual rainfall, humidity and temperature at MOHdivisionlevel. This information was usedto investigate the comprehensive trend of annual rainfall, humidity and temperature, and was used for both spatial association analysis and spatial statistical analysis.

2.8 Temporal Analysis

To examine temporal patterns, we used data on monthly dengue cases, rainfall,humidityand temperatureduring the period from January2010through December2013. The moving average (MA) was calculatedand visualizedto examine thetemporal climatetrend associated withoutbreak ofdengue. We also calculated the average monthlyvalues from data on monthlyrainfall, humidity and temperaturewithin the period to investigate the comprehensive trend and to be used for the chi-square test.The chi-square testwas used to test monthly differences indengue cases, rainfall,humidityand temperatureacrossthe study period. The statistical significance was set at 0.05.

2.9Spatial Association Analysis

UnivariateLocal Indicators of Spatial Association (LISA) was appliedto measure the local spatial autocorrelationof dengue outbreak using GeoDa(Anselin, 1995; Anselin et al., 2006).LISA are statistics that measure spatial dependence and evaluate the existence of local clusters within the spatial arrangement of a given variable. They are based on a statistical index I developed by Moran to measure the global spatial autocorrelation of the overall data clustering in the area under investigation (Moran, 1950). Moran's I ranges from −1 (negative spatial autocorrelation) to 1 (complete spatial dependence), with 0 indicating anabsence of spatial dependence (i.e., random distribution) (Guessous et al., 2014).

Local spatial autocorrelation analysis was performedbased on the Local Moran LISA statistics, which yields a measure of spatial autocorrelation for each individuallocation.The LISA statistic reveals five categories of spatial autocorrelation that appear on the cluster map legend:1) not significant, 2) high-high, 3) low-low, 4) low-high and 5) high-low (Anselin, 2003; Singh et al., 2011).High-high and low-low represent positive spatial autocorrelation, andhigh-low and low-high represent negative spatial correlation (Anselin, 2003;Martinez et al., 2014).A finding of significant clustering at $p < 0.05$ suggests that dengue incidencevalues are too similar across these neighboring provinces to have occurred by chance, providing significant evidence for rejecting the null hypothesis of spatial randomness (Martinez et al., 2014).

2.10Spatial 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 factorswere categorized intwolevels: above average and below average.The threshold values fortheselevels weredeterminedbased onthe averagevalues for these factorsfrom the results obtained with spatial analysis in GIS.Land cover differed among MOH divisions,with some MOH divisionsshowing a total absence ofa given land cover type.Regarding the land cover data, the threshold values forthe levels werecategorized as two-levelbased onthe presence or absence of eachland cover.The categorized data, dengue case and control (i.e., populationminus dengue case) were used for the chi-square test.The statistical significance was set at 0.05.

As a second exploratory analysis, using the results from the chi-square test, wecomparedthe differences inecological,socio-economic and demographicfactorsbetweenthe areas of significant high-high clustering(i.e., endemic areas) and the areas of significant low-high clustering (i.e., non-endemic areasestimated to be controlled by some factors)as identified in the univariate LISA analysis.

3. RESULTS

3.1 Results of Temporal Analysis

Humiditytends to rise inearlyJanuary,remaining high during the dry season,andthen decliningwith theincrease in rainfallin early September.These changesare acceleratedat lowertemperature.

The distribution of monthly dengue casesindicated a strong seasonal pattern.Dengue case tended to increase after exponential increases or decreasesin rainfall. The chi-square testresults supportedthese tendencies. We observed significant monthly differences indengue cases and rainfall ($p < 0.01$), while humidityand temperaturewere not significant.

3.2 Results of Spatial Association Analysis

The LISA cluster map shows two types of geographical clustering (high-high and low-high).The area of significanthigh-high clustering ofthe average valuesfrom a set of annual dengue incidencesaccounted for 8.3% and occurred in NallurMOH division.The area of significantlow-high clustering ofthe average valuesfrom a set of annual dengue incidencesaccounted for 16.7%and occurred in Kopay and TellipallaiMOH divisions.The Moran's I statistic was −0.08,suggesting a random spatial pattern.

3.3Results of Spatial StatisticalAnalysis

The spatial statistical analysis revealedthe dengue outbreak was significantly associated withecological,socio-economic and demographic factors.Significantly more dengue cases were observed inMOH divisions(66.7%)withaverage annualrainfall of >1353 mm compared to in those with average annualrainfall of <1353mm ($\chi^2 = 112.8; p < 0.01$). Correspondingly, we also observed significantly more dengue cases inMOH divisions(66.7%)with average annualhumidity of >39.62 mm compared to in those with average annualhumidityof <39.62mm ($\chi^2 = 55.6; p < 0.01$). Moreover, significantly more dengue cases occurredinMOH divisions(58.3%)with an average annualtemperature of >31.2°C compared to in those with an average annualtemperatureof <31.2°C ($\chi^2 = 104.7; p < 0.01$).

Dengue occurrence was also significantly associated with the presence or absence of built-up areaconsidered to represent urbanization($\chi^2 = 264.7; p < 0.01$).The presence of built-up area inMOH divisions(33.3%) significantly influenced dengue occurrence, withsignificantly more dengue cases observed inMOH divisions(50.0%) thathad a>18%ratioofurbanizationtoMOH divisionarea compared to in those with a <18%ratioofurbanizationtoMOH divisionarea($\chi^2 = 40.7$; $p < 0.01$).We also found significantly more dengue cases inMOH divisions(33.3%) with a population density of >1150 compared to those with a population density of <1150 ($\chi^2 = 347.2; p < 0.01$).

The chi-square test results showedNallurMOH divisionto be ahigh-high clustering area, withbuilt-up land area and a higherpopulation density, whileKopay and TellipallaiMOH divisionswerelow-high clustering areaslackingbuilt-up land area and having lowerpopulation densities. These results suggest significant differences in the presence or absence of built-up area and higherpopulation density between high-highclustering areas and low-highclusteringareas.Presence of built-up area and higher population densitycould influence the dengue occurrence.

4. CONCLUSION

Our present results showedthat dengueoutbreak wasassociated with rainfall, humidity, temperature, built-up areaconsidered to representurbanization, urbanization and higher population density. Furthermore, our analyses quantitatively indicatedto what degree these factors influenced dengueoccurrence. Our findings indicatethat these factorsimpact vulnerability todengue by creating conditions of either susceptibility within humancommunities or of exposure to the vector and proximity to breeding habitats.

The presently observed temporal association underlines the fact that rainfall, humidity and temperature (considered as ecological factors) can strengthen forecasting models. The spatial association found in our studyhighlightsthe fact that built-up areaand urbanization(considered as ecological factors) and higher population density (a socio-economic and demographicfactor) can also strengthen forecasting models. Spatial-temporal models must be developed and strengthened by incorporatingecological and socio-economic and demographicfactors for further analysis.

Dengue transmission within Sri Lanka is spatially heterogeneous.Further research must focus on the whole island to improve the accuracy ofspatial and temporalmodels.An integrated spatial-temporal prediction model using ecological and socio-economic and demographic factors could lead tosubstantial improvementsin the control and prevention of dengue by allocating the rightresources to the appropriate places at the right time.

5. REFERENCES

Anselin, L (1995), Local indicators of spatial association—LISA,Geographical Analysis, Vol. 27, pp. 93-116

Anselin, L (2003),Local Spatial Autocorrelation, In GeoDa™ 0.9 User's Guide, University of Illinois, Urbana-Champaign, Urbana, IL, pp. 99-101

Anselin, L,Syabri I and Kho Y (2006), GeoDa: An introduction to spatial data analysis, Geographical Analysis, Vol. 38, pp. 5-22

Canyon, DV, Hii JL and Müller R (1999), Adaptation of Aedesaegypti (Diptera:Culicidae) oviposition behavior in response to humidity and diet, Journal of Insect Physiology, Vol. 45, No. 10, pp. 959-964

Gubler, DJ (1997), Dengue and Dengue Hemorrhagic Fever: Its History and Resurgence as a Global Public Health Problem, In: Gubler DJ, and Kuno G, eds., Dengue and Dengue Hemorrhagic Fever, CAB International, London, pp. 1-22

Gubler, DJ (1998), Dengue and dengue hemorrhagic fever, Clinical Microbiology Reviews, Vol. 11, No. 3,pp. 480-496

Gubler, DJ (2011), Dengue, Urbanization and Globalization: The Unholy Trinity of the 21[st] Century, Tropical Medicine and Health, Vol. 39, No. 4 Supplement,pp. 3-11

Guessous, I, Joost S, Jeannot E, Theler JM, Mahler P,Gaspoz JM and GIRAPH Group (2014), A comparison of the spatial dependence of body mass index among adults and children in a Swiss general population, Nutrition Diabetes, Vol. 4, pp. e111

JAXA (2014), JAXA Global Rainfall Watch, Available: http://sharaku.eorc.jaxa.jp/GSMaP/index.htm Accessed August 2014

Kanakaratne, N, Wahala WM, Messer WB, Tissera HA, Shahani A, Abeysinghe N, de-Silva AM andGunasekera M (2009), Severe

Dengue Epidemics in Sri Lanka, 2003–2006, Emerging Infectious Diseases, Vol. 15, No. 2, pp. 192-199

Lian, CW, Seng CM and Chai WY (2006), Spatial, environmental and entomological risk factor analysis on a rural dengue outbreak in Lundu District in Sarawak, Malaysia. Tropical Biomedicine,Vol. 23,pp. 85-96

Martinez, AN, Mobley LR, Lorvick J, Novak SP, Lopez AM andKral AH (2014), Spatial analysis of HIV positive injection drug users in San Francisco, 1987 to 2005, International Journal of Environmental Research and Public Health, Vol. 11, No. 4, pp. 3937-3955

Moran, PAP (1950), Notes on continuous stochastic phenomena,Biometrika,Vol. 37, pp. 17-23

NASA (2014), National Aeronautics and Space Administration, MODIS Web, Available:http://modis.gsfc.nasa.gov/data/ Accessed August 2014

Ooi, EE andGubler DJ (2008), Dengue in Southeast Asia: epidemiological characteristics and strategic challenges in disease prevention, Cadernos deSaúdePública,Vol. 25, Supplement,pp. 115-124

RESTEC (2014), Global Satellite Mapping of Precipitation (GSMaP), Available: https://www.restec.or.jp/. Accessed August 2014

Rodhain, Fand Rosen L (1997), Mosquito vectors and dengue virus-vector relationships, In: Gubler DJ, andKuno G, eds., Dengue and Dengue Hemorrhagic Fever, UK: CAB International, Wallingford,pp. 45–60

Singh, A, Pathak PK, Chauhan RK and Pan W (2011), Infant and child mortality in India in the last two decades: a geospatial analysis, PLoS One, Vol. 6, No. 11, pp. e26856

Tam, CC,Tissera H, de Silva AM, De Silva AD, Margolis HS andAmarasinge A (2013), Estimates of Dengue Force of Infection in Children in Colombo, Sri Lanka, PLOS Neglected Tropical Diseases, Vol. 7, No. 6, pp. 1-7

Tran, HP, Adams J, Jeffery JA, Nguyen YT, Vu NS, Kutcher SC, Kay BH and Ryan PA (2010), Householder perspectives and preferences on water storage and use, with references to dengue, in the Mekong Delta, southern Vietnam, International Health, Vol. 2, No. 2, pp. 136–142

WHO South East Asia Regional Office (2011), Comprehensive Guidelines for Prevention and Control of Dengue and Dengue Haemorrhagic Fever – Revised and Expanded Edition, New Delhi, Available: http://www.searo.who.int/entity/vector_borne_tropical_diseases/documents/SEAROTPS60/en/index.html Accessed May 2013

WHO (2012), Dengue and Severe Dengue, Fact Sheet Nu117,Available: http://www.who.int/mediacentre/factsheets/fs117/en/ Accessed April 2012