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Review:

The Role of GIS And Remote Sensing in the Control of Malaria

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Abstract: Effective control of mosquito requires adequate knowledge of not just the breeding sites but also the habitats and all other environmental factors relating to the Anopheline vector's life. This is not just to avoid the nuisance they cause but most importantly to curtail the spread of the diseases they transmit. This paper identified environmental factors being chiefly responsible for the proliferation of the vector with Geographic Information System (GIS) and Remote Sensing (RS) as viable tools in the control of the diseases they transmit. Effective application and utilization of the spatial technologies also forms a major aspect in the Malaria Early Warning System (MEWS). GIS and RS technology explore all minute details related to the environment, thus it remains a vibrant tool in the epidemiological studies of vector borne diseases.

Key Words: Geographic Information System, Remote Sensing, Malaria Early Warning System, Anopheline Mosquito

Introduction:

Malaria, the world over, remains a major health concern. It is responsible for continuous mortality and morbidity among pregnant women and children especially in the tropics. [1] The causal agent; *Plasmodium* spp. accounts for over 650,000 deaths annually [2] and is being spread by a selected number of *Anopheles* vector mosquito. [3]. Despite several efforts like the World Health Organization Roll Back Malaria (RBM) Initiative, 3.2 billion people still live in areas at risk of transmission of the disease. [4] Sadly, most people under this category are domiciled in the African South of the Sahara thereby accounting for 90% of the 212 million malaria incidence worldwide in the year 2015. [5] This high rate of incidence is made possible by the abundance of the mosquito vector which was prompted by the favourable environment in which they thrive. These environmental factors which include rainfall, humidity, seasonality in climate and temperature [3], accounts for 70-90% of risk of the disease. [4] Although control of these vector species has however, for long being based on synthetic insecticidal application, their increasing resistance [5] to these synthetic chemicals pose a threat to the curtailment of the malaria disease, hence the need for a more robust and effective control measure. With the fact that appropriate vector control requires a vast knowledge of the ecology of breeding and resting habitats as well as behavior of the various species of mosquito [6], the advent of a tool with such functionality and great efficiency becomes imperative.

Geographic Information System (GIS) and Remote Sensing (RS) are novel technologies that have evolved as a frontrunner in the study of the epidemiology of Malaria. [7] GIS, being the core of spatial technology integrates a wide range of data sets available from different sources including RS and Global Positioning System (GPS). [8] As a matter of fact, GIS and especially RS are used not only in mapping the habitats, but also densities of vectors as well as prediction of disease incidence. [7] These spatial technologies (GIS and RS) help in the systematic and regular monitoring of the earth's environmental conditions [8] and has been useful in identifying the spatial limits of the disease prevalence and risk mapping with relevant risk factors using environmental indices. [9] This, in the long run makes it easy to understand the link between disease prevalence and vector distribution.

Global Information System (GIS) on a technical terms describes any information system that integrates, stores, edits, analyzes, shares, and displays geographically referenced data or spatial data. [10,11] However, all methods of collecting information about earth without touching it are forms of Remote Sensing and the data are acquired through Satellites, radars and aerial photographs. [12] The application of GIS and RS in the research and control of Malaria is therefore the focus of this review article.

Malaria Emergence

For effective transmission of the malaria parasite, survival of the mosquito vector becomes paramount. The abundance of the vector however, in relation to enabling environment combined with the probability of the vector feeding off a susceptible human host determines to a large extent, the risk of malaria infection. In order to understand this link, we need to comprehend the role which environmental conditions, vegetation, Land use or pattern as well as identifying breeding habitats play.

Environmental condition

Rainfall, temperature and relative humidity, when favourable are all viable avenues for the proliferation of the malaria vector. The association between malaria epidemic and rainfall are two inseparable entities. In tropical Africa for example where malaria is endemic and disease incidence accounts for 90% of all malaria cases worldwide [2], rain produced therein are the heaviest as it is formed from deep convective storms and clouds with coldest top surface temperature. However, while increasing precipitation may increase vector population by increasing *Anopheles* breeding sites, excessive rains may also have opposing effects on the population as small breeding sites such as ditches and pools are being washed away. [13, 14]

Temperature on the other hand influences both the speed of the development of the malaria parasite inside mosquito vector and the rate of development of the mosquito. [15] *Plasmodium falciparum* (which is the main cause of malaria mortality especially in Africa) transmission is limited by temperature below 160C – 190C and also cannot occur at temperatures above 330C – 390C. This indicates that increasing temperature may restrict malaria transmission in some geographic regions. This in essence means that Regions of high altitude as well as high temperature range experience low or no malaria transmission.

Relative humidity, being an integral factor of vector breeding and survival, parasite development and spatial diffusion of malaria transmission [16, 17] increases or decreases in relation to a factor called saturation deficit which is derived by subtracting the actual water vapour pressure from maximum possible vapour pressure at a given temp. It is an important environmental variable in larval and adult survivorship. [17]

These environmental variables in the long run have effects on Disease distribution; pathogen development in vector; development, reproduction, activity, distribution, and abundance of vectors; transmission patterns and intensity; outbreak occurrence.[18-20]

Vegetation

Vegetation near human habitation increases the population of malaria vectors and thereby increasing transmission.[21] Mosquito do prefer canopy coverage [22] and are known to take shelter in tree holes.[23] Rice irrigation schemes as also been reported [17] as excellent breeding sites for *Anopheles gambiae* early in the growth cycle of the plants. In addition to that, the availability of plant sugar increases egg numbers [24] and survival potential of *An. gambiaeeven* beyond ages at which they are old enough to transmit malaria. Moreover, the type of vegetation which surrounds the breeding sites provides the needed potential resting, sugar feeding supplies, and protection from climatic conditions for adult mosquitoes.[24]

Land Use Pattern

Topography is an important factor in understanding the malaria epidemiological situation at local scale. [9] Topography and slope for example explains the difference in the distribution of malaria and schistosomiasis in two municipal sites of Philippines. [24] In Tanzania, identifying down slope flat areas of malaria risk illustrates how topography could help identify local areas prone to epidemics in the highlands. [25]

Application of RS in Malaria Control

RS being defined as the acquisition of information on an object or phenomenon without direct or physical contact with it [26] works through electromagnetic radiation reflected or emitted by the Earth's surface. These are recorded by sensors on board satellites. The launch of Landsat-1 41 years ago and other satellite sensors such as Terra (Advanced Space borne Thermal Emission, ASTER; and Moderate Resolution Spectrordiometer, MODIS) in 1999, National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) in 2002, Radarsat-1 (SAR) in 1995 and Meteosat-7 (VISSR) in 1997, has made the use of remotely sensed data to map and monitoring the Earth's surface features be on the increase, especially for malaria studies. [27]. The visual interpretation of the multispectral and multitemporal satellite sensor data products derived from the earth observation resource satellites IRS LISS-I, LISS-II, LISS-III, and IRS WiFS. [15] IKONOS, Landsat TM, Satellite Pour l'Observation de la Terre (SPOT), and the meteorological satellites NOVA-AVHRR has been used for mapping the mosquito breeding habitats (31) and with spatial consistency and overall accuracy of 90%. [15] These studies have contributed towards a better understanding of malaria vector ecology. [28]

The applicability and usability of RS in malaria epidemiological studies is borne out of the fact that many diseases have links with certain environmental features or factors which may be land use and land cover, land surface temperature (LST), rainfall, vegetation and elevation. [29]

Remote sensing imageries in a GIS were also used for identification and characterization of the habitats that produced potential *Anopheles* vector mosquitoes. RS derived environmental variables, such as the Normalized Difference Vegetation Index (NDVI), the enhanced vegetation index (EVI), and LST, have been used to monitor and develop a risk map for vector-borne disease. [18] In addition using remote sensing data (NDVI), mosquito larval abundance was easily estimated and subsequently used to predict adult abundance 7–22 days in advance. It was also found to be useful in mapping landscape ecology using high spatial resolution images [30, 31] as well as mapping Environmental components using low spatial resolution images.

Factors, such as the transmission parameters, have also been extracted indirectly from RS data. In addition, precipitation, LST and vegetation indices derived from RS have been shown to be beneficial for the early detection and prediction of malaria, making it vital for malaria control. [3, 32] Spatially complete and almost continuous characterization of the Earth's surface and large area coverage is also included among the advantages of the RS data.

GIS Application in malaria control

The usefulness of GIS in the control of vector borne diseases and especially Malaria cannot be overemphasized. Empirical knowledge being the basis of the traditional method of vector-borne control is out rightly currently inefficient in control studies as it crude, laborious, expensive, erroneous and time consuming. Over the past few decades, the efficacy of the application of GIS in malaria control studies has been tremendously demonstrated. [33, 34] GIS integrates hardware for capturing managing, analyzing and displaying all forms of geographically referenced information. Its ability to analyze landscape level relationship of vectors and diseases 44is an important feature that makes it useful and reliable.

GIS has been used for mapping, monitoring, visualizing, retrieving, analyzing, and modeling the geo-referenced data with high accuracy. This has been demonstrated in mapping out the diversity and the ecology of vectors, disease prevalence, disease transmission, spatial diffusion. [21]

Furthermore, the efficiency of GIS for disease surveillance and health information management has been unprecedented. Web mapping GIS using Application Programming Interface (API) is important for drawing disease epidemiological information. This is however made possible through the embedded customized web mapping GIS (ASP, .Net, html, java, python, CSS, PHP, Arc IMS, Geo ext, C, C++, Visual Basic, Arc objects), which has user interface facilities for browsing, querying, and table sorting. [35]

GIS-based malaria incidence mapping has been used for risk assessment at national, regional, town and village level (Figure 1). Such mapping is considered crucial for analyzing past as well as present disease trends. [9] Further uses can be found in; mapping to produce overall distribution maps for the six species of *An. gambiae Giles* complex in Africa [36] as well as describing the overall extent of *An. dirus* complex distribution and its distribution across Southeast Asia.

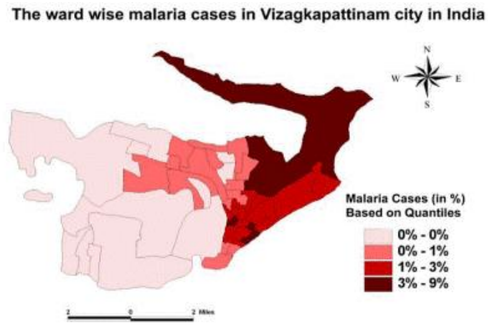

Figure-1: The mapping of ward-wise malaria cases in Visakhapatnam city in India

GS and RS integration in Malaria control and their application in Malaria Early Warning System

RS generally enhances the ability to generate data while GIS can analyze landscape level relationship of vectors and diseases. Utilization of geo-statistical tools (GIS) combined with high quality data (RS) has capability to provide new insight into malaria epidemiology and the complexity of its transmission potential in endemic areas. [9] Not only that, they both assess the ecological factors that contribute to observed distribution of breeding grounds (Figure 2 and 3). Both tools have been useful in acquiring, managing, interpreting and analyzing both spatial and temporal data sets useful in the study of disease. RS data in GIS have been used widely for identification, characterization, monitoring, and surveillance of breeding habitats and mapping of malaria risk. [9] For instance, GIS maps developed from aerial photographs in Dar-es-Salaam, Tanzania facilitated efficient larval surveillance and complete coverage of targeted areas with larval control. [13] Integrated use of remote sensing and GIS has been successfully demonstrated in many studies related to mapping of malaria risk in different parts of Africa. [37, 38]

The novelty of GIS and RS can further be seen in the case of the Malaria Early warning system (MEWS), which is a system that allows the integration of datasets like historical case data, environmental and meteorological data in a modeling form for early detection, prediction and forecasting of malaria. The World Health Organization (WHO) Roll Back Malaria campaign had proposed the development of operational MEWS for prompt detection, prevention and control of malaria epidemics. [39] In achieving this, there is need for reliable and accurate information as regards the location, time and magnitude of epidemics and its likeliness to occur. Several MEWS approaches to malaria warning signal which includes monitoring and consideration of the dynamic factors which may make populations more vulnerable to severe epidemic outbreak; monitoring seasonal climate (either dry, normal or wetter); monitoring of the weather (temperature, rainfall, etc); epidemiological / entomological surveillance as well as the use of mathematical or statistical models with historical malaria cases and environmental risk indicators, all are borne out of the fact that the distribution of mosquitoes and subsequent transmission of malaria in sub-Saharan Africa is climate driven. [38] The advantage of GIS and RS in this framework is that, being spatial range and temporal data analyzing tools, they provide a wide range of environmental data which can form the bases of epidemiological forecast models that is economical, accurate, fast and reliable.

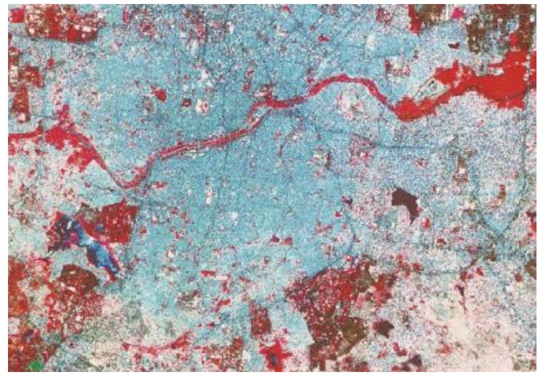

Figure 2: Raw data LISS: iv image

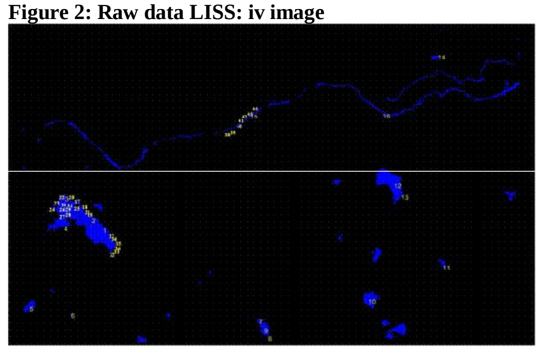

Figure 3: GIS Analysis

Conclusion

Malaria is a curable disease, despite the fact that the environmental drivers that determine the life cycles of the vector, host and the *Plasmodium* parasite are complex. They can be monitored and analyzed using technologies such as RS and GIS. Not only are they providing solutions to the menace presently, they can also be used as a warning system which would prevent epidemics. Integration of GIS with Remote Sensing has helped in identification, characterization and monitoring of breeding habitats of the vector. Despite shortcomings in some aspects of the technology, improvements such as the Vectorial capacity model are novel remedy to the challenges in its functionality. However, not only has RS technology provided a tool for mapping the breeding habitats of anopheline mosquitos, it has also worked in the prediction of densities of vector species. RS surely do not detect the mosquitoes, but it reveals the indirect parameters of their ecology and behaviour which helps in thriving of vector species. Coupled with GIS, statistical analysis and sound knowledge of the ecology of mosquito vector populations, these improved spatial technology will play a key role in the macrostratification of vast malaria risk or prone areas for prioritizing the control measures in a cost effective way.

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