

Research Article

Temporal changes in land cover types and the incidence of malaria in Mangalore, India

Venkata Raghava Mohan^{*1} and Elena N. Naumova²

¹Departments of Community Medicine, Christian Medical College, Vellore, Tamil Nadu, India.

²Department of Civil and Environmental Engineering, Tufts University School of Engineering, Medford, MA USA.

***Correspondence Info:**

Venkata Raghava Mohan

Professor,

Department of Community Health

Christian Medical College, Vellore 632 002, Tamil Nadu, India.

E-mail: venkat@cmcvellore.ac.in

Abstract

Background: Malaria contributes to 881000 deaths worldwide annually and India is a major contributor in the region. This study aimed at detecting land cover changes and assesses their relationship with the burden of malaria in Mangalore taluk of southern India.

Methodology: Landsat TM images were obtained from the U.S. Geological Survey data repository. The statistics for the malaria incidences in the region were obtained from the National Vector Borne Diseases Control Program division of the State of Karnataka. The images were preprocessed, classified and change detection statistics were employed for major land cover types.

Results and Conclusions: An increase in the urban land cover by 20% with a reduction in the mountainous terrain by 34.7% and vegetation by 38.7% was noted between the years 2003 and 2005. The annual incidence of malaria increased five-fold from 203 to 1035/100000 population during the period. This study demonstrates the application of publicly available remote sensed data as a cost effective approach to study the agent, host and environment relationships in resource scarce settings which would provide valuable information planning and policy making at regional levels.

Keywords: Malaria, remote sensing, supervised classification, Land cover types, NDVI

1. Introduction

Malaria is a complex and finely evolved vector-borne infectious human disease. In spite of global initiatives from various angles to curb this disease, an estimated 247 million people are infected and about 881,000 deaths occur annually¹. Poorer tropical and subtropical regions of the world in Africa, South Asia, parts of Central and South America, the Caribbean, Southeast Asia, the Middle East, and Oceania are the regions with high malaria transmission². India greatly contributes to the global malaria incidence. The plethora of various species of malaria vectors, a hospitable environment for growth and proliferation of the parasites and vectors and a malaria-susceptible human lineage have established India as a hot-spot for malaria infection^{3,4} and India alone continues to contribute about 60% of Southeast Asian malaria incidences. The launch of the National Malaria Control Program (NMCP) resulted in a drastic drop of malaria cases from 75 million cases annually in 1947 to less than 50,000 in mid-sixties. However, after its near eradication malaria staged a dramatic comeback with nearly 2 million recorded cases every year since 1995⁵ and a clear change in malaria epidemiology: an increase in the insecticide resistance, in proportions of malaria due to *P. falciparum* throughout the country, and rise in urban malaria⁶⁻⁹.

While the role of environmental factors, such as temperature, rainfall, relative humidity in the epidemiology of vector-borne diseases is well known, urbanization is emerging as an important factor associated with an increase in malaria¹⁰⁻¹². A study done in Brazil showed that for the years 1997 and 2006, a 4.3% increase in deforestation per year was associated with a 48% increase in the risk in malaria after adjusting for the area and access to health care in the districts¹³.

While the environmental requirements for the maintenance of lifecycle vary between different vectors¹⁴, all vectors, including female *Anopheles* mosquitoes need water to complete their life cycle. Studies on the characteristics of the preferred habitats have shown that deforestation and land clearing contribute to the dynamic malaria patterns in a region. The mosquito biting rates and larval counts have been shown to increase with the degree of deforestation and demonstrate seasonality with significantly lower bite rates during rainy seasons which could be a result of the wash-out effect of breeding sites and reduced larval survival with changes in the ambient temperature¹².

Over the last few decades, newer technologies have been developed which can better describe and characterize changes in land cover types. The advent of remote sensing (RS) technology since 1970, a tool for the surveillance of habitats, densities of vector species and even prediction of the incidence of diseases, has opened up new vistas in the epidemiology of malaria and other vector-borne diseases. Number of studies has demonstrated successful utilization of RS data for better understanding the relationship between environmental factors and malaria transmission on the local and global scales. It has been shown that changes in the incidence of malaria transmission in Thailand are associated with changes in vegetation covers detected by Landsat satellite imagery using the Normalized Difference Vegetation Index (NDVI)¹⁵. In the study conducted in coastal Kenya changes in mosquito larva habitats associated with wetland areas and flooded vegetation were detected with RADARSAT-1 wetland mapping to help in assessing potential risk of vector-borne disease environment¹⁶. Using GIS technology to detect effects of landscape structure on *Anopheles* mosquito population it has been shown that in Northern Thailand *Anopheles* diversity was negatively correlated with landscape diversity, percentage cover of agriculture and fruit orchards and positively correlated with forest cover¹⁷. A study looking at the incidence of malaria in different regions of Jalpaiguri district in West Bengal, India has shown the malaria related morbidity and mortality to be highest in areas with higher tea gardens¹⁸. A feasibility study using multi-date IRS 1A and 1B satellite data was undertaken in collaboration with the Indian Space Research Organization. It was found that false color composite images can help in the development of base maps of the study area and macro stratification of mosquito conditions was possible. Correlation of changes in the area of land use features namely water bodies and vegetation with mosquito density was found to be significant in few of the six selected sites in and around Delhi. The limitation of satellite resolution (36.5 meters) was felt as the smaller habitats of *Anopheles* mosquitoes were not detectable¹⁹.

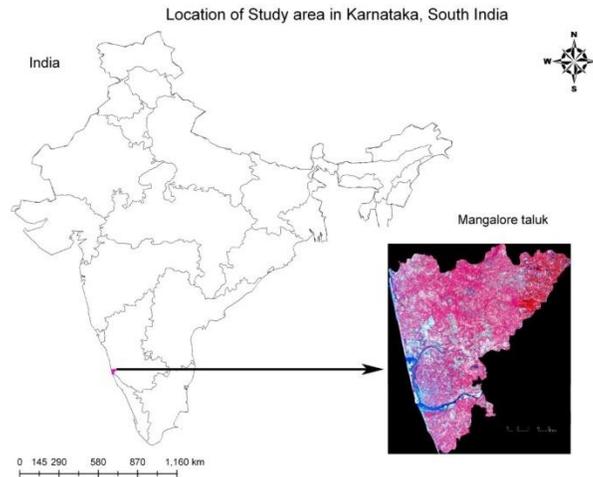
The objective of this study was to examine the changes in land use and land cover types, which favor mosquito breeding, and the trend in the incidence of malaria in Mangalore taluk of the State of Karnataka in South India using remote sensing imagery (with the 30m resolution) for the years 2000 and 2003. The selected study region has one of the highest malaria incidence in India and the incidence has been increasing⁵. The availability of favorable natural habitats and increasing artificial water collections due to construction related activities has rendered this region more susceptible to malaria and has been projected that the urban sprawl in this coastal belt of the state would contribute to 30% of the total available area by the year 2050^{5,20}.

2. Methodology

2.1 Study area

Mangalore taluk, on the western coast of Karnataka in South India spans an area of around 854 km², situated between 13°08'0.11"N and 76°46'24.23"E coordinates (Figure 1). This geographic region bordered by the Arabian Sea on its West, by the thick forested area on its east is rich with natural resources. This coastal region has experienced a dramatic increase in the extent of urbanization over the last three decades: between 1972 and 1999 the amount of developed land increased by 146%. During this period, the population in the region grew by about 54%. As per the 2001 census, the total population of the taluk was 882,856 with 68.08 % living in urban areas; males accounting for 49.24% and females accounting for 50.76% of the total population.. The population density of the taluk is 1048 persons/km², which was 2.5 times higher than the district average of 416 persons/km^{2,20,21}.

Figure 1. Location of Mangalore taluk in South India.



2.2 Health Data

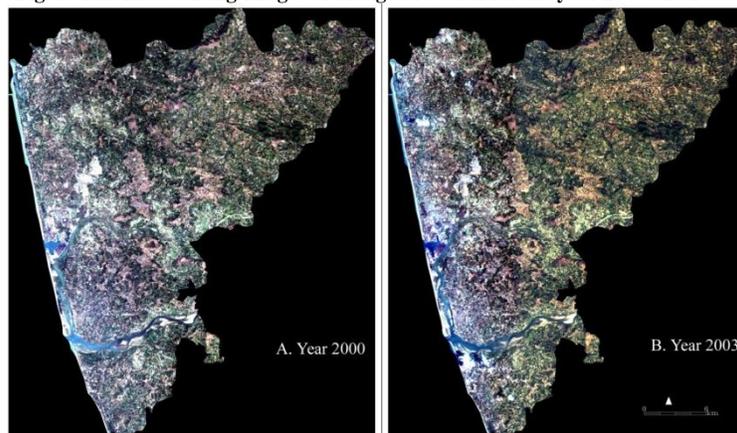
The annual counts for the malaria cases in the region for the period 1990 to 2007 were obtained from the National Vector Borne Diseases Control Program (NVBDCP) division of the State Public Health Department of Karnataka⁵. The population in the study area was computed based on the annual growth rate and the State level projections provided by the Census bureau, Ministry of home Affairs, Government of India^{21,22}. The population densities over time were calculated using the projected population and the overall area of the region as estimated by the RS images. Annual malaria incidence rates (per 100,000 population) were calculated for the region. The trend in rates was assessed using a linear regression model.

2.3 Remote Sensing and GIS Data

Remote sensing (RS) data for the region were obtained as Landsat TM images for the years 2000 (dated 14th April and 20th December 2000) and 2003 (dated 23rd April and 27th January 2003) from the U.S. Geological Survey data repository. The Geographic Information System (GIS) shape files for India and the study region were obtained from the Tufts University GIS repository. The GIS vector files were processed and mapped using ArcGIS 9.1 (Environmental Systems Research Institute Inc., Redlands, CA, USA).

The RS data was processed and analyzed using the software ENVI 4.6 (ITT Visual Information Solutions, Boulder, CO, USA). Initially, the RS images were mosaicked after basic layer stacking, and were clipped using the shape file for the study area. The mosaicked and clipped RS images for the study area are shown in Figures 2a and 2b. Unsupervised classification was performed on the mosaicked and clipped images using K-means cluster algorithm after Principal Component analysis for the year 2000²³. The land cover types were classified into four major classes of land cover types (Urban, Water, Vegetation and Mountain). A supervised image classification was then performed on the clipped RS image for the year 2000 with 10 classes initially and a minimum of 15 (Region of interest) ROI polygons for each class. Later on these 10 classes were combined into four major classes of land cover types (Urban, Water, Vegetation and Mountain).

Figure 2. Remote sensing images of Mangalore taluk for the year 2000 and 2003.



Both the unsupervised and the supervised classifications for the year 2000 were compared with the supervised maximum likelihood classification for four major classes of land cover types (Urban, Water, Vegetation, Mountain) with a minimum of 15 ROI polygons for each class and a minimum of 300 ROI points for each class for accuracy assessment. Based on the accuracy reports and commission and omission errors between the two methods, supervised maximum likelihood classification was performed on all further images. Change detection statistics was performed on the classified maps using the post classification comparison method²³.

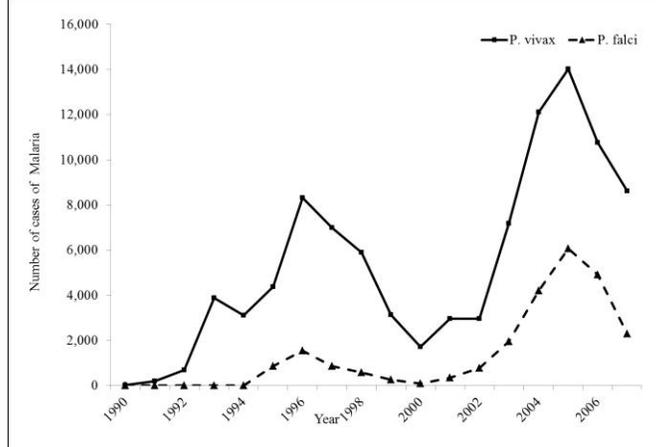
2.4 NDVI transformation

NDVI transformation was performed on the raw, mosaicked images using bands 4(Near Infra Red) and 3(Red) for the Landsat TM images. The range of NDVI varied from -1 to +1, with values of 0 to 0.2 indicating bare soils (with scanty vegetation), and 0.2 to 0.7 reflecting different categories of green vegetation. Using image exploration and also based on earlier studies from this region, density slicing was performed on the NDVI transformations and vegetation with NDVI more than 0.2 (representing dense thick vegetation)²⁴⁻²⁷ were highlighted and exported as separate classes for each study year.

3. Results

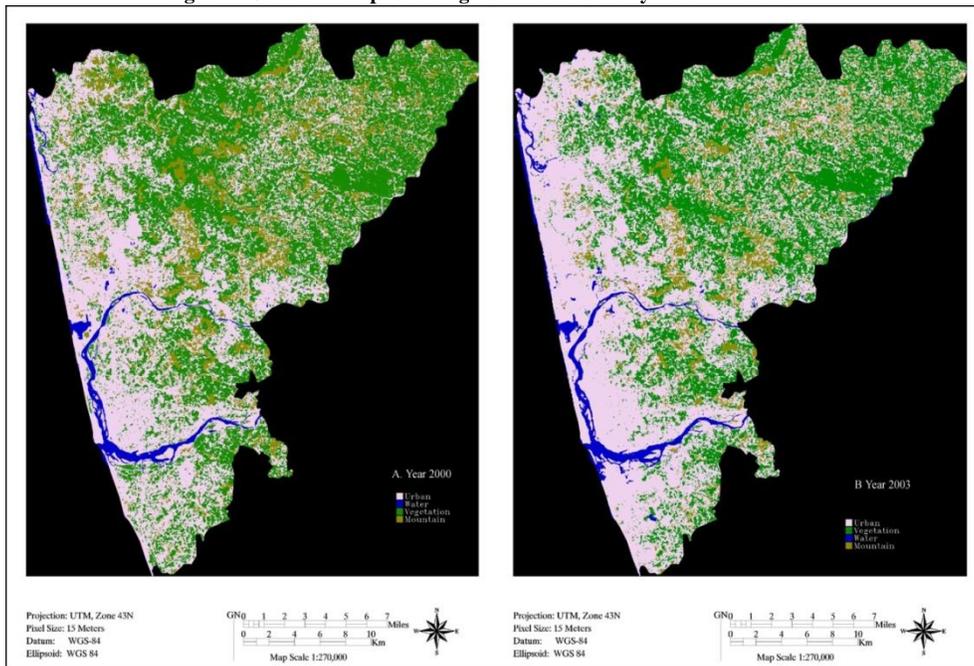
Mangalore is endemic for malaria and nearly 40% of cases of malaria are caused by *P. falciparum* infection. The absolute numbers of malaria cases in Mangalore taluk has been on the rise since the mid-1990s and the trend in the incidence rates are shown in Figure 3. Between the study years, absolute numbers of all malaria cases reported in the region increased five-fold from 1798 to 9138. Annual malaria incidence rates increased from 203 cases to 1035 cases per 100000 population in three years. The annual increase in malaria incidence rate, population and population density were 277/100000, 12182 and 18.33 persons/km² respectively.

Figure 3. Trend of malaria in Mangalore taluk over the years 1990 to 2007.

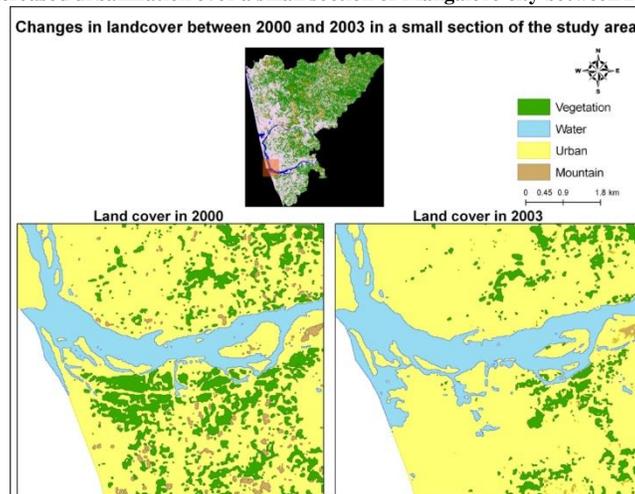


The classified maps of the study area following supervised classification technique are shown in Figures 4a and 4b. On visual exploration, an increase in the area of urbanization can be noted between the years 2000 and 2003. Mangalore taluk spanned an area of 738.81km² of which Urban, Vegetation, Mountain and Water types of land cover contributed to 44.9%, 40%, 12.8% and 2.3%, of the total area in the year 2000 and 53.9%, 34.7%, 8.3% and 3.1%, respectively in the year 2003. Change detection statistics performed on the classified maps showed that the Urban areas had increased by 66.2 km² and the fresh water covered areas had increased by 5.37 km².

Figure 4. Classified maps of Mangalore taluk for the year 2000 and 2003.



The increase in urbanization was noted more in the regions adjoining the rivers and the coast in the study area. Figure 5 shows the changes over the 3 year period in a small section of Mangalore city.

Figure 5. Increased urbanization over a small section of Mangalore city between 2000 and 2003.

The area covered by thick and healthy vegetation formed 46.88 km² and 44.73 km² of the total study region in the years 2000 and 2003 respectively. A 4.5% reduction in thick vegetation cover (NDVI>0.2) was noted between the years.

4. Discussion

This pilot study illustrates dramatic changes in the land use, land cover, population density and malaria incidence in the coastal area of Mangalore. Considering that with even very modest deforestation of 4% per year, the risk of malaria can potentially increase by 50% in areas with conditions favorable for vector breeding and high malaria incidence¹³, we have observed changes that might have serious consequences for malaria transmission in the region. We demonstrated that four land cover types that affect life cycles of malaria vectors were changed between the years 2000 and 2003: with the annual increase in the urban land cover by 6.7%, a reduction in the mountainous terrain by 11.6% and vegetation by 12.9%. Over 3 years, a 4.5% reduction in the level of thick vegetation (NDVI>0.2) was noted in the region, which could be because of increased urbanization. The fresh water and stagnant water collections had increased by ~10% annually. Some of these artificial water collections, favoring mosquito breeding and transmission of the disease, are due to construction related activities and collections after rainfall in places like disused vehicle tires, tree holes, used coconut shells, open water tanks, open wells etc. which are associated with human activities⁵.

With its unique geographic position (8° 4' to 37° 6' N latitude and 68° 7' to 97° 25' E longitude), diverse topography and climatic variations, India contributes greatly to the global malaria burden²⁸. It has been shown that in India the water bodies, coconut/arecanut plantations, marshy areas, moist soil, rocks with vegetation are the landscapes critical for mosquito breeding^{4,29,30}. Recent increases in malaria related morbidity and mortality has been noted in the coastal regions of India which is mainly due to urban malaria. Mangalore taluk, located on the western coastal region of South India has experienced an increase in the urbanization over the last two decades and a corresponding increase in malaria related morbidity and mortality. Recent studies show that malaria was on the rise among construction workers in this region⁵.

The data on annual malaria incidence in the region indicate a complex pattern with a clear decline between 1999 and 2003 and a sharp peak in 2004. One of the main reasons for this decline in the number of cases of malaria in this region after 2004 is the formation of a special “malaria cell” in the area, which focused on active surveillance with special emphasis on migrant workers, construction workers, hotel workers and inmates of orphanages. The active surveillance for sources combined with source reduction activities, anti-larval and anti-adult insecticide spraying operations were intensified in the region⁵. However, the overall trend of malaria in this region is rising along with the increase in the population, population density and urbanization in the area. The population density in this region has increased by over 100 people per km² in the last five years, which approximates to an addition of roughly around 25 new families per km². We believe that the increase in the population density with increasing urbanization, deforestation is associated with an increase in the breeding sites of mosquitoes due to construction related activities in this region. This could lead to increased vector breeding, increased vector – human contact, resulting in an increase in the bite rates and consequently an increase in number of mosquito borne diseases including malaria in this region.

This study along with other investigations conducted in India has demonstrated a strong potential for using satellite imagery to delineate the breeding habitats of the major malaria vectors and to forecast the risk of malaria transmission due to human activity^{4,18,19,29-31}. The use of remote sensing techniques to map disease risk and vector distribution has evolved and range from using simple correlations between spectral signatures from different land use–land cover types and species abundance to complex techniques that link satellite-derived seasonal environmental variables to vector biology³²⁻³⁵. In a study looking at comparisons of satellite-derived precipitation, temperature, humidity, vegetation and elevation measures in different districts of Kenya has demonstrated the differences in mosquito larval breeding habitats in relatively smaller geographical regions ranging from open shallow sunlit puddles closer to homes to permanent vegetated aquatic habitats such as stream pools of rivers varying between different species of vectors³⁶. A study looking at the dynamics of mosquito population in rice fields in California revealed that that rice fields with rapid early season vegetation canopy development, located near livestock pastures had greater mosquito larval populations than fields with more slowly developing vegetation canopies located further from pastures and the sensitivity of these predictions were up to 90% accurate³⁷. The ability to foresee flooding of mosquito habitats by remote sensing was found to have importance bearing on developing strategies for mosquito control & disease prevention¹⁸.

The difficulties in obtaining good quality remotely sensed data for the region beyond the year 2003 due to high cost for purchasing data for independent investigators and the non-availability of the information on malaria burden at sub taluk (at a refined spatial resolution) in India, limited information on local meteorological data, which are often obtained from different locations, incomplete and are not uniform, were some of the important limitations faced during the study. In India, the estimated economic loss due to malaria are huge and ranged between \$506.82 million to \$630.82 million between 1990-1993³⁸ and up to \$1 billion in 1995-96³⁹. The total Disability Adjusted Life Years (DALYs) lost due to malaria was 1.86 million years in 1997 based on the WHO reported incidence and still would be an underestimation in India, higher among (1.074 million) and the maximum DALYs lost were among the economically productive age groups from 15 to 44 years of age (53.25%), followed by children < 14 years of age (27.68%)⁴⁰. India has spent up to 25% of its health budget on malaria control from 1977-1997, and starting in 1997, India planned to spend \$40 million on malaria control, a 60% increase from the previous year⁴¹. From this point of view, availability of high quality data for research and prevention purposes can offer a low cost solution.

This study serves as a useful demonstration of how public access to remotely sensed data serves as a cost effective approach to study relationships between the environment, agent and the host. The presented approach can easily be adapted to other vector borne diseases, which contribute to a significant amount of morbidity and mortality in the developing world. In conclusion, with access to remotely sensed data of good spatial, spectral and

temporal resolution and effective disease surveillance systems it is possible to study the interactions between the environment and the diseases even in resource scarce settings using novel methods and this would prove invaluable to health planners and policy makers at regional levels.

Ethical approval

This study has been approved by the Institutional Review Board of the Christian Medical College for publication (Ref: IRB-EXP 4-30-01-2012).

References

- Centers for Disease Control and Prevention. Malaria. cited 2010 Mar 10; Available at: <http://www.cdc.gov/malaria/index.html> (accessed March 10, 2010).
- Hopkins Technology. Malaria. Available at: <http://www.hoptechno.com/bookmalaria.html> (accessed March 11, 2010).
- Yadav RL, Lal S, Kaul SM. Malaria epidemic and its control in India. *Fam Med* 1999; 3:39-41.
- Srivastava A, Nagpal BN, Rekha S, Alex E, John R, Subbarao SK, et al. GIS based malaria information management system for urban malaria scheme in India. *Computer methods and programs in biomedicine* 2003; 71:63-75.
- Kakkaliya BS. Malaria. Available at: <http://www.malariasite.com> (accessed March 10, 2010).
- Akhtar R, Learmonth A, Keynes M. The resurgence of Malaria in India 1965-76. *GeoJournal* 1977; 1:69-80.
- Chwatt BLJ. Global Review of Malaria control and eradication by attack on the vector. *Miscellaneous Publications of the Entomological Society of America* 1970;7:7.
- Learmonth ATA. Some Contrasts in the Regional Geography of Malaria in India and Pakistan. *Transactions and Papers (Institute of British Geographers)* 1957; 23:37-59.
- Sharma VP, Mehrotra KN. Malaria resurgence in India: a critical study. *SocSci Med* 1986; 22:835-45.
- Vittor AY, Pan W, Gilman RH, Tielsch J, Glass G, Shields T, et al. Linking deforestation to malaria in the Amazon: characterization of the breeding habitat of the principal malaria vector, *Anopheles darlingi*. *Am J Trop Med Hyg* 2009; 81:5-12.
- Tadei WP, Thatcher BD, Santos JM, Scarpassa VM, Rodrigues IB, Rafael MS. Ecologic observations on anopheline vectors of malaria in the Brazilian Amazon. *Am J Trop Med Hyg* 1998; 59:325-35.
- Vittor AY, Gilman RH, Tielsch J, Glass G, Shields T, Lozano WS, et al. The effect of deforestation on the human-biting rate of *Anopheles darlingi*, the primary vector of *Falciparum* malaria in the Peruvian Amazon. *Am J Trop Med Hyg* 2006;74:3-11.
- Olson SH, Gangnon R, Silveira GA, Patz JA. Deforestation and malaria in Mancio Lima County, *Brazil. Emerg Infect Dis* 2010; 16:1108-15.
- Alameda County Mosquito Abatement District. Biological Notes on Mosquitoes. Available at: <http://www.mosquitoes.org/LifeCycle.html> (accessed April 3, 2010).
- Nualchawee K, Singhasivanon P, Thimasam K, Dowreang D, Linthicum K, Sithiprasasna R, et al. Correlation between malaria incidence and changes in vegetation cover using satellite remote sensing and GIS techniques. Paper presented at: The International Geoscience and Remote Sensing Symposium (IGARSS); 1997; New York, USA.
- Kaya S, Sokol J, Pultz TJ. Monitoring environmental indicators of vector-borne disease from space: a new opportunity for Radarsat-2. *Canadian Journal of Remote Sensing* 2004; 30:560-5.
- Overgaard HJ, Tsuda Y, Suwonkerd W, Takagi M. Characteristics of *Anopheles minimus* (Diptera: Culicidae) Larval Habitats in Northern Thailand. *Environ Entomol* 2009; 31:134-41.
- Dutta S. Malaria Epidemiology on Jalpaiguri District Applying Remote Sensing & Geographic Information System. PhD thesis. Centre for Remote Sensing, University of North Bengal; 2007. Available at: <http://sevas.org.in/thesis/node/497> (accessed January 10, 2013).
- Sharma VP, Dhiman RC, Ansari MA, Nagpal BN, Srivastava A, Manavalan P, et al. Study on the feasibility of delineating mosquito-genic conditions in and around Delhi using remote sensing satellite data. *Indian J Malariol* 1996; 33:107.
- Sudhira HS, Ramachandra TV, Jagadish KS. Urban sprawl: metrics, dynamics and modelling using GIS. *International Journal of Applied Earth Observation and Geoinformation* 2004; 5:29-39.
- Directorate of Census Operations Karnataka. District Census Handbook - Dakshina Kannada District. 1981.
- Government of India. Projected Total Population by sex as on 1st March-2001-2026 India, States and Union Territories. Available at: http://www.censusindia.gov.in/Census_Data_2001/Projected_Population/Projected_Population.pdf (accessed July 10, 2010).
- Lillesand MT, Kieffer WR, Chipman WJ. Digital Image Interpretation and Analysis. In: Flahive R, editor. *Remote Sensing and Image Interpretation*. 6 ed. NJ: John Wiley & Sons Inc.; 2008. p. 545-81.
- Ganapathy S, Ramachandra TV. Vegetation Analysis using GIS and Remote Sensing. ENVIS Technical Report. Ministry of Environment and Forests. Government of India; 2007.
- Ganapathy S, Ramachandra TV. Vegetation Analyses in Uttara Kannada District using GIS and Remote Sensing techniques. ENVIS Technical Report 24. Ministry of Environment and Forests. Government of India; 2008.
- Banerjee UK, Kumari S, Paul SK, Sudhakar S. Remote Sensing and GIS based ecotourism planning: A case study for western Midnapore, West Bengal, India. Available at: <http://www.gisdevelopment.net/application/miscellaneous/misc028.htm> 2010 (accessed August 1, 2010).
- Short NM. The Vegetation Index; Other Vegetation Scenes. Available at: <http://ces.iisc.ernet.in/hpg/envis/Remote/section334.htm> (accessed January 10, 2013).
- Singh V, Mishra N, Awasthi G, Dash AP, Das A. Why is it important to study malaria epidemiology in India? *Trends Parasitol* 2009; 25:452-7.
- Srivastava A, Nagpal B, Saxena R, Subbarao S. Predictive habitat modeling for forest malaria vector species *An. dirus* in India - a GIS-based approach. *Curr Sci* 2001; 80:1129-34.
- Jeganathan C, Khan SA, Chandra R, Singh H, Srivastava V, Raju PLN. Characterisation of Malaria Vector Habitats Using Remote Sensing and GIS. *Journal of the Indian Society of Remote Sensing* 2001; 29:31-6.
- Kalluri S, Gilruth P, Rogers D, Szczer M. Surveillance of arthropod vector-borne infectious diseases using remote sensing techniques: a review. *PLoS Pathog* 2007; 3:1361-71.
- Sithiprasasna R, Ja Lee W, Ugsang D, Linthicum K. Identification and characterization of larval and adult anopheline mosquito habitats in the Republic of Korea: potential use of remotely sensed data to estimate mosquito distributions. *Int J Health Geogr* 2005; 4:17.
- Wood BL, Beck LR, Washino RK, Palchick SM, Sebasta PD. Spectral and spatial characterization of rice field mosquito habitat. *Int J Remote Sens* 1991; 12:621-6.
- Rogers DJ, Randolph SE, Snow RW, Hay SI. Satellite imagery in the study and forecast of malaria. *Nature* 2002; 415:710-5.
- Connor SJ, Thomson MC, Flasse SP, Perryman AH. Environmental information systems in malaria risk mapping and epidemic forecasting. *Disasters* 1998; 22:39-56.
- Hope LA, Hemingway J, McKenzie FE. Environmental factors associated with the malaria vectors *Anopheles gambiae* and *Anopheles funestus* in Kenya. *Malar J* 2009; 8:268.
- Wood BR., Washino R, Beck L, Hibbard K, Pitcairn M, Roberts D, et al. Distinguishing high and low anopheline-producing rice fields using remote sensing and GIS technologies. *Prev Vet Med* 1991; 11:277-82.
- Sharma VP. Re-emergence of malaria in India. *Indian J Med Res* 1996; 103:26-45.
- Sharma VP. Malaria: cost to India and future trends. *Southeast Asian J Trop Med Public Health* 1996 Mar; 27:4-14.
- Kumar A, Valecha N, Jain T, Dash AP. Burden of malaria in India: retrospective and prospective view. *Am J Trop Med Hyg* 2007; 77:69-78.
- Jayaraman KS. India plans \$200 million attack on malaria. *Nature* 1997; 386:536.