Am. J. Trop. Med. Hyg., 74(1), 2006, pp. 17–19

SHORT REPORT: ANALYSIS OF MALARIA CASES IN BANGLADESH WITH REMOTE SENSING DATA

ATIQUR RAHMAN,* FELIX KOGAN, AND LEONID ROYTMAN

National Oceanic and Atmospheric Administration Cooperative Remote Sensing Science and Technology Center, The City College of New York, New York, New York; National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Service, Camp Spring, Maryland

Abstract. Epidemiologic data of malaria cases were correlated with satellite-based vegetation health (VH) indices to investigate if they can be used as proxy for monitoring malaria epidemics in Bangladesh. The VH indices were represented by the vegetation condition index (VCI) and the temperature condition index (TCI). The VCI and TCI estimate moisture and thermal conditions, respectively. Sensitivity of VCI and TCI was assessed using correlation and regression analysis. During cooler months (November–March) when mosquitoes are less active, the correlation was low. It increased considerably during the warm and wet season (April–October), reaching 0.7 for the TCI in early October and −0.66 for the VCI in mid September.

Bangladesh is an Asian country where malaria has become one of the biggest health concerns. Most malaria cases are reported in three administrative regions (divisions) of Bangladesh, as shown in Figure 1A (http://www.bangladeshgov.org/bdmaps). Mosquitoes are very sensitive to moisture and temperature, and their activities can be monitored by weather conditions.[1] However, the weather station network in Bangladesh is not dense enough for efficient monitoring. Therefore, this report investigated the potential of using remote sensing technology in this endeavor.

Anopheles dirus is the most widespread mosquito in Bangladesh.[2,3] The malaria parasite (*Plasmodium*) is transmitted by adult infected female mosquitoes that bite humans to obtain blood necessary for egg development. The time from laying of eggs to development of an adult mosquito is 20–25 days.[4,5] Over the next 20–30 days, female *A. dirus* can bite and spread malaria.[4,6]

Three weather parameters are important for mosquito activity and malaria epidemiology: temperature, humidity, and rainfall.[1,2] Temperature and humidity in Bangladesh are relatively stable from year to year. However, annual rainfall fluctuates between 2,000 and 3,000 mm. Two seasons are defined in the annual cycle: a warm, wet season from April to October, and a cool, dry season from November to March. During the cool, dry season, mosquitoes are less active and the number of malaria cases is small. This number increases considerably during the warm, wet season.[5,7]

Two types of data were used in this study: malaria statistics collected from the Directorate General of Health of the Bangladesh Ministry of Health and satellite data collected from United States National Oceanic and Atmospheric Administration (NOAA). Malaria statistics were represented by the annual number of malaria patients expressed as a percentage of the total number of people with fever tested in hospitals. Figure 1B shows annual percentage of malaria cases in Bangladesh from 1992 to 2001. It is apparent that the percentage of infected people is gradually increasing and these numbers fluctuate from year to year due to changes in the weather. The long-term tendency in malaria dynamics shown in Figure 1B was approximated by linear Equation 1. The weather-related variations around the trend were expressed as a ration of actual cases to the estimated from the trend (Equation 2).

$$Y_{trend} = 5.15 + 1.09 \times Y \quad (1)$$

$$DY = (Y/Y_{trend} \times 100 \quad (2)$$

where Y is actual percent of malaria cases per year, Y_{trend} is the percent of malaria cases estimated from trend, and DY is deviation (%) from the trend. DY can be explained by comparing two years, 1994 and 1997. In 1997, DY was only 61% or 39% below the trend, whereas in 1994, DY was 122% or 22% above the trend. These estimations indicate that the 1997 (smaller % of cases) was an unfavorable year for mosquitoes development and malaria transmission, whereas 1994 (larger % of cases) was favorable.

Satellite data were presented by radiances measured by the Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA afternoon polar orbiting satellites. They were collected from the NOAA/National Environmental Satellite, Data, and Information Service Global Vegetation Index (GVI) data set during 1992–2001. The GVI has spatial resolution of 4 km sampled to 16 km and one-day temporal resolution sampled to a seven-day composite.[8,9] The radiances in the visible (Channel 1), near infrared (Channel 2), and infrared (Channel 4) spectral bands were used in this study. Data were collected for the most populated areas of Bangladesh districts, which have the largest percentage of malaria cases (Figure 1A). The post-launch calibrated Channel 1 and Channel 2 radiances were used to calculate the normalized difference vegetation index (NDVI = [Channel 2 − Channel 1]/[Channel 2 + Channel 1]) and Channel 4 data were converted to brightness temperature (BT).[9,10] Weekly NDVI and BT have some noise related to variable transparency of the atmosphere, bi-directional reflectance, and position of sun and sensor. This noise should be reduced to use the data for environmental monitoring. Noise removal was fulfilled by smoothing annual vegetation condition index (VCI) and temperature condition index (TCI) time series with a statistical filter. This filter combined five- span median smoothing with least square technique.[9]

The vegetation health (VH) concept was designed to extract the weather component from NDVI and BT values.[9] The NDVI and BT represent two environmental signals: ecosystem, which explains long-terms changes in vegetation driven by climate, soils, vegetation type, topography, etc., and

* Address correspondence to Atiqur Rahman, National Oceanic and Atmospheric Administration Cooperative Remote Sensing Science and Technology Center, The City College of New York, 141st Street and Convent Avenue, New York, NY 10031. E-mail: fmatiq@yahoo.com

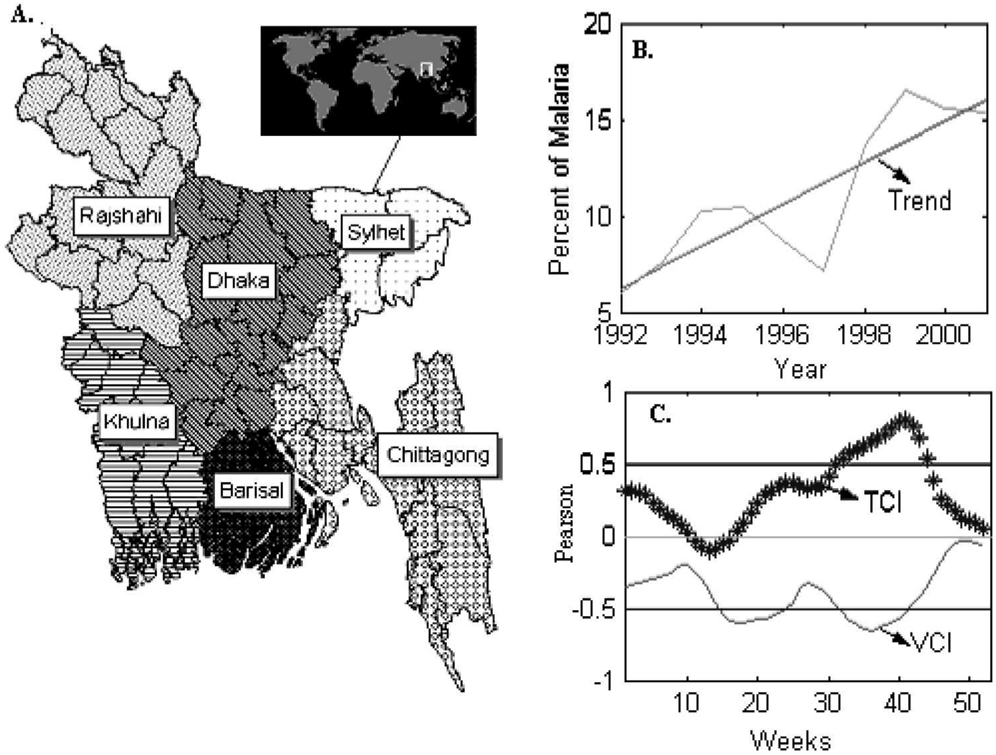

FIGURE 1. **A**, Bangladesh and area of satellite data collection. **B**, Annual malaria cases in Bangladesh and trend line. **C**, Correlation coefficient dynamics of the percent deviation of malaria cases from trend versus Temperature Condition Index (TCI) and Vegetation Condition Index (VCI).

weather, which explains short-term variations in each ecosystem driven by weather fluctuations.[11] To separate weather components, we first calculated climatology of smoothed NVDI and BT. It was approximated by 12-year maximum (MAX) and minimum (MIN) values of NDVI and BT derived for each week and pixel. The (MAX-MIN) criteria were used as climatology to describe and classify vegetation greenness and moisture (NDVI) and temperature (BT). Because the minimum and maximum values in the annual cycle delineate ecosystem component of NDVI and BT for the years with extreme weather conditions, the area between these MAX-MIN approximates the weather-driven component of NDVI and BT. The VCI and TCI indices are invariant of ecologic background and reflect weather fluctuations only. Deviation of NDVI and BT from the corresponding MAX-MIN climatology was used to approximate NDVI and BT fluctuations from year to year. As the result, VCI and TCI were approximated by the following equations:

$$\text{VCI} = 100 \times (\text{NDVI} - \text{NDVI min})/(\text{NDVI max} - \text{NDVI min}) \quad (3)$$

$$\text{TCI} = 100 \times (\text{BT max} - \text{BT})/(\text{BT max} - \text{BT min}) \quad (4)$$

where NDVI, NDVImax, and NDVImin (BT, BTmax, and BTmin) are smoothed weekly NDVI (BT), their multiyear absolute maximum and minimum, respectively.[9] The VCI and TCI change from 0 to 100, reflecting changes in moisture (VCI) and thermal (TCI) conditions from extremely unfavorable (vegetation stress) to favorable, respectively. The VCI and TCI value around 50 estimates near normal conditions. When the indices are below 50, conditions deteriorate, indicating different levels of vegetation stress. When they increase to 100, conditions are improving. Average values of VCI and TCI were calculated for the Dhaka, Chittagong and Sylhet divisions, which have the largest number of malaria cases in Bangladesh. Because our data contained nine years of observations, we were able to express NDVI and BT in the form of anomalies.

Correlation dynamics of de-trended malaria cases (DY) versus VCI and TCI are shown in Figure 1C. The correlation results show that during cooler months (early spring and late fall) when mosquitoes are less active, the correlation is low for both indices. When the mosquito season starts in April, the correlation becomes stronger. Maximum correlation for TCI (around 0.7) occurs during September–October; for VCI, the maximum has two peaks at the end of April (–0.60) and in mid-September (–0.66). These results are compatible with mosquito activity during April–October when several generations of mosquitoes contribute to malaria transmission.

It is important to emphasize that the correlation of DY with TCI is positive, indicating that larger number of malaria cases are associated with cooler conditions (TCI > 60). However, during drought years when vegetation is under stress (TCI < 40), fewer people have malaria. These results are consistent with those of climate studies indicating that hot weather depresses mosquito activity and malaria transmission in Bangladesh.[12] The correlation of DY with VCI is negative, indicating that a larger number of malaria cases (DY above trend) is associated with drier conditions (VCI < 40), whereas it is the opposite for a smaller number of malaria cases.

The results of correlation analysis in Figure 1C were used to develop regression equations. Three options were investigated: using TCI, VCI, or their combination. These equations are

$$DY = 69.41 + 0.63 \times TCI_{41};\ MCC = 0.79;\ E = 11.48\% \quad (5)$$

$$DY = 129.14 - 0.55 \times VCI_{17};\ MCC = 0.60;\ E = 15.05\% \quad (6)$$

$$DY = 79.76 + 0.54 \times TCI41 - 0.12 \times VCI36;\ MCC = 0.80;\ E = 12.1\% \quad (7)$$

where MCC is multiple correlation coefficient and E is the error of estimation.

Regression coefficients indicate larger contribution of TCI versus VCI, especially when both indices are in Equation 7. The error of estimation was slightly smaller when only TCI is used as a predictor. The earliest assessments can be done at the very beginning of malaria season in late April (week 17) using VCI-based equations. However, the error of this estimate is larger than when indices of later months are used. The results of this study show that AVHRR-based VH indices can be used as proxy for numerical estimation of the number of malaria cases in Bangladesh.

Received August 1, 2004. Accepted for publication May 7, 2005.

Authors' addresses: Atiqur Rahman and Leonid Roytman, National Oceanic and Atmospheric Administration Cooperative Remote Sensing Science and Technology Center, The City College of New York, 141st Street and Convent Avenue, New York, NY 10031, Telephone: 212-650-7000, E-mails: fmatiq@yahoo.com and eelr@ee-mail.engr.ccny.cuny.edu. Felix Kogan, National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Service, 5200 Auth Road, Camp Spring, MD 20746, E-mail: felix.kogan@noaa.gov.

REFERENCES

1. Githeko A, Lindsay S, Confalonieri U, Patz J, 2000. Climate change and vector-borne diseases: a regional analysis. *Bull World Health Organ 78:* 200–207.
2. Boëte C, Koella J, 2002. A theoretical approach to predicting the success of genetic manipulation of malaria mosquitoes in malaria control. *Malaria J 1:* 3.
3. Elias M, Rahman M, 1987. The ecology of malaria carrying mosquito *Anopheles* and its relation to malaria in Bangladesh. *Bangladesh Med Res Counc Bull 13:* 15–28.
4. Smith D, McKenzie E, 2004. Statics and dynamics of malaria infection in *Anopheles* mosquitoes. *Malaria J 3:* 13.
5. Rosenberg R, Maheswary N, 1982. Forest malaria in Bangladesh, I. Parasitology. *Am J Trop Med Hyg 31:* 175–191.
6. Nagpal B, Sharma V, 1995. *Indian Anophelines*. New Delhi: Baba Barkha Nath Printers, 416–423.
7. Faiz MA, Yunus EB, Rahman MR, Hossain MA, Pang LW, Rahman ME, Bhuiya SN, 2001. Failure of national guidelines to diagnose uncomplicated malaria in Bangladesh. *Am J Trop Med Hyg 67:* 396–399.
8. Kidwell KB, 1997. *Global Vegetation Index User's Guide*. Technical Report, NOAA. Suitland, MD: U.S. Department of Commerce, 30–45
9. Kogan F, 2001. Operational space technology for global vegetation assessment. *Bull Am Meteorol Soc 82:* 1949–1964.
10. Rogers D, Hay S, Packer M, 1996. Predicting the distribution of tsetse flies in west Africa using temporal Fourier processed meteorological satellite data. *Ann Trop Med Parasitol 90:* 225–241.
11. Hay S, Snow R, Rogers D, 1998. Predicting malaria seasons in Kenya using multitemporal meteorological satellite sensor data. *Trans R Soc Trop Med Hyg 92:* 12–20.
12. Thomson M, Connor S, 2001. The development of malaria early warning systems for Africa. *Trends Parasitol 17:* 438–445.