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Md Zahidur Rahman
*CUNY La Guardia Community College*

Leonid Roytman
*CUNY City College*

Abdelhamid Kadik
*CUNY La Guardia Community College*

Howard Miller
*CUNY La Guardia Community College*

Dilara A. Rosy
*University of Dhaka*

# Early Detection and Monitoring of Malaria

Md Z Rahman[1], Leonid Roytman[2] , Abdelhamid Kadik[3], Howard Miller[4], and Dilara A Rosy[5]
[1,3, 4] 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
[5]University of Dhaka, Dhaka, Bangladesh

## ABSTRACT

Global Earth Observation Systems of Systems (GEOSS) are bringing vital societal benefits to people around the globe. In this research article, we engage undergraduate students in the exciting area of space exploration to improve the health of millions of people globally. The goal of the proposed research is to place students in a learning environment where they will develop their problem solving skills in the context of a world crisis (e.g., malaria). Malaria remains one of the greatest threats to public health, particularly in developing countries. The World Health Organization has estimated that over one million die of Malaria each year, with more than 80% of these found in Sub-Saharan Africa. The mosquitoes transmit malaria. They breed in the areas of shallow surface water that are suitable to the mosquito and parasite development. These environmental factors can be detected with satellite imagery, which provide high spatial and temporal coverage of the earth's surface. We investigate on moisture, thermal and vegetation stress indicators developed from NOAA operational environmental satellite data. Using these indicators and collected epidemiological data, it is possible to produce a forecast system that can predict the risk of malaria for a particular geographical area with up to four months lead time. This valuable lead time information provides an opportunity for decision makers to deploy the necessary preventive measures (spraying, treated net distribution, storing medications and etc) in threatened areas with maximum effectiveness. The main objective of the proposed research is to study the effect of ecology on human health and application of NOAA satellite data for early detection of malaria.

**Keywords**: Malaria, detection, health, environmental, satellite, data

## 1. INTRODUCTION

Malaria remains one of the greatest threats to public health, particularly in developing countries. The World Health Organization has estimated that over one million die of Malaria each year, with more than 80% of these found in Sub-Saharan Africa. In 2005, President G.W. Bush announced a $1.2 billion aid package for AFRICA with the goal to reduce 50% of the malaria-related deaths in 15 of the most affected African countries.The anopheles mosquitoes transmit malaria. They breed in the areas of shallow surface water that are suitable to the mosquito and parasite development. These environmental factors can be detected with satellite imagery, which provide high spatial and temporal coverage of the earth's surface. These indicators produced from the Advanced Very High Resolution Radiometer's vegetation health indices are utilizing reflectance information in visible, near infrared and infrared wavelengths. Using these indicators and collected epidemiological data it is possible to produce a forecast system that can predict the risk of malaria for a particular geographical area, with up to four months lead time. This valuable lead time information provides an opportunity for decision makers to deploy the resources (spraying, treated net distribution, storing medications and etc) in threatened areas with maximum effectiveness.

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 (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-

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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 transmission.

## 2. STUDY AR

The worldwide distribution of malaria is illustrated by the map in **Figure 2.3**. Malaria transmission occurs in more than 100 countries. Regions include Africa, Asia, islands of the South, west, and central Pacific Ocean, Latin America, certain Caribbean islands, and Turkey. These areas, all between $45^0$ N and $40^0$ S latitude, possess tropical or subtropical zones wherein anopheles mosquito habitats exist.

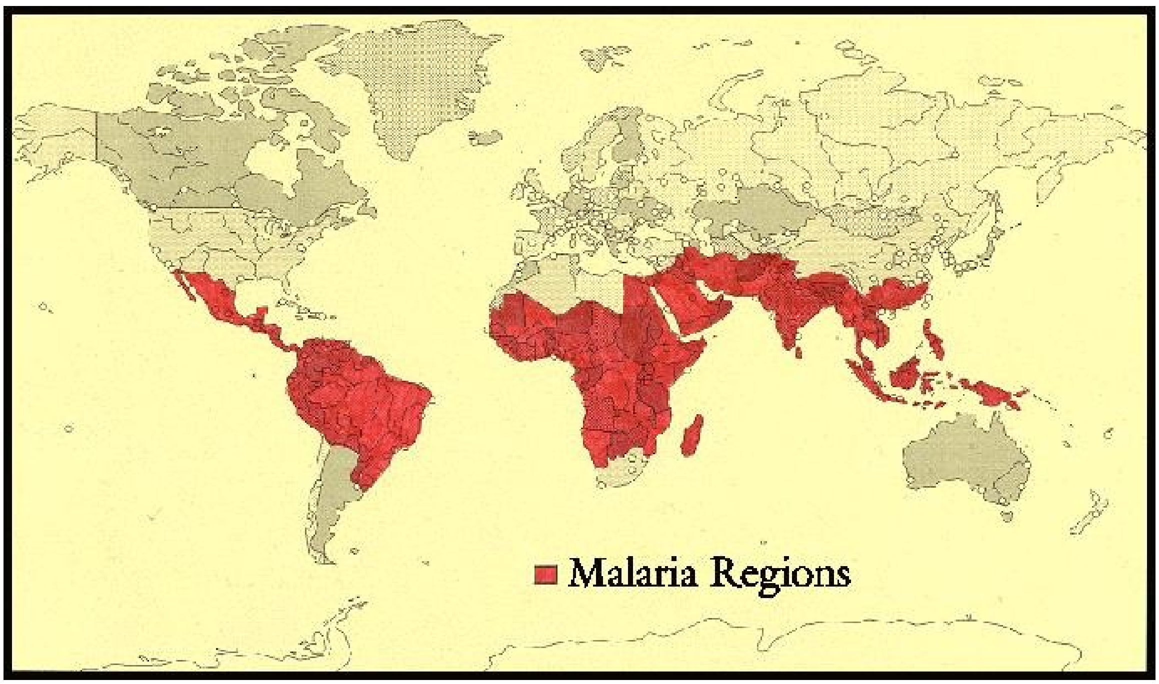



**Figure 2.3** Distribution of malaria
(http://iri.ldeo.columbia.edu/iri/programs/training/bamako1999/report/malaria.regions)

**Malaria Epidemiological Types**

Five major epidemiological types of malaria have been defined which are:
i) Malaria of Forested Hills,
ii) Malaria of Forest Fringe,
iii) Malaria of Plain Border Belt Areas,
iv) Malaria of Plain Rural Areas and
v) Malaria of Urban Areas

The effects of temperature on both the vectors and parasites of malaria are easily seen in the latitudinal and altitudinal boundaries to malaria transmission. However, these boundaries seem to be changing as many highland areas have experienced malaria epidemics in the past few years. It has been hypothesized that increasing temperatures could be part of the reason why malaria can now survive at higher altitudes. Many other confounding factors, however, could be causing the increase in malaria in these areas.

In addition to predictions of the effects of climate change on malaria, studies which identify factors that are most responsible for any changes in malaria are important in order to understand the complexities of malaria in the actual world. There are many variables that affect malaria transmission in addition to climatic changes, such as environmental modification (e.g. deforestation, increases in irrigation, swamp drainage), population growth, limited access to health care systems, and lack of or unsuccessful malaria control measures. Some studies have been done on the subject, yielding differing results as to which factor or factors are most responsible for the increase in malaria. Most of the studies, however, do not take into account all of the factors that are related to malaria transmission. This makes it difficult to assess the true determinants of malaria in each area.

## 3. METHODOLOGY

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.

## 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

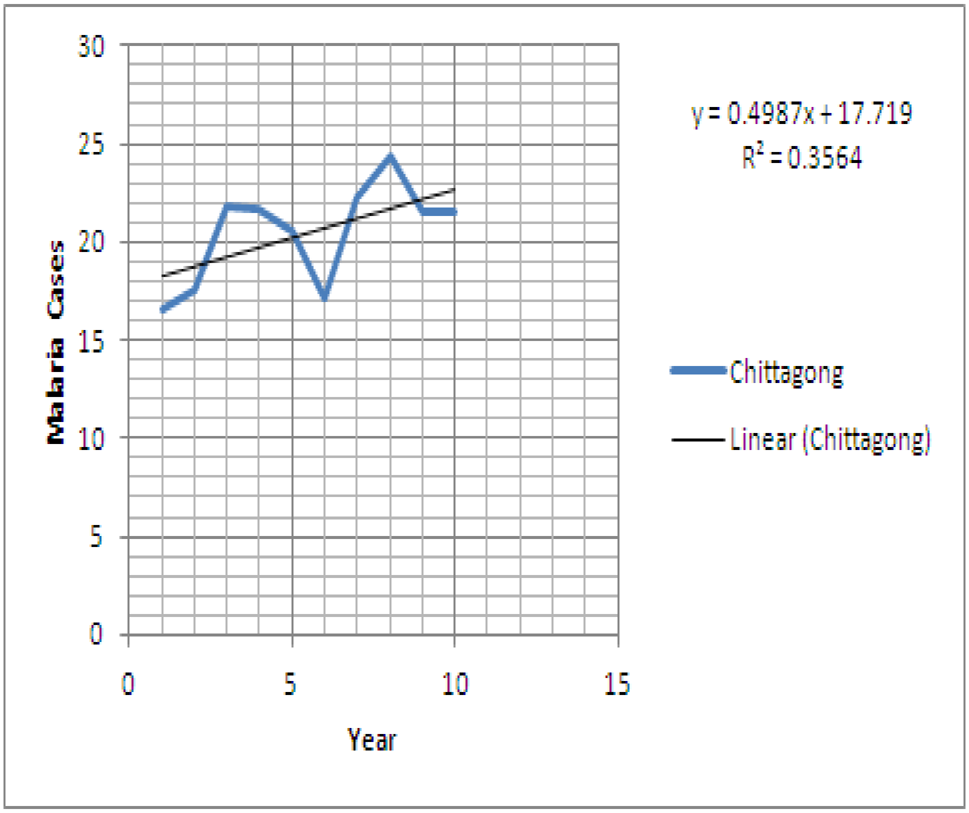
**Table 1** Malaria statistics of coastal divisions 1992-2001

| 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 |

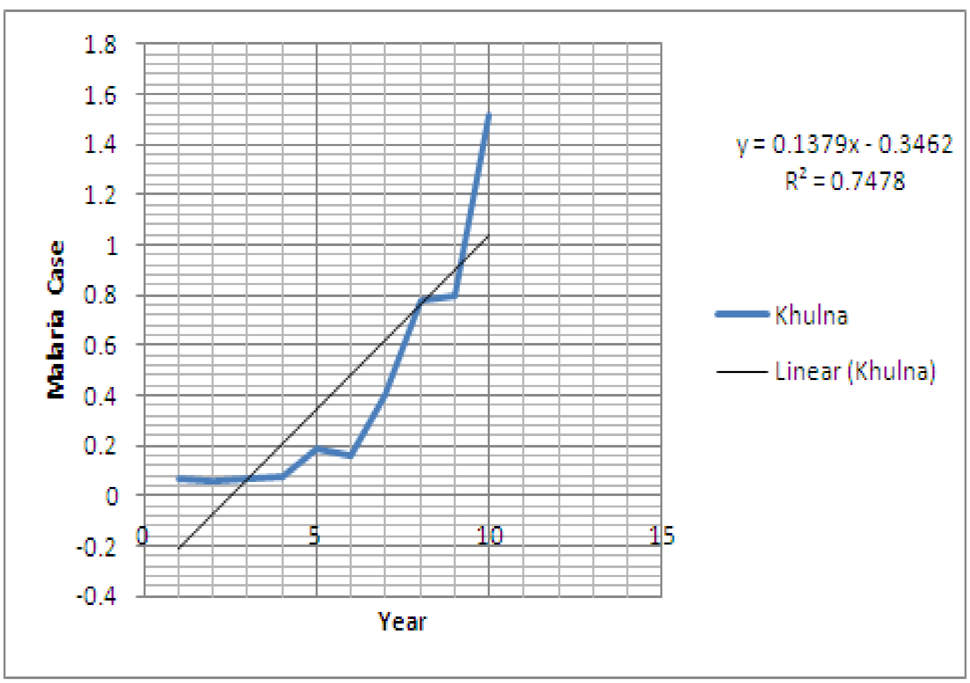
Figure 2 shows annual percent of malaria cases in coastal division during 1992-2001. As seen, malaria is on a rise during the 1990s. Although the Government of Bangladesh made efforts to eradicate malaria, the number of cases in Chittagong division was growing which is associated with poverty in this 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.

$$Y_{trend} = a + b*Year \qquad (4)$$
$$DY = (Y / Y_{trend})*100 \qquad (5)$$

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.



30
25
20
15
10
5
0
Malaria Cases
0
5
10
15
Year
y = 0.4987x + 17.719
R² = 0.3564
Chittagong
Linear (Chittagong)

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Malaria Case
0
5
10
15
Year
y = 0.1379x - 0.3462
R² = 0.7478
Khulna
Linear (Khulna)

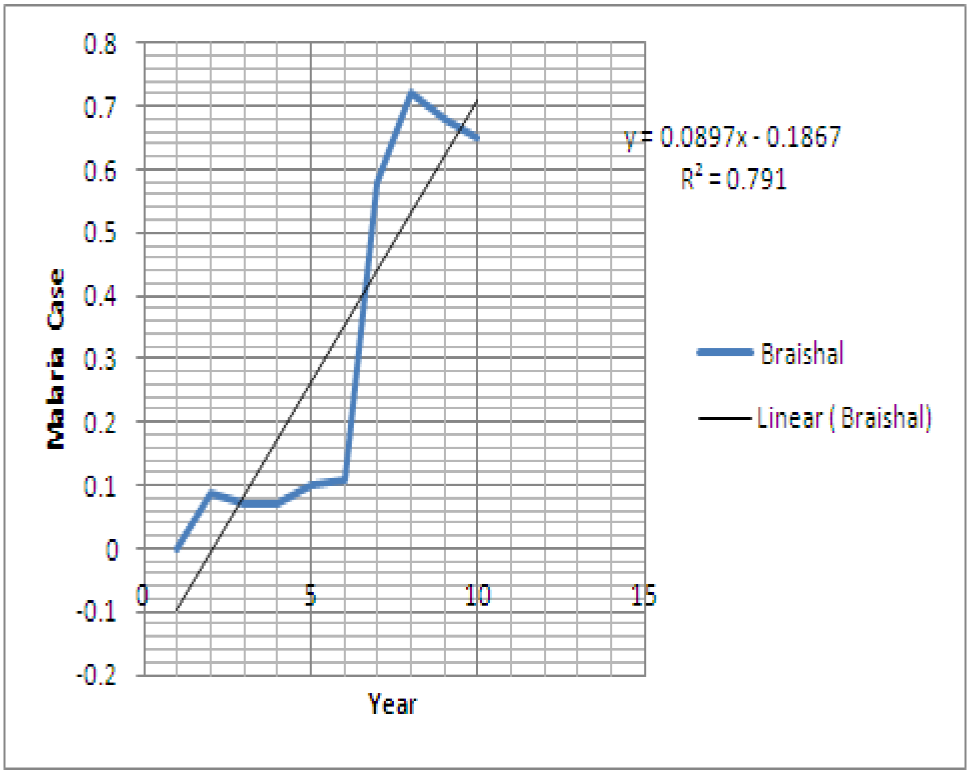



Fig. 2. Annual malaria cases in coastal divisions and trend line, 1992-2001

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.

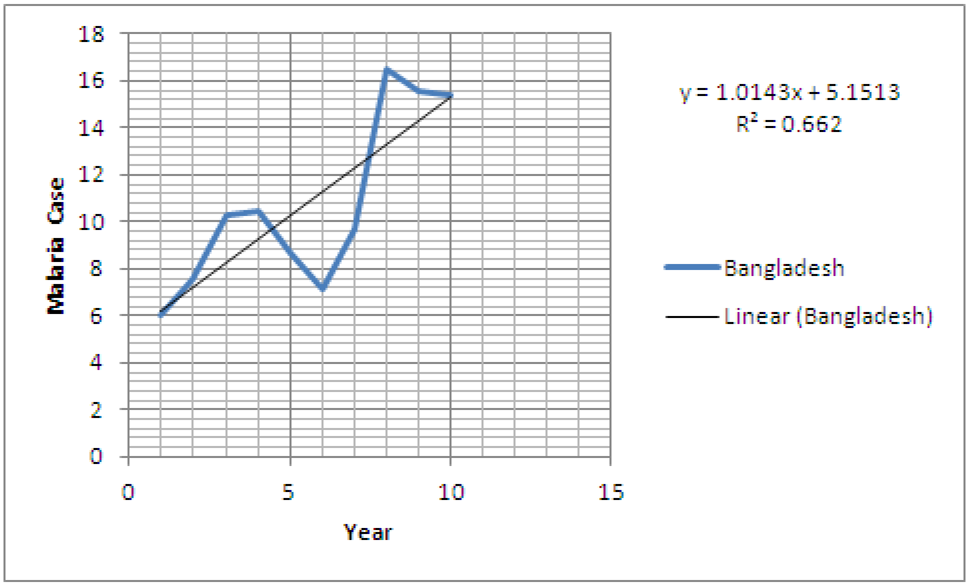



Fig. **3**. Annual malaria cases in all of Bangladesh and trend line, 1992-2001

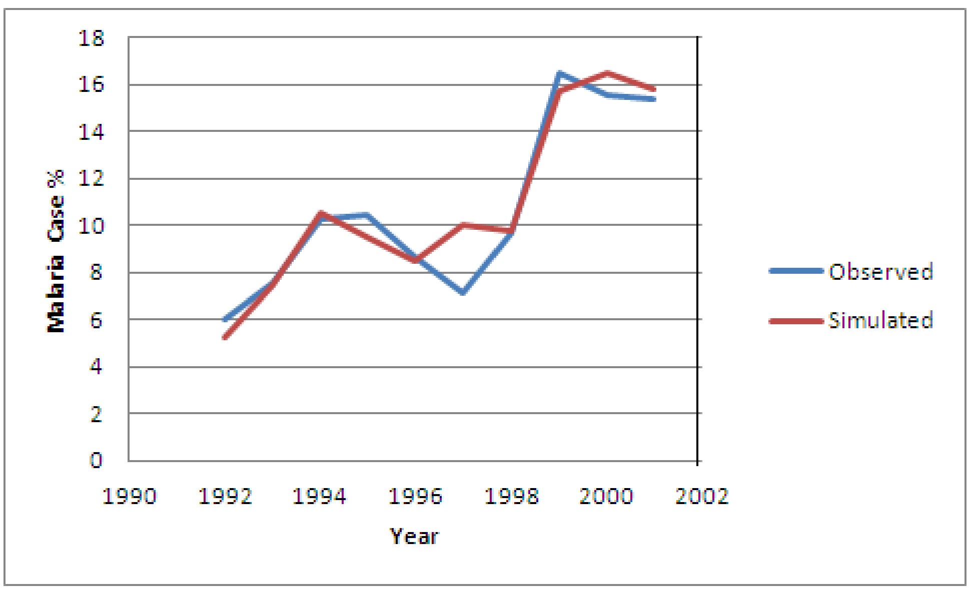



Fig. 4. Simulated and observed malaria cases for all of Bangladesh

## 6. CONCLUSIONS

In this study we have developed an educational program that targets undergraduate students. The goal of the program is to place students in a learning environment where they will develop their problem solving skills in the context of a world crisis (e.g., malaria). We entailed students to strengthen not only their technical skills, but also their understanding of how culture, politics, economics and the like can impact the decision making process when determining a feasible solution to a complex social problem. Students analyzed malaria data using excel and build a regression model to predict malaria. Students revewed literature related to malaria accompanied with an investigation of Vegetation Health and its correlation with the threat of Malaria. This research studied the effect of ecology on human health and application of NOAA satellite data for early detection malaria. Students achieved necessary skills throughout this research which was able to interpret, analyze and investigate malaria data, and and build a model for early detection malaria.

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