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REMOTE SENSING: A VISIONARY TOOL IN MALARIA EPIDEMIOLOGY

Malaria is still a major public health problem. In India nearly 2-3 million cases occur every year with about 1000 deaths. Control of malaria requires case detection and treatment of affected individuals, and for curtailment of malaria transmission, control of mosquito vectors is undertaken. Vector control requires knowledge of the ecology of breeding and resting habitats and behaviour of various species of mosquitoes. The life of mosquitoes is influenced by variations in climatic conditions, and hence there is diversity in the distribution and habitats of different vector species. Periodical surveys are essential for arriving at any conclusion for developing vector control strategy. Routine entomological surveys over vast geographic areas are impractical, time consuming and expensive and therefore are confined to limited areas.

The advent of remote sensing (RS) technology since 1970[1], 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. The advances in RS has been so rapid that by the time a review[2-10] is published, new applications of the technology are available. The advances in the field of satellite remote sensing in the context of malaria are reviewed in this write-up.

The Definition

The literal meaning of remote sensing is to sense any object from a distance. The human eye and cameras also act as remote sensing devices. But the actual science of remote sensing started in 1971 when scientists of the National Aeronautics and Space Administration (NASA) of USA, used colour infrared aerial photography to identify the habitats of a nuisance mosquito, *Aedes sollicitans*[11]. This study prompted scientists to exploit the use of satellite remote sensing with the launch of Landsat satellite in 1972.

Principal and Utilisation

The principle of RS rests on the fact that every object absorbs some part of radiation received from sunlight. Depending upon its physical and chemical properties, the object absorbs some part of radiation while the remaining part is reflected in specific wavelengths of the electromagnetic spectrum (EMS). This reflected energy is channelised through a telescope to detectors/sensors present on board the satellites. The sensors are sensitive to different bands/channels of EMS. The sensors convert the light energy into electrical voltages which are translated to digital numbers (DN values) ranging from 0 to 63. The digital image produced by sensors is a two dimensional array of discrete picture elements (Pixels). The DN values of each pixel represents the reflectance of object. Based on different DN values, the objects are distinguished from each other. The digital data are transmitted to receiving stations on earth and stored in the form of computer compatible tapes (CCT). In India satellite data can be procured from the National Remote Sensing Agency Data Centre, Hyderabad in the form of compact discs. The digitized data are analysed on computers by digital image processing techniques or sometimes by visual interpretation from photographic products. The reflectance values of different bands are combined together to get a spectral signature so that all possible features may be distinguished from each other. In digital image processing, features with different spectral signatures are identified and a small portion of them is verified on the ground. The information is fed into computers by defining the training sets and the whole impage is classified so as to distinguish different land use features. The quantification of each land use feature in a scene is also possible. The size of pixel may range from few metre to kilometer depending upon the spatial resolution of sensor of satellites. The sensors can be calibrated to record the reflected energy in different spectral regions of EMS. The band requirement for environmental monitoring is usually restricted to visible spectrum of light (0.4 to 0.7 μm), infrared and microwave. The satellites pass over a particular part of the earth at fixed time intervals repeatedly making it possible to monitor changes in the land use categories *viz.* water bodies, vegetation, human settlements, *etc.* Remote sensing has application in urban development, road net-work, forests, soil mapping, geology, crop estimation, detection of fire in forests, mines, oil sleek in sea, *etc.* The remote sensing satellites are in space at the height of about 900 km and are sun synchronous.

The remote sensing done by aerial photography and satellite remote sensing is known as passive remote sensing as these devices depend upon sunlight and the radiation emitted is not their own. Alternately, radar transmits short bursts of microwaves to illuminate the surface. The return signals from the features are recorded by radar and the features are distinguished. Remote sensing by radar is called active remote sensing. There are some limitations in the usage of aerial photography and radar which are beyond the scope of the present review.

Detection of Habitats of Mosquito Vectors

Barnes and Cibula[12] classified vegetation and terrain suitable for *A.sollicitans* breeding based on aerial photography and Landsat 1,2 multispectral scanner (MSS) imageries. They also surveyed the vegetation cover over Mexico which supported screw worm fly, *Cochiliomyia hominivorax.* Later Hayes *et al*[13] identified fresh water plants associated with the breeding habitats of *Ae.vexans,* a flood water mosquito and *Culex tarsalis* breeding in permanent pools with occasional flooding. Three types of breeding habitats *viz.* permanently flooded, occasional flooding and frequently flooding were classified based on multidate satellite data of Landsat 1,2 MSS, plant species available, wet lands and other features in the Lewis and Clarke lake, USA. Based on computer generated maps, the breeding habitats were identified and limitations of satellite imageries particularly resolution were also discussed[13].

In India, a feasibility study using multidate IRS 1A and B satellite data was undertaken[14] in collaboration with the Indian Space Research Organization in and around Delhi by selecting six sites with different ecological features. It was found that false colour composite images can help in the development of base maps of the study area and macrostratification of mosquitogenic conditions is possible. The limitation of satellite resolution (36.5 m) was felt as the smaller habitats of anopheles mosquitoes were not detectable. Correlation of changes in the area of land use features *viz.* water bodies and vegetation with mosquito density was found significant in some sites.

Further, based on IRS LISS (linear image self scanning) II data, mosquito larval production was estimated[15] in the Sanjay lake and surrounding ponds in Delhi. The margins of the lake were divided in segments and sampling of larvae was done at 6 metre intervals. In order to estimate the mosquito larval production, a multiplication factor (26.5) was derived. The estimated density correlated with man hour density of mosquitoes in surrounding dwellings.

Predicting Densities of Malaria Vectors

In 1992, Wood *et al*[16] utilized, Landsat thematic mapper (TM) data (with 30 m resolution) with geographic information system (GIS) and identified high mosquito producing rice fields in California. The reflectance of canopy of the rice plantation in early season of its growth was detected and correlated with the larval density of *Anopheles freeborni*. Distances between rice fields and source of blood meal for mosquitoes *ie* pastures with livestock were measured using GIS. The results revealed that the rice fields in early canopy growth located near pastures (with livestock) supported the production of more larvae than the fields with less developed rice plantations and which were away from pastures. The accuracy of larval density prediction was possible up to 85%.

In another study using RS and GIS, the prediction of density of *An.albimanus* was possible in Belize[17]. The breeding habitats of *An. albimanus* were identified as marshy areas and river margins. The distances of houses from these breeding habitats were measured using pathfinder GIS and confirmed by global positioning system. Three ranges of distances *ie* 0-500, 501-1500 and >1500 m habitats were selected and the adult densities in houses near the larval habitats were recorded as landing rate of 0.5 mosquitoes per human per minute as high. By SPOT satellite imageries (resolution 20m) the land cover classification of low sparse macrophytes and tall dense macrophytes (which support the growth of *An. albimanus*) was found accurate up to 82-94%. Predictions of mosquito densities were accurate up to 89% for high density sites while 100% for the sites >1500m away, *ie* low. The study highlighted that a good understanding of the ecology and behaviour of mosquito species is essential. The real advantage of remote sensing was found in the extent of aerial coverage, mapping and quantification which could not have been possible otherwise by ground surveys.

Monitoring of Environmental Parameters Affecting Populations of Mosquito Vectors

The role of environmental factors *viz.* temperature, rainfall and relative humidity in the epidemiology of vector-borne diseases is well known. Meteorological data obtained from different places are not uniform and therefore limit their use for modeling of diseases. The advanced very high resolution radiometer (AVHRR) sensor on polar orbiting meteorological satellites of National Oceanic and Atmospheric Administration (NOAA) and Meteostat satellite provide data about rainfall (based on cold cloud duration), vegetation state (NDVI), land surface temperature and soil and vegetation moisture contents. Meteorological satellites observe vast areas of earth and cover the earth daily.

Tucker *et al*[18] and Linthicum *et al*[19] established that the normalised difference vegetation index (NDVI) is a reliable indicator of rainfall (as per sensor of NOAA AVHRR, NDVI is a ratio of reflectance in band 2-1/ band 2+1). The NDVI values are obtained in the range of -1.0 to 1.0. The values of 0 to 0.2 indicate bare soils (with scanty vegetation), 0.2 to 0.7 different categories of green vegetation and negative values indicate the presence of water. The NDVI data are obtained in block of 10 days *ie* 1-10th, 11-20th and 21 to the end of month. The values are usually composited fortnightly or monthly. Linthicum *et al*[20] further extended their work by correlating high NDVI values with the flooding of breeding habitats of Aedes and Culex spp, the vectors of Rift Valley fever virus in Kenya. When NDVI values were 0.43 or above flooding occurred resulting in the washing away of the breeding habitats of Aedes and Culex mosquitoes. High NDVI values generally corresponded with high rainfall. The ability to foresee flooding of mosquito habitats by remote sensing was found to have important bearing on developing strategies for mosquito control and disease prevention.

It was realized that high resolution satellites do not offer seasonal monitoring of smaller areas because of cloud cover on particular days of satellite pass and time lag in revisit. Therefore from 1990 onwards many studies have shown the application of polar orbiting satellites like that of NOAA as well as Meteostat which cover the earth daily (IRS 1C with WiFS sensor can also provide data about NDVI). Satellite data on cold cloud duration (CCD), NDVI and soil and vegetation moisture contents can be collected. In a study carried out in Africa[21], monthly composite NDVI values were correlated with density of fresh water species of *An. gambiae.* The density of mosquitoes increased in response to rainfall and decreased after cassation of rains. Time series of clinical malaria cases versus NDVI values also indicated good association in Niger. Realising the limitations of using satellite data and malaria incidence particularly spatial and temporal clustering of cases due to various factors, statistical methods capable of integrating temporal point and continuous data into the same model were suggested to maximize the potential use of satellite data.

Prediction of Malaria Risk and Seasons

The field of remote sensing has progressed from the stage of detection of breeding habitats to identification of villages with high malaria risk. Beck *et al*[22] used RS and GIS techniques to identify the landscape features (unmanaged and managed pastures, transitional swamps, mangroves, secondary forests, banana plantations, annual crops, burnt fields, inland water, urban areas and riparian vegetation) up to one km perimeter (flight range of vector mosquito) of 40 villages and correlated it with the density of *An. albimanus* and malaria incidence. The study used multiband Landsat TM data and colour infrared aerial photography to verify the landscape elements and GIS to create buffer of 1 km around villages. Stepwise discriminant analysis could identify high risk, low risk and non-malarious villages with 90% accuracy. This study highlighted that one should identify the landscape elements critical to abundance of a particular vector species in an area and the landscape elements should be detectable at remote sensing scale.

The latest application of RS was found to be in the prediction of malaria seasons in Kenya[23] by using NOAA and Meteostat satellites. Land surface temperature, reflectance in middle infrared, rainfall and NDVI values were derived from satellite data. These variables were correlated with mean percentage of total malaria cases in each month using temporal fourier analysis. NDVI in the preceding month correlated significantly with malaria incidence. The NDVI of 0.35-0.40 were found to indicate for more than 5% of annual malaria cases in a month. The malaria seasonality maps based on 0.4 NDVI threshold were found most accurate. Prediction of malaria infection in Gambian children was also possible using RS data[24].

The Future

The foregoing account indicates that RS technology has provided a tool for mapping the breeding habitats of anopheline mosquitoes, prediction of densities of vector species and even development of risk maps of malaria. It may not be helpful for delineating the smaller habitats particularly container breeding, overhead tanks, stored water, *etc.* which are usually prevalent in urban areas. The purpose of RS is not to detect the mosquitoes, but the indirect parameters of their ecology and behaviour which help in thriving of vector species. Remote sensing is likely to become a rapid epidemiological tool for surveillance of vector-borne diseases and malaria in particular. Detection of water quality parameters[25] will further help in the detection of the species specific habitats of malaria vectors. The meteorological satellites derived environmental parameters particularly NDVI are likely to serve as indicator for early warning system for malaria. Coupled with GIS, statistical analysis, sound knowledge of ecology of mosquito vector populations, improved remote sensing will play a key role in the macrostratification of vast malarious areas for prioritizing the control measures in a cost effective way.

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