6-5-2014

Environmental Data Analysis and Remote Sensing for Early Detection of Dengue and Malaria

Md Zahidur Rahman
CUNY La Guardia Community College

Leonid Roytman
CUNY City College

Abdelhamid Kadik
CUNY La Guardia Community College

Dilara A. Rosy
University of Dhaka

Environmental Data Analysis and Remote Sensing for Early Detection of Dengue and Malaria

Md Z Rahman[1], Leonid Roytman[2] , Abdelhamid Kadik[3] and Dilara A Rosy[4]
[1,3]Department of Mathematics, Engineering, and Computer Science, LaGuardia Community College of the City University of New York, 31-10 Thomson Avenue, Long Island City, NY-11101
[2]Department of Electrical Engineering, The City College of the City University of New York, 138 Street & Convent Avenue, New York, NY-10031
[4]University of Dhaka, Dhaka, Bangladesh

ABSTRACT

Malaria and dengue fever are the two most common mosquito-transmitted diseases, leading to millions of serious illnesses and deaths each year. Because the mosquito vectors are sensitive to environmental conditions such as temperature, precipitation, and humidity, it is possible to map areas currently or imminently at high risk for disease outbreaks using satellite remote sensing. In this paper we propose the development of an operational geospatial system for malaria and dengue fever early warning; this can be done by bringing together geographic information system (GIS) tools, artificial neural networks (ANN) for efficient pattern recognition, the best available ground-based epidemiological and vector ecology data, and current satellite remote sensing capabilities.

We use Vegetation Health Indices (VHI) derived from visible and infrared radiances measured by satellite-mounted Advanced Very High Resolution Radiometers (AVHRR) and available weekly at 4-km resolution as one predictor of malaria and dengue fever risk in Bangladesh. As a study area, we focus on Bangladesh where malaria and dengue fever are serious public health threats. The technology developed will, however, be largely portable to other countries in the world and applicable to other disease threats. A malaria and dengue fever early warning system will be a boon to international public health, enabling resources to be focused where they will do the most good for stopping pandemics, and will be an invaluable decision support tool for national security assessment and potential troop deployment in regions susceptible to disease outbreaks.

Keywords: Malaria, GIS, ANN, AVHRR, VHI, Data, Dengue, satellite remote sensing

1. INTRODUCTION

Vector-borne diseases (mosquito-borne diseases) have become a major international public health concern. Mosquito vectored diseases include protozoan diseases, i.e., malaria, dengue, dog heart-worm and yellow fever. Among the aforementioned, malaria is the most widely spread, and dengue intensified recently, creating a global problem. They are pandemic across many countries, infect millions of people every year, and are leading causes of morbidity and mortality. Presently, vaccines and effective drug treatment for dengue fever are unavailable, or, in the case of malaria, are limited by the development of drug-resistant pathogen strains. Due to these issues, public health interventions must target the mosquito vector. The *Anopheles* mosquitoes that transmit malaria and *Aedes* mosquitoes that transmit dengue fever flourish under specific large-scale environmental conditions of temperature, humidity and standing water that vary somewhat by mosquito species and strain. Vector-borne diseases are spread by mosquitoes which create different types of epidemics and many are regarded as contributing factors, such as: living condition of people, climate and landscape. The type of standing water in which the mosquito chooses to lay eggs depends upon the species. The presence of beneficial predators such as fish and dragonfly nymphs in permanent ponds, lakes and streams usually keep these bodies of water relatively free of mosquito larvae. However, swamps, clogged ditches and temporary pools and puddles are all prolific mosquito breeding sites. Other sites in which some species lay their eggs include tree holes and containers such as old tires, buckets, toys, potted plant trays, saucers, plastic covers or tarpaulins. Some of the most annoying and potentially dangerous mosquito species, such as the Asian tiger mosquito, come from these sites. Wet and warm weather normally stimulate mosquito multiplication and trigger an increase in the number of people bitten by mosquitoes, which is potentially favorable for development of epidemics.

Climate can be used as a predictor for mosquito development. Information from the Advanced Very High Resolution Radiometer (AVHRR) on-board the National Oceanic and Atmospheric Administration's (NOAA) polar-orbiting meteorological satellites were used to estimate land surface temperature (LST) and atmospheric moisture. Cold cloud duration (CCD) data derived from the High Resolution Radiometer (HRR) on-board the European Meteorological Satellite program's (EUMETSAT) and Meteosat satellite data were used to estimate rainfall. Temperature, atmospheric moisture and rainfall were independently derived from Meteorological data over Africa. These data were then used to test the accuracy of each methodology, so that the appropriateness of the two techniques for epidemiological research could be compared. Spatial information (SI) was a more accurate predictor of temperature, whereas Remote Sensing

Sensing Technologies for Global Health, Military Medicine, and Environmental Monitoring IV, edited by Šárka O. Southern, Mark A. Mentzer, Isaac Rodriguez-Chavez, Virginia E. Wotring, Proc. of SPIE Vol. 9112, 91121C · © 2014 SPIE · CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2050587

(RS) provides better surrogate for rainfall; both were equally accurate at predicting atmospheric moisture. The implications of these results for mapping short and long-term climate change and, hence, their potential for the study and control of disease vectors are considered. An increasing number of health studies have used remotely sensed data for monitoring, surveillance, or risk mapping, particularly of vector-borne diseases like malaria and dengue. Most of human health studies using remote sensing have focused on data from NOAA's Advanced Very High Resolution Radiometer (AVHRR), Landsat's Multispectral Scanner (MSS) and Thematic Mapper (TM) and France's Système Pour l'Observation de la Terre. We aim to develop the capability to monitor and predict the occurrence of favorable environmental conditions that promote malaria or dengue fever transmission using observations from earth-monitoring satellites. We desire to rely on remote sensing as much as possible because it provides regular coverage in space and time, which is particularly important in areas where ground-based weather and hydrological monitoring stations are sparse. As well, remote sensing of attributes that exercise a persistent influence on regional weather patterns, such as sea surface temperatures, snowpack, and soil moisture, offer the possibility of predicting the development or persistence of environmental conditions that promote malaria or dengue fever transmission weeks to months in advance. In this paper, we focus on malaria and dengue fever in Bangladesh, a country where we conducted studies on the relationship between remotely sensed indices and malaria and urban dengue epidemics. The risk mapping system developed will guide interventions, including vector control, prevention of transmission (e.g. through mosquito netting), and treatment efforts. We expect that the techniques we develop for integrating different remote sensing products (in a GIS framework) to create an outbreak warning system based on epidemiological data will be readily extendible to create analogous monitoring and early warning systems for waterborne diseases, food shortages, and other hazards that are strongly affected by environmental conditions.

2. STUDY AREA

Bangladesh is located in a tropical region in Southeast Asia and lies between 20°34’ and 26°38’ north latitude, and 88°01’ and 92°41’ east longitude. Bangladesh has its borders, on all sides but south, with the Indian states of Mizuram, Tripura, Assam and West Bengal. The southern deltaic region faces the Bay of Bengal. It has a small inter-country border with Myanmar [1]. Bangladesh has 64 districts and 6 administrative divisions: Barisal, Chittagong, Dhaka, Khulna, Rajshahi and Sylhet (Figure 1). It has a population of 88 million with a population density of 868 persons per square kilometers. Eighty percent of total population lives in rural area. Bangladesh is mostly comprised of low, mostly flat alluvial plain; it’s hilly in southeast, intersected by numerous rivers and rivulets, canals, swamps and marshy lands. Nearly two-thirds of the people in Bangladesh are employed in the agriculture sector, with rice as the single most important product. Natural resources found there are natural gas, arable land, timber and coal.

Malaria parasite (plasmodium) in Bangladesh is transmitted by female Anopheles mosquitoes. Out of the 15 species, *Anopheles Dirus* (AD) is most spread in the Southeast Asia [8, 9]. Breeding habitats of AD can be puddles on footpaths and turbulence pits at the heads of drainage gullies, which are able to hold water for some time without supplemental rainfall.

Mosquitoes transmit malaria year around. However during the cooler season (November-March) mosquitoes are less active and the number of malaria cases are few. This number increases considerably during warm and wet seasons. Malaria is transmitted by an adult infected female which bites in order to get human blood for laying eggs. Mosquito hatching periods from eggs to an adult stage is 7-15 days, and the incubation period for development of malaria after being bitten by an infected mosquito is 8-35 days. An entire cycle, when AD is able to bite and transmit malaria is 15-50 days. Therefore, during April-October, four to five cycles of malaria transmission may occur. After laying eggs, larvae appear in 4-10 days; the following pupae stage requires 1-4 days, and then after a couple of days, depending on water temperature, the adult mosquito is ready to bite. Distribution of malaria cases in Bangladesh in 1994 is shown in Figure 1.

Percent of Malaria cases for Bangladesh per division for 1992-2001 from DG Health of Bangladesh are shown in Table 1 Table1 shows that Countrywide, between 1998 and 2001 a general increase in the number of reported cases by 4 -5%. This increase can be explained in two ways, one is, the government adopt a new program “Essential Services Package” for fighting malaria and vector-borne diseases, second most important one is reoccurrence of malaria outbreaks along the border area [10].The positive cases increased in the Chittagong, Khulna and Rajshahi division, which are the border area and mostly forest covered.

Dengue fever (DF) and dengue hemorrhagic fever (DHF) are caused by four antigenically distinct but related dengue virus (official name: Dengue virus [DENV]) serotypes transmitted primarily by *Aedes aegypti* (yellow fever mosquito). DHF, the severe form of the disease, is endemic and frequently intensifies into epidemics in Southeast Asia, resulting in frequent hospitalizations and deaths. Recently, dengue has emerged as a substantial global health problem with increased incidence in new countries and tropical areas. DF was documented in Bangladesh from the mid-1960s to the mid-1990s, but an outbreak of DHF has not been previously reported. During late June 2000, a 28-year-old patient was admitted to a hospital in Dhaka, Bangladesh, with hemorrhagic fever, ascites, pleural effusion, and thrombocytopenia. An enzyme-linked

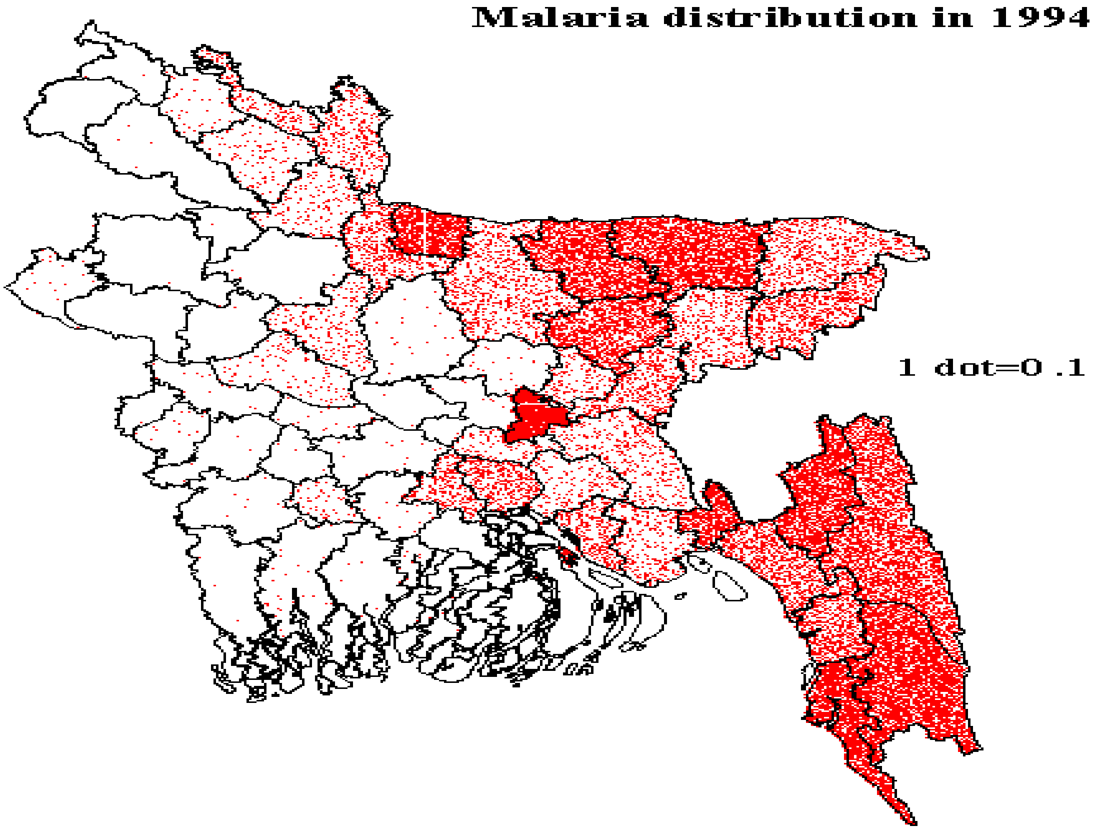


Fig. 1. Geographical Map of Bangladesh with the area study (Malaria and Dengue Distribution area)

immunosorbent assay (ELISA) for anti-dengue antibodies confirmed the case as DHF. That summer, an outbreak of DF (>5,000 hospitalized cases reported) and DHF occurred in Dhaka and other major cities of Bangladesh.

3. METHODOLOGY

Three data types were used in this study: malaria statistics, satellite data, and meteorological data. Malaria statistics were represented by annual total clinical malaria cases for 1992-2001. The data were collected from the Directorate General of Health, Bangladesh's Ministry of Health. These data provided the number of malaria cases from all patients with fever who came to the hospitals of Bangladesh. The data were aggregated to local administrative unit health centers and to district level. These data included the number of persons tested and the number of positive malaria cases. In this study, the latter was expressed in percentage of the former.

Satellite data included radiances measured by the Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA afternoon polar orbiting satellites. They were collected from the NOAA/NESDIS Global Vegetation Index (GVI) data set from 1992 through 2001. The GVI has spatial resolution of 4 km (sampled to 16 km) and daily temporal resolution sampled to 7-day composite. The radiances in the visible (Ch1), near infrared (Ch2) and infrared (Ch4) were used in this study. Post lunch-calibration was applied to Ch1 and Ch2 radiances and normalized difference vegetation index (NDVI) was calculated (NDVI= (Ch2-Ch1)/ (Ch2+Ch1)); the Ch4 radiances were converted to brightness temperature (BT).The method for processing NDVI and BT included removal of high frequency noise from the annual time series, approximation of annual cycle, calculation of multi-year climatology, and derivation of medium frequency variations associated with weather fluctuations.

High frequency noise (related to fluctuating transmission of atmosphere, sun/sensor geometry, bi-directional reflectance, random noise and etc) was removed by statistical smoothing of NDVI and BT annual time series using a combination of median filter and least square technique. After removal of high frequency noise, seasonal cycle in NDVI and BT become evident. Climatology of NVDI and BT was approximated by multi-year maximum (MAX) and minimum (MIN) values taken from smoothed data [2, 3]. The MAX and MIN for each pixel and week were calculated from twelve years of historical data described in Kogan (2001) [7]. The difference between MAX and MIN (MAX-MIN) represents those extreme fluctuations in NDVI and BT associated with weather fluctuations. The (MAX-MIN) criteria were used to describe and classify weather-related ecosystem's "carrying capacity" [4, 5]. Following Kogan (2001) the MAX, MIN and MAX-MIN values were used to approximate vegetation health indices: Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI) [6, 11, 12].

$$VCI=100*(NDVI - NDVI\ min)/ (NDVI\ max - NDVI\ min) \quad (1)$$

$$TCI=100*(BT\ max - BT)/ (BT\ max - BT\ min) \quad (2)$$

$$VHI=a* VCI + (1 - a)* TCI \quad (3)$$

Where NDVI, NDVImax, and NDVImin (BT, BTmax, and BTmin) are smoothed weekly NDVI (BT), their multi year absolute maximum and minimum respectively; *a* is a coefficient quantifying a share of VCI and TCI contribution in the VHI (Kogan 2001) [7] . The VCI, TCI and VHI change from 0 to 100, reflecting changes in vegetation conditions from extremely unfavorable (vegetation stress) to optimal (favorable), respectively. These indices estimate moisture (VCI), thermal (TCI) and combination of both (VHI) conditions. The VCI, TCI and VHI values around 50 estimates near normal conditions. If these indices approach to 0 then condition deteriorate indicating vegetation stress. On the opposite side of the scale, the conditions are estimated as favorable.

Ten-day average temperature (TºC) and humidity (H %) and 10-day total rainfall (R, mm) data were collected from 34 meteorological stations in Bangladesh during 1992-2001. Meteorological parameters (T, R and H) were expressed as a deviation from mean value during 1992-2001 (percent of mean for R, difference from mean for T and H) in order to evaluate weather anomalies during the annual cycle. Regional average T, H and R were calculated as average values from weather stations, in the divisions.

4. RESULTS AND DISCUSSION

Malaria parasite (plasmodium) in coastal divisions is transmitted by female Anopheles mosquitoes. The Chittagong division has 60-80 percent of all malaria cases in Bangladesh. Breeding habitats of AD are puddles on footpaths and turbulence pits at the heads of drainage gullies, which are able to hold water for sometime without supplemental rainfall. Mosquitoes in coastal divisions transmit malaria year around. However during the cooler season (November-March) mosquito are less active and the number of malaria cases are few. This number increases considerably during warm and wet seasons. Malaria cases of coastal divisions are shown in Table 1

Table 1 Malaria statistics of coastal divisions 1992-2001

Y\N	Bangladesh	Rajshahi	Khulna	Braishal	Dhaka	Chittagong	Sylhet
1992	6.02	0.72	0.067	0	5.4	16.6	9.6
1993	7.6	0.57	0.057	0.086	7.6	17.55	8.76
1994	10.24	0.69	0.07	0.07	7.7	21.76	21.25
1995	10.45	0.7	0.08	0.07	6.9	21.63	20.67
1996	8.7	0.34	0.19	0.10	3	20.53	8.8
1997	7.17	0.2	0.16	0.11	2.03	17.10	7.4
1998	9.7	0.46	0.4	0.58	2.5	22.21	7.03
1999	16.5	0.56	0.78	0.72	2.4	24.3	5.85
2000	15.53	0.29	0.8	0.68	1.7	21.47	8
2001	15.39	0.39	1.52	0.65	1.7	21.47	8

Figure 2 shows annual percent of malaria cases in coastal division during 1992-2001. As seen, malaria is on a rise during the 1990s. Although the Government of Bangladesh made efforts to eradicate malaria, the number of cases in Chittagong division was growing which is associated with poverty in this region. Variations in the number of cases around the trend are associated with weather changes from year to year. The long-term tendency in malaria cases dynamics was approximated by linear equation (1) and weather-related variations around the trend were expressed as a ration (equation 2) of actual cases to the estimated from the trend.

Y_{trend} = a+ b*Year (4)

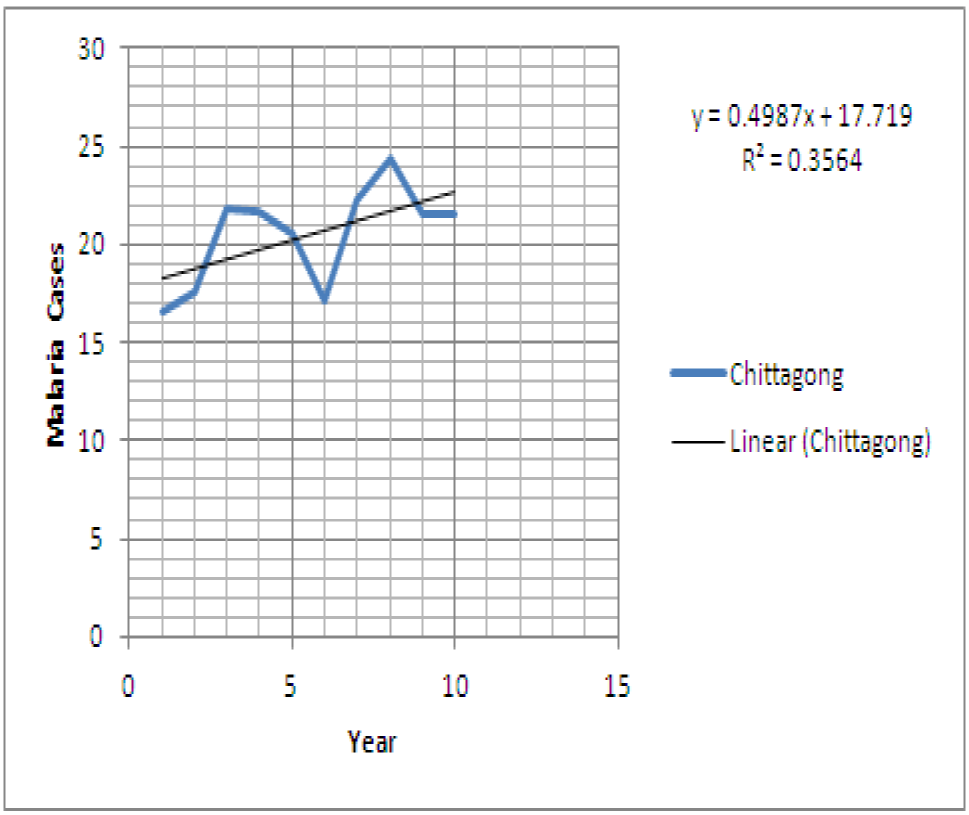
DY= (Y / Y_{trend})*100 (5)

Where, Y_{trend} is percent of malaria cases for weather conditions near normal; Y is % of malaria cases; Year is year number; a is intercept; b is slope; DY is deviation from trend expressed in percentage.

Intercepts and slopes for these divisions are shown in Table 2.

The DY for Chittagong division can be explained by comparing two neighboring years 1997 and 1998. In 1997, DY was 86% or 14% below the trend, while in 1998 DY was 108% or 8% above the trend. These estimates indicate that the 1997 was an unfavorable year for mosquito development, while 1998 was favorable.

The DY for Khulna division can be explained by comparing two extreme years 1997 and 1999. In 1997, DY was 33% or 67% below the trend, while in 1997 DY was 103% or 3% above the trend. These estimates indicate that the 1997 was an unfavorable year for mosquito development, while 1999 was favorable.



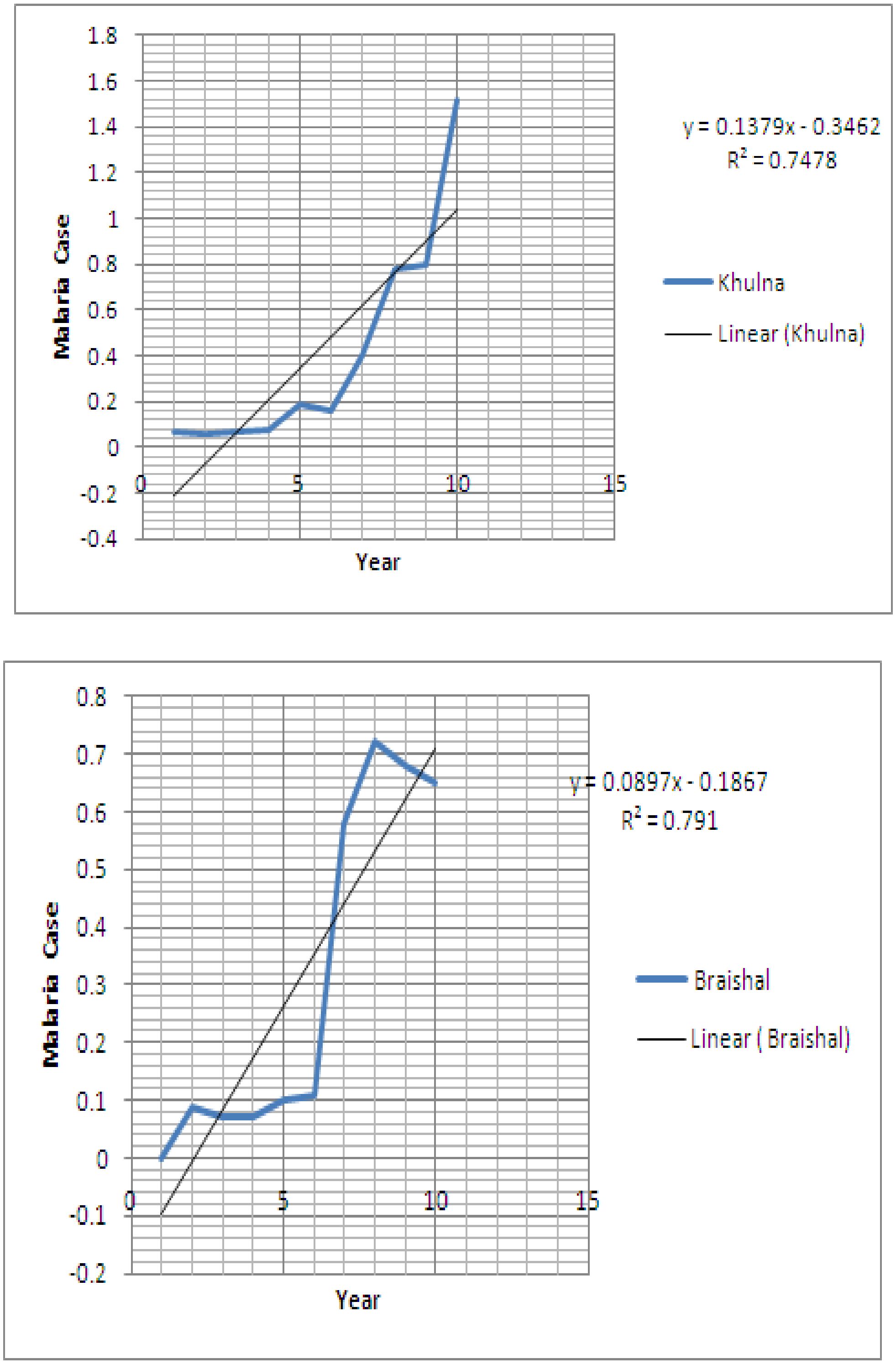


Fig. 2. Annual malaria cases in coastal divisions and trend line, 1992-2001

Table 2. Intercepts and slopes for coastal divisions

Division	Intercept(a)	Slop(b)
Chittagong	18.65	0.50
Khulna	-0.35	0.14
Barisal	-0.18	0.089
Bangladesh	5.153	1.014

Statistical analysis for whole Bangladesh

Figure 4 shows the modeled and observed % of malaria cases for 10 years. In general, for each year, the simulated percent of malaria cases differs 1-2% with those of observed percents, except for the year of 1997. This provides additional qualitative evidence that the model will be able to effectively predict the percent of malaria cases.

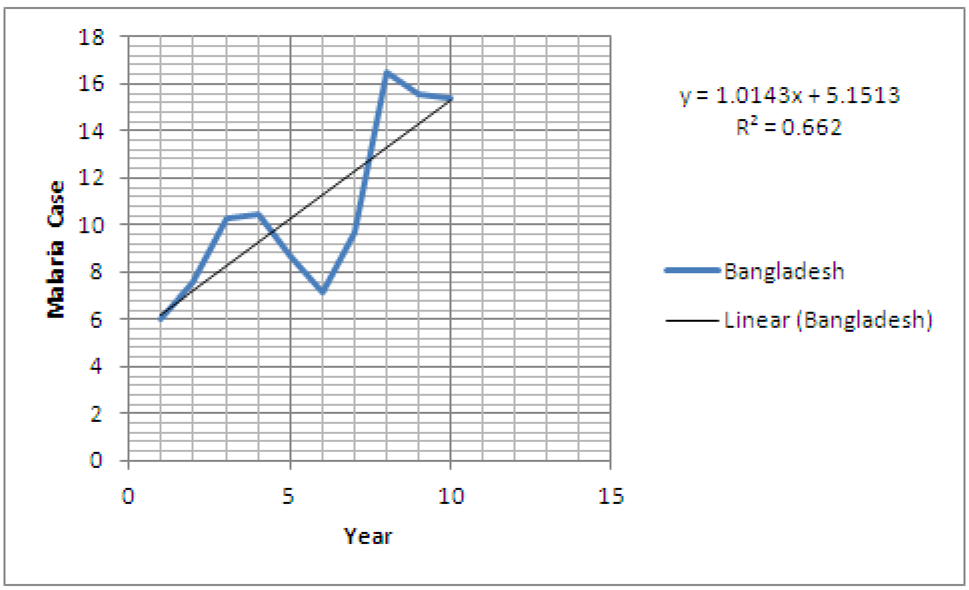


Fig. **3**. Annual malaria cases in all of Bangladesh and trend line, 1992-2001

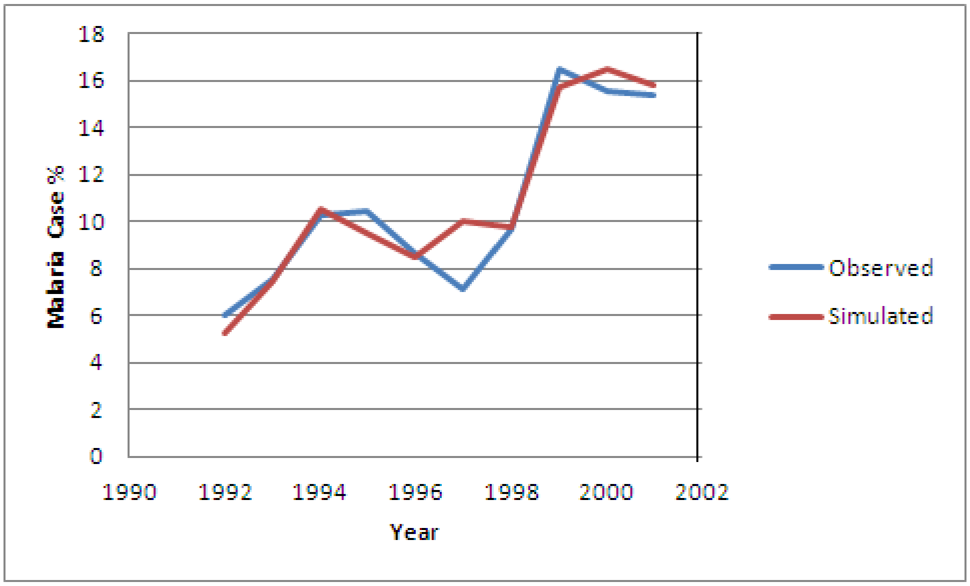


Fig. 4. Simulated and observed malaria cases for all of Bangladesh

6. CONCLUSIONS

Malaria and dengue fever affect the health and wealth of nations and individuals alike. Malaria and dengue fever are understood to be both diseases of poverty and causes of poverty, have significant measurable direct and indirect costs, and have been shown to be major constraints to economic development. Annual economic growth tends to rise when the risk of vector-borne diseases is low. Public expenditures include spending by government on maintaining health facilities and health care infrastructure, publicly managed vector control, education and research. Mosquitoes in Bangladesh, in all divisions, transmit malaria year round. In general, two seasons are defined in the annual cycle: wet and warm during April-October, and cool and dry during November-March. Throughout the cooler season mosquitoes are less active and the number of malaria cases are few. These numbers increase considerably during the warm and wet season.From 2 administrative divisions malaria is developed in the coastal zone (Chittagong, Khulna, Barisal). In mountain plain areas malaria is much less prevalent due to climate. Our research in the coastal division's mosquito activity season starts at the end of April (week 16) when the correlation between number of malaria cases and VHI increases. For dengue fever we could not develop an equation for monitoring the disease since the data sample was limited. The risk free of contracting vector-borne diseases in endemic areas will get investment, both internal and external, and affect individual and household decision making in many ways that have a positive impact on economic productivity and growth. The result of this study showed that AVHRR-based vegetation health indices could be used as a proxy for analysis and numerical estimation of the number of malaria cases in all of Bangladesh and for all divisions. However, these estimations and analyses are limited to certain time periods of the year and should not be used for all seasons.

REFERENCES

[1] Azad, Abdul, "Directorate General Health Services," http://www.dghs.gov.bd (2013)

[2] Curran, P., "Multispectral remote sensing of vegetation amount.", Prog. Phys.Geogr., 1980, 4, 315-341

[3] Gutman,G., "Review of the workshop on the "Use of satellite-derived vegetation indices on weather and climate prediction models," Bull. Am. Met. Soc., 1990, 71 (10), 1058-1063

[4] Justice,C.O, Townshend, J.R.G., Holben, B.N. and Tucker, C.J. "Analysis of the phenology of global vegetation using meteorological satellite data. Int. J.Rem. Sens., 1985, 8, 871-918.

[5] Kogan,F.N., "Remote sensing of weather impacts on vegetation in non-homogeneous areas.", Int. J. Remote Sensing, 1990, 11, 1005-1019.

[6] Kogan, F. N., "World droughts in the new millennium from AVHRR-based vegetation health indices. American Geophysical Union, 2002, 83, 557, 562-563

[7] Kogan, F.N., and X. Zhu, "**E**volution of long-term errors in NDVI time series," *Adv. Space Res*. Vol. **28** (1), page

149-153(2001).
[8] Iyengar, M. O., “Studies on Malaria in the deltaic region of Bengal.”, Journal of the Malaria Institute of India, 1942, 4,435-446.
[9] Iyengar, M. O., “Problems relating to malaria control in deltaic Bengal.”, T ,Journal of the Malaria Institute of India,1944, 5,435-447.
[10] McMichael, A, J.,Haines, A and Slooff, R., “Climate Change and Human Health.”, World Health Organization, Geneva, Switzerland, 1996, 297.
[11] Malingreau, J.P., “Global vegetation dynamics: satellite observations over Asia.”,Int. J.Remote Sensing, 1986, 7, 181-1106
[12] Tarpley, J.D., Schneider, S.R., and Money, R.L., “Global vegetation indices from NOAA-7 Meteorological satellite.” J. Climate Appl. Meteor., 1984, 23, 491-494.