REVIEW ARTICLE

REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS (GIS) AS THE APPLIED PUBLIC HEALTH & ENVIRONMENTAL EPIDEMIOLOGY

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ABSTRACT
The public health epidemiology is the study of horizontal and vertical structure of the disease infection state, and health related events and attempt to explain the environmental risk factors (biological, physical, and chemical agents); social settings and factors affecting human contact with these agents, and socioeconomic and environmental condition. GIS has been used to mapping the epidemiological information which includes the burden of disease epidemic transmission, spatial distribution and the determinants of health related states or events in specified population with reference to space and time. Perhaps, remote sensing and GPS has been integrated under the GIS umbrella for disease surveillance, situation analyze and the spatial modelling of disease transmission. The first application of cartography was used in the public health epidemiology for mapping diarrhea disease in London, during 1854 by Jonson Snow, UK physician. However, the applied GIS and remote sensing have not only become essential tool in mapping the both vertical and horizontal epidemiological information, disease surveillance, health monitoring, surveying, sampling design, disease control programs, predicting the disease transmission, and most importantly, incorporated the ge0spatial epidemiological analysis of proximity, similarity, geometry, and cognitive of the disease incidence and the socioeconomic and the ecological variables. It has also become significant decision making tool in heath monitoring, health care management and public health epidemiology. The ERDAS Imagine image processing software and the ARC GIS, Map INFO, Geovariogram+, SPSS are used to mapping, spatial analysis and image processing of the both non-spatial and spatial data. The illustrations are used in the present study based on the data generated from the source of author's research works and publications, which has relevant information on the public health epidemiological aspects of vector borne disease transmission and GIS for epidemic control and management in India.
Key Words: Remote Sensing; Geographic Information Systems (GIS); Health Monitoring; Health Care Management; Geospatial Analysis; Spatial Modelling; Public Health Epidemiology

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Introduction

Public health epidemiology is the study of the frequency and spatial pattern of disease, and health-related events and attempt to explain the environmental risk factors (biological, physical, and chemical agents); social settings and factors affecting human contact with these agents; and socioeconomic and environmental conditions associated with disease infection, epidemic transmission, spatial diffusion, horizontal and vertical magnitudes of the disease/infection state, which includes age, gender, height, weight, disease host, epicenter of the disease, disease nature (foreign or indigenous), and socioeconomic conditions of the occurrences of diseases with reference to space and time.

Geographic information systems (GIS) is the computer software for data capturing, thematic mapping, updating, retrieving, structured querying, and analyzing the distribution and differentiation of various phenomena, including communicable and non-communicable diseases across the world with reference to various periods. I may perhaps coin the words, "GIS is tailor-made maps/layers of thematic map information". The remote sensing satellite data products are reliable, offer repetitive coverage, and are accurate. It has been used for studying and mapping the surrogate information relevant to the environments of the disease transmission at particular periods. Integrated remote sensing and GPS under the GIS umbrella have also been used for disease surveillance and epidemic control. GIS has been used to map the epidemiological information that includes the burden of epidemics, spatial distribution, and the determinants of health-related states or events in specified population with reference to space and time.

This article deals with the issues of integrating qualitative and quantitative methods of analysis, and the examples provide excellent, clear, and detailed definition and illustration of the various forms with system process. The study of public health epidemiology contains the information relevant to the occurrence of diseases, infection rate, age group, sex, disease transmission, site specification of the patients, host availability of the parasite or virus loads, and so on. This information was used to state the horizontal and vertical structures of the diseases and history of the disease with reference to space and time. GIS has been used to map the geographical distributions of disease prevalence (communicable and non-communicable diseases), the trend of the disease transmission, and the spatial modelling of environmental aspects of disease occurrences.[16,18-27,31] GIS was also used for spatial analysis and modelling, cause-and-effect analysis, cognate models, and temporal analysis.[12,16,20]

GIS has the inbuilt facility of conventional and the scientific knowledge of traditional, fundamental concepts of formal mapping with signs and symbols, variety of colours, shades, lines and polylines, and patterns. It has the computer-aided designs, symbols, and colours for thematic or customized mapping, and perhaps, embed mapping facilities, overlay analysis, cluster analysis, nearest-neighbour analysis, pattern recognition, temporal analysis, interpolation of point data (Kriging, Co-kriging, Universal Kriging), spatial correlation, fussy analysis, linear determinant analysis, the probability of minimum and maximum likelihood analysis, and so forth for geospatial analysis of thematic information. Thus, remote sensing and GIS could be used for mapping, studying, and analyzing the information relevant to the disease transmission of public health epidemiology with reference to space and time.[4,5,10-31,34-36]

GPS for Epidemic Surveillance

GPS has been used directly on top of a map for site-specific location to collect field data in real time, convert and log real-time GPS coordinates. It has been assisting to conduct a field survey to collect information continuously and to automatically update the geographic coordinates with minimum 500 points. The latest version of geographic tracker includes a map basic application, which allows the "GPS tracking" by showing a real-time GPS-derived position directly on top of a map. It has facilities to collect and attribute field data directly into your geospatial database engine (GIS software) in real time, an exciting concept that may be called "GPS Geo-coding". The geographic tracker can process live or simulated GPS message data ("Live GPS Data" or "Simulated GPS Data") on online database connectivity. GPS has been used for disease surveillance in crucial situations such as during dengue epidemic in India. The dengue vector (*Aedes* species) mosquito's flight range between 200 m and 400 m, and has outdoor resting practice and bites during the daytime, and therefore, the reconnaissance survey was conducted in the nearest house of closeness to the intersection points of 100-m grid samples. The available GPS instrument has the inbuilt error of ± 100 m. Therefore, the GPS instrument under the GIS umbrella is found useful for mapping dengue vector breeding habitats with site specifications, including the house locations, streets, house type, and locality/areas with interval of 100 m, and is found effective in epidemic control in the country.[12,18]

GIS for Mapping the Point Data and Interpolation of Contour Surface

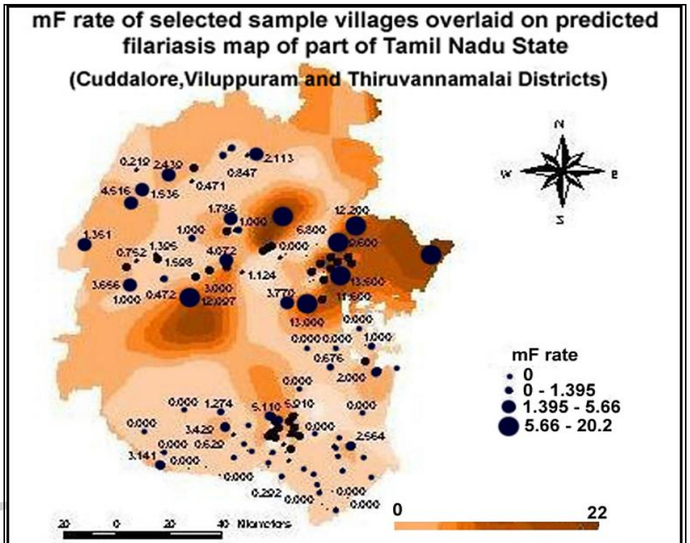

Figure-1: The filariasis mF rate was mapped using graduated point symbol, and it was superimposed on the predicted interpolation map of filariasis in part of Tamil Nadu, India [map source: M Palaniyandi, 2014]

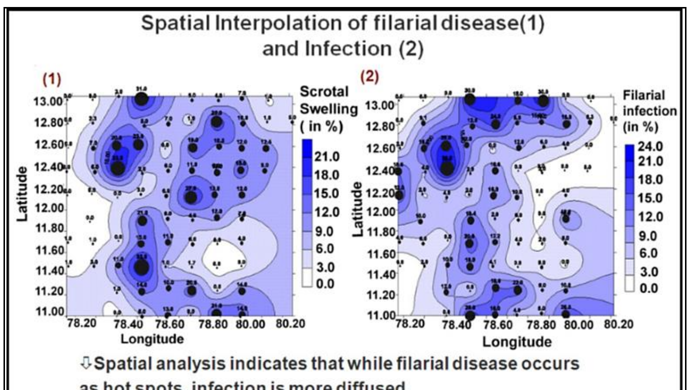

Figure-2: The filarial disease (1) and the mF infection rate (2) of selected sample points, and the predicted map of spatial diffusion of filariasis transmission [map source: M Palaniyandi, 2014]

GIS has been used for mapping epidemiological data and for spatial interpolation of data for places where data were not available/ unsurveyed places (Bailey TC, 1995, Cressie NAC, 1993, and Srividya A, *et al,* 2002). The GPS instrument was used to collect the filariasis epidemiological information of the selected villages, based on the GIS-based 25 km× 25 km grid sample procedures. The data pertaining to the (micro filarial) and disease rate were mapped with graduated point symbol, and the interpolation of contour surface was created for predicting the filariasis mF rate in the areas where data were not collected. The mF infection rate of selected sample villages was overlaid on the interpolation of contour surface of the predicted filariasis map of part of Tamil Nadu, India (Figures 1 and 2). The procedures applied in the study have been used for mapping the disease infection in the area where data were not available, implementing disease surveillance, management of disease control programs, and management of the disease in countries like India.

GIS for Mapping the Lineament Data using Line Symbols for Host Analysis

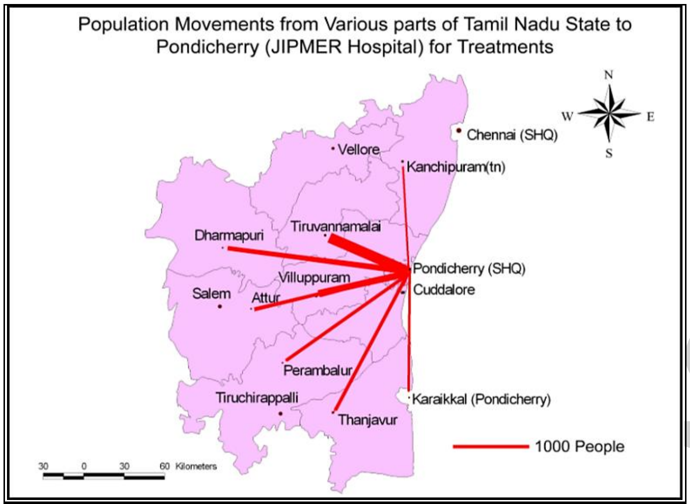

Figure-3: The mapping of population movements from various parts of Tamil Nadu to Pondicherry (JIPMER Hospital) for seeking health treatments using line symbol, flow map

The population movements to specialized hospitals located in the cities, floating population of the hospital outpatients and the inpatients, health services, and road and rail facilities to the hospitals have been mapped using line symbols and flow maps. Breeding habitats of malaria vector mosquitoes (A*nopheles* genus) and the Japanese encephalitis (JE) vector mosquitoes (*Culex* genus) such as the drainages, irrigation canals, rivers, and streams were mapped using line symbols. The site specifications of the houses in the streets with breeding habitats of dengue vector mosquitoes of *Aedes* species (*Aedes aegypti* or *Aedes albopictus*) have been mapped with line symbols. The mosquitogenic conditions suitable for profusion of mosquitoes around the rice fields and the lineament features of irrigation canals from the water resources (rivers, streams, lakes, tanks, dams, etc.) with 2.5-km buffer zone of malaria and JE vector mosquitoes flight range have also been mapped with line symbols.[10-14,18,20] Generally, a cartographic flow map technique with graduated line symbol is used for the optimum public health service coverage analysis, for example, the mapping of population movements from various parts of Tamil Nadu to Pondicherry (JIPMER Hospital) for seeking health treatments using line symbol is a geographical hypothetical model[17] (Figure 3).

GIS for Mapping Disease Prevalence with Polygon/Area Symbol

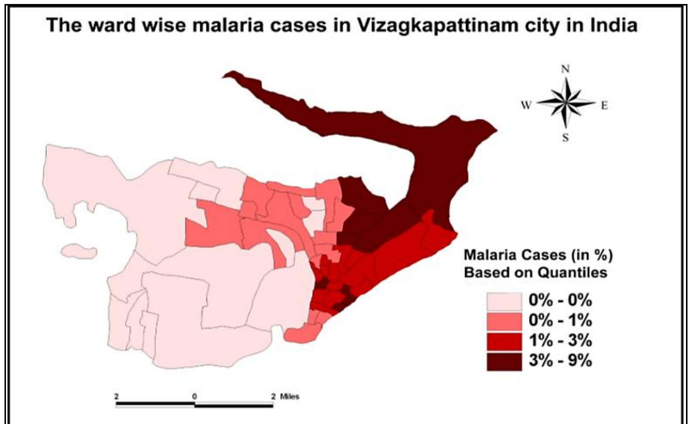

Figure-4: The mapping of ward-wise malaria cases in Visakhapatnam city in India (map source: M. Palaniyandi, 2013)

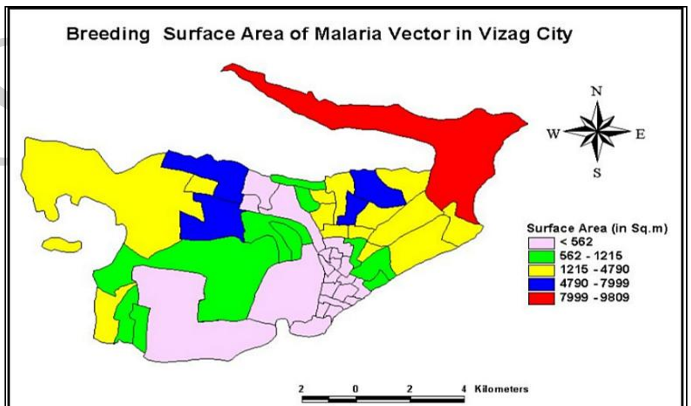

Figure-5: The mapping of ward-wise malaria vector breeding surface in the Visakhapatnam metropolitan areas, India (map source: M. Palaniyandi, 2013)

GIS has been used for mapping the district-level malaria disease prevalence and the epidemiological information with polygon symbol. The traditional method of vector-borne disease control was based on the empirical knowledge; however, it was most crude, laborious, expensive, erroneous, and time consuming, whereas the remote sensing and GIS techniques are scientific, accurate, fast, and reliable. GIS and remote sensing have been used for mapping habitats of vectors and their abundance and density, and assessing the risk of vector-borne diseases.[21] Perhaps, these were used for finding the source of infection, root cause of disease transmission, and diffusion of the diseases.[12,19,20-23,25,32] These were also used for assessing the community at risk of disease transmission, and thus are epidemiologically important for choosing appropriate controlling methods and priority areas for both vector and disease control.[12,19,21,25,32] (Figures 4 and 5)

GIS for Disease Surveillance and Health Information Management

GIS facilitates structured querying and decision-making process to a certain level. The structured spatial queries relevant to demographic features, disease prevalence, environmental aspects, and the socioeconomic risk factors have provided the diffusion of disease transmission, and hence, the action plan for disease control operations was implemented to prevent the epidemics in the country. The web mapping GIS using application programming interface (API) has been made readily available to customize the embed mapping of the real-time epidemiological disease information to the individual and planners for browsing the information from the public domain of health GIS websites. The web mapping GIS using API is becoming important, especially the embed 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 and drawing the disease epidemiological information in different parts of the country.[10,13,22] (Figure 6)

Integrated Remote Sensing and GIS for Mapping, Geospatial Analysis, and Spatial Prediction of Vector-Borne Epidemics

The geostatistical analysis of remote sensing and climate, geoenvironmental variables, and the spatial models have been providing us significant and reliable results, and the guidelines of algorithms for predicting the people of community at risk of disease transmission with reference to space and time.[37] For example, a Geo-Environmental Risk Model (GERM) for filariasis transmission was developed using remote sensing and GIS during 2000–2003.The GERM model provided us reliable, scientific, accurate, and spatially significant guidelines for predicting the probability of filariasis transmission risk in Tamil Nadu region. The model was customized according to the environmental parameters, encompassing altitude, 0–2000m mean sea level; temperature, 8–37°C; rainfall, 300–1500mm; and relative humidity, 40–90% for deriving filariasis risk index (FRI). On the basis of the results of the FRI analysis, geo-environmental filariasis transmission risk map was created at the GIS platform, and it was further stratified

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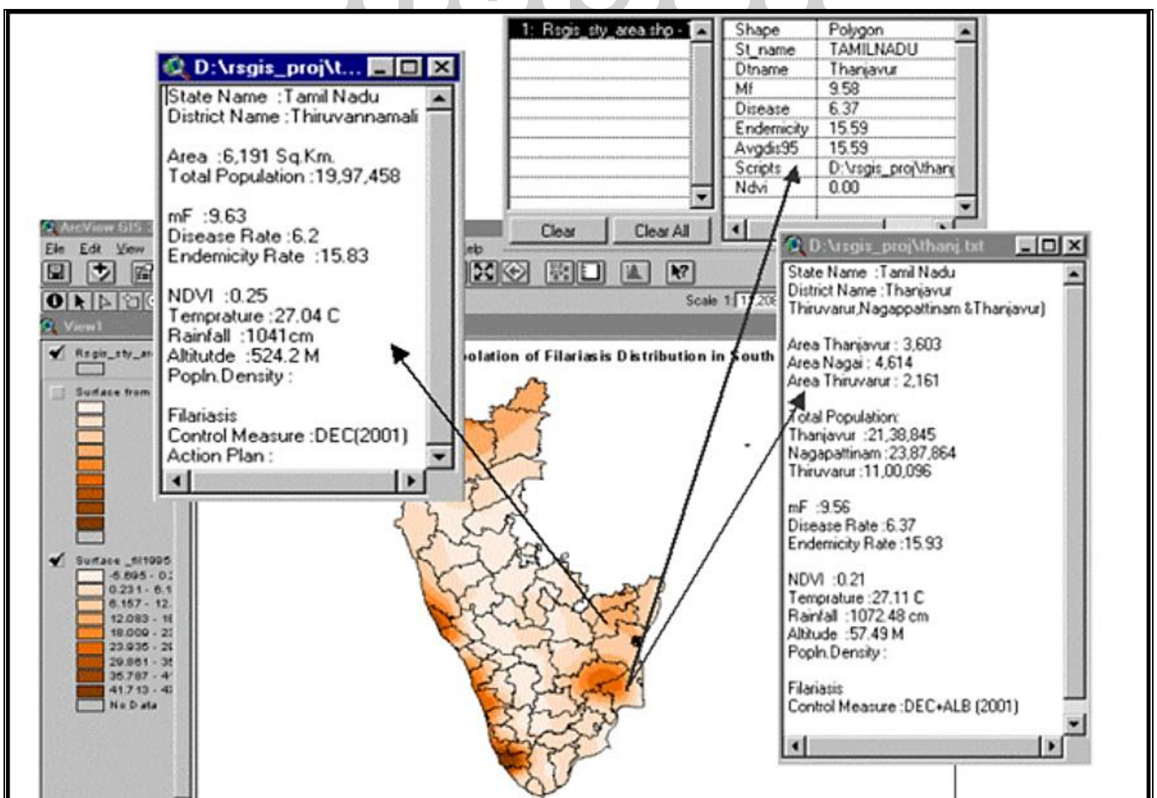

Figure-6: The customized mapping of user friendly structured query of spatial database of filariasis epidemiological information available in the server (map source: M.Palaniyandi, 2014)

into four spatial entities, which were hypothesized as potentially high risk (FRI: 31–38), moderate risk (FRI: 23–30), low risk (FRI: 15–22), and no risk (FRI: <15) areas. The GERM spatial model for filariasis transmission risk was validated in the different geographical regions (plain, plateau, hills, river beds, coastal areas, and the uplands) with supported ground truth data and ICT kits. The negative value of spatial prediction provides the guidelines for decision making and planning for deciding to pass up the areas for resurveying or to avoid the implementation of disease control program where the efforts need not be taken/are not required.[19,23,32] Hence, this model could assist the planners in preparing the action plan at the right place and in the right way. A geospatial model could be importantly useful in decision making for disease control program (Figure 7a).

Remote sensing and GIS for potential mapping of vector breeding habitats

The visual interpretation of the multispectral and multitemporal satellite sensor data products derived

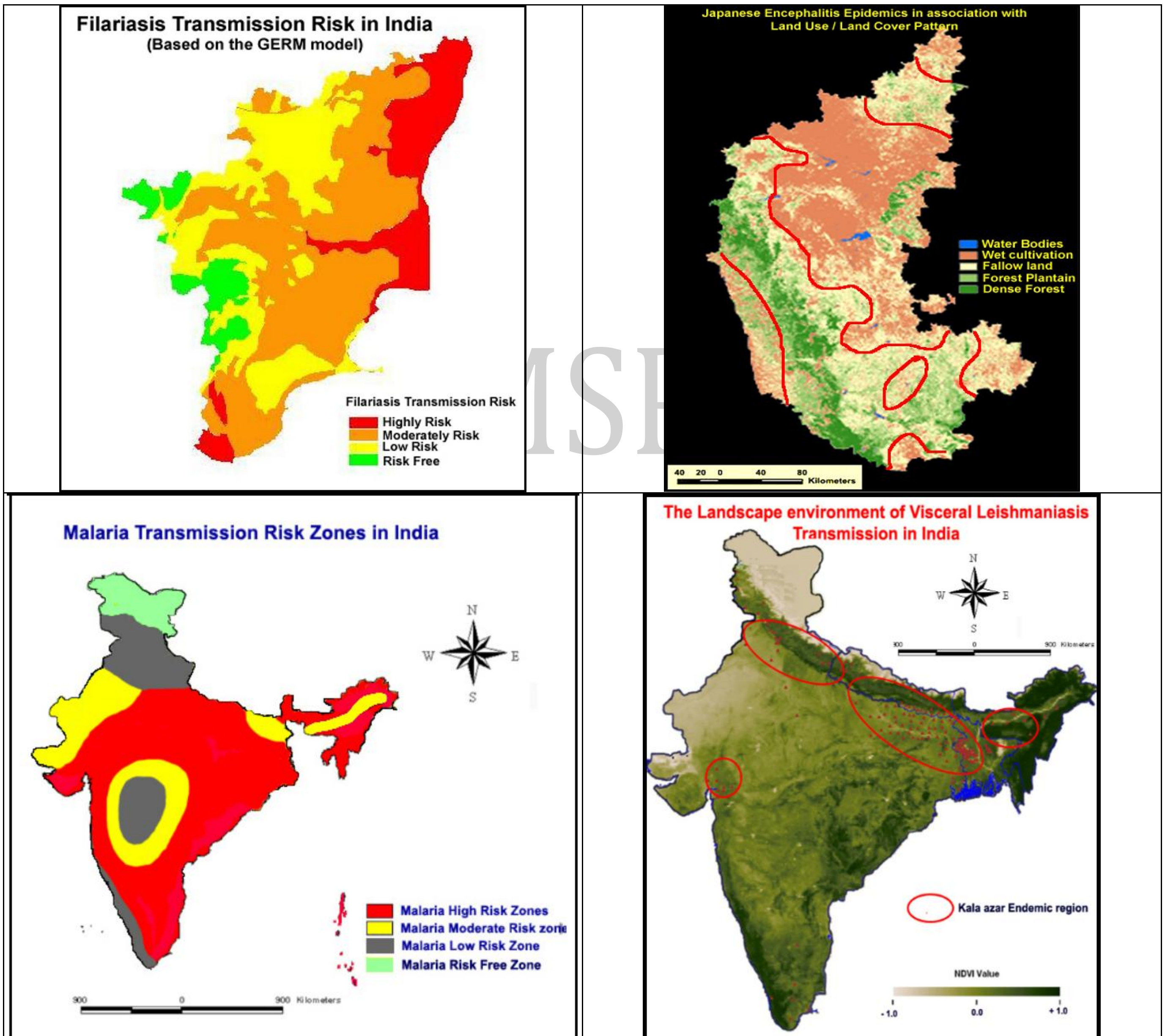

Figure-7: (a) The integrated remote sensing and GIS for spatial prediction of filariasis transmission risk in different regions of Tamil Nadu, based on the GERM model (map source: S.Sabesan S, et.al.,2006). (b) The spatial association between the JE epidemics and land-use categories derived from the satellite remote sensing IRS WiFS data of Karnataka, India (map source: M Palaniyandi, 2013). (c) Malaria transmission risk in India (map source: M.Palaniyandi, 2013). (d) The geographical distribution of visceral leishmaniasis is spatially associated with the mean composite NDVI value between 0.08 and 0.53 (95% significance and 5% error precision with confidence interval, CI 0.413–0.544), p<0.001 (map source: M.Palaniyandi, et al., 2014)

from the earth observation resource satellites IRS LISS-I, LISS-II, LISS-III, and IRS WiFS[12,14,21,24,26,33,34], IKONOS, Landsat TM, SPOT, and the meteorological satellites NOVA-AVHRR has been used for mapping the mosquito breeding habitats[38-40]. The range of normalized difference vegetation index (NDVI) values derived from the satellite data was highly significant with the vector abundance and the spatial occurrence of vector-borne diseases.[9,12,24,38-40] The vectors and vector-borne diseases have been directly controlled by the geo-climatic variables, and the NDVI values derived from the space-borne remote sensing data.[3,6,7,8,12,30,36,38-40] Remote sensing data under the umbrella of GIS was potentially useful for mapping the breeding habitats of JE vector mosquitoes and land-use/land-cover changes, which are potential sites for JE epidemic transmission in the country.[12,14,20] The NDVI values derived from the IRS WiFS satellite data provides the value of $< 0.0 – 0.22$ for wet rice cultivation areas with breeding habitats positive for *Culex* genus immature JE vector mosquitoes; the NDVI values >0.2 and <0.4 show actively photosynthesizing vegetation, which is vulnerable to high risk of JE transmission, and followed by the NDVI values of >0.4 to <0.6 and <0.022 and > 0.013, having the moderate risk of JE transmission during the Kharif and Rabi crop seasons, respectively.[12,14,20] (Figure7b)

Geospatial analysis of malaria transmission and the environment

The spatial relationship between the climatic variables and the *Anopheles* genus malaria vector shows that the model is statistically significant.[1-7,12,14,25,33,34,38-40] The optimal temperature range for the development of *Anopheles* vector species of malaria is between 20°C and 30°C. However, transmission of *Plasmodium vivax* requires a minimum average temperature of 15°C and that of *Plasmodium falciparum* requires a minimum temperature of 19°C. It has been observed in India that the *P. vivax* vector requires 15–25 days to complete its cycle if the temperature remains within 15–20°C. The relative humidity for both species remains within 55–80% and their life cycle maybe completed even within 6–10 days, if the temperature remains within 25–30°C range. The relative abundance of the malaria vectors is directly controlled by the climatic variables. The multivariate geostatistical model predicted accurately the spatial association of the malaria cases with the climatic variables and the relative abundance of malaria vector breeding habitats.[26] (Figure 7c)

Climate, landscape, and the environment of visceral leishmaniasis transmission

The geoclimatic aspects related to the occurrence of visceral leishmaniasis, sandfly fever, and cutaneous leishmaniasis are determined by the geoclimatic variables.[7,31] The visceral leishmaniasis vector abundance is found between June and September [2], with *Phlebotomus argentipes* most active profusion when the temperature is between 27.5 and 31°C. The impact of temperature has direct influence on profusion and longevity of sandfly populations and distribution of vegetation condition has also provide a synoptic view [35] to an overall accuracy of more than 80%. The geographical and seasonal distribution of the major vectors *Phlebotomus martini* and *Phlebotomus orientalis* of kala-azar (visceral leishmaniasis) is analyzed using GIS.The best fit for the distribution of *P. martini* in the dry season is associated with the composite NDVI value of 0.07–0.38 and land surface temperature 22–33°C with a predictive value of 93.8%, and the best fit for *P. orientalis* in the wet season is associated with the composite NDVI value of –0.01 to 0.34 (Figure 7d), with a predictive value of 96.3%. In India, the specific crop vegetation types have been correlated with kala-azar transmission.[12,15]

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GIS for Optimum Service Coverage for Disease Control and Management

The spatial clustering, nearest-neighborhood analysis was done for easy understanding of the filariasis spatial pattern and disease clustering, and the spatial ring buffering was created for optimum service coverage of the patients. Different distance rules of 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 km were created over the disease distribution map, using spatial ring buffering technique at the GIS platform. The minimum, maximum, and mean distances of each disease cluster were calculated against each distance rule/ring buffering. The lymphedema cases proportionally high in the 56–75 years age group and the lymphedema grade II cases in high percentage were found in all the human settlements. The list of existing primary health centers / government hospital is shown on the Pondicherry urban boundary map. The study shows that the ring buffering distance of 0.7 km has the optimum service coverage. The hypothesis of this study that the aged patients could travel a distance of less than 1 km from their residence to the health centers for morbidity management is carefully examined. The study area required 15 centers with 0.7-km ring buffer or coverage area. Of 15 centers, 10 already exist, and only 5 more new centers are required for covering all the patients. We suggest opening self-help health service centers with coverage distance of less than 1 km in urban areas like Pondicherry for lymphatic filariasis morbidity management.[29] (Figure 8)

GIS for Mapping, Health Monitoring, and Decision Making

GIS has been facilitating integrated remote sensing, database management systems, computer cartography, and geostatistics. It has been used for mapping, monitoring, visualizing, retrieving, analyzing, and modeling the geo-referenced data with high accuracy. For example, it was used for mapping the biodiversity and the ecology of vectors, disease prevalence, disease transmission, spatial diffusion, etc. It has been used for monitoring the past, present, and future disease control programs (Figure 9a b). The national mass drug administration programs in different states aim toward

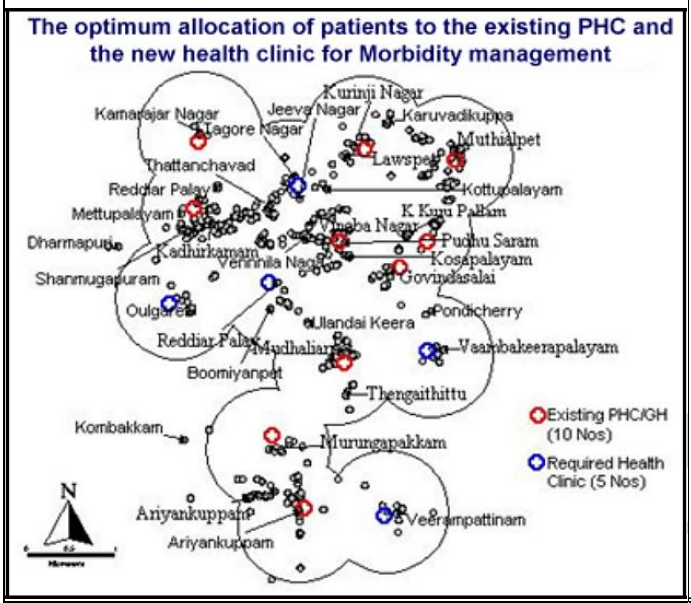

Figure-8: The GIS-based optimum allocation of the patients to the existing PHCs and the proposed places for new health clinics for filariasis morbidity treatment—the service coverage is based on the coverage area with 0.7-km buffering zone (map source: M. Palaniyandi, 2008)

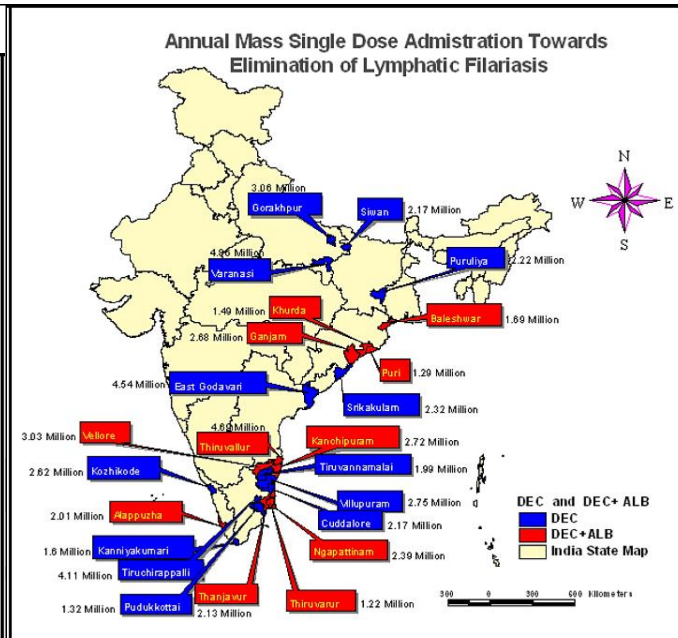

Figure-9 (a): The national mass drug single doss administration programs towards the elimination of filariasis disease and control in different states of India.

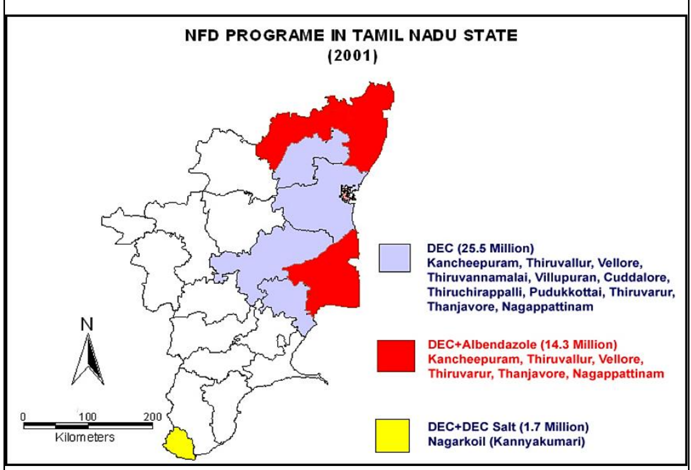

Figure 9 (b): The national mass drug single doss administration towards the elimination of filariasis disease in part of Tamil Nadu state in India. (map source: M. Palaniyandi, 2014)

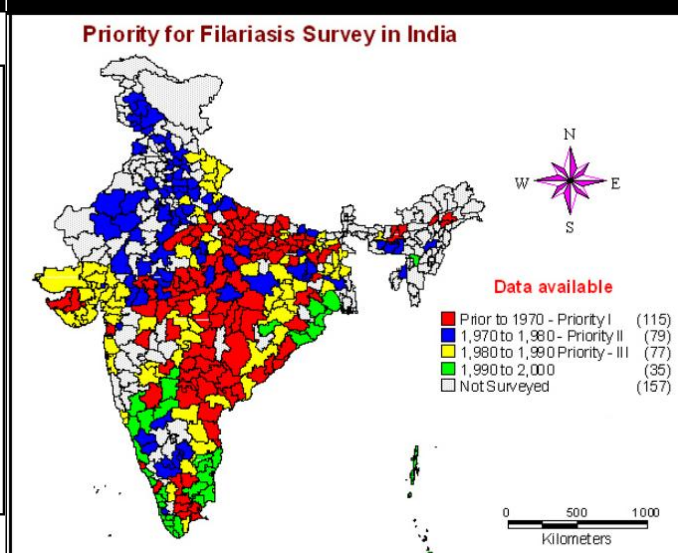

Figure-10: The priorities of districts for resurveying the filarial antigenemia detection for implementing the national filariasis disease control program in India (map source: M. Palaniyandi, 2014) the elimination of filariasis disease in India. The current situation of the disease prevalence in the country, based on the historical data, may cause error in the disease control program. Therefore, it is mandatory to resurvey the areas for health monitoring (Figure 10).

Conclusion

This study deals with the issues of integrating qualitative and quantitative methods of analysis, and the examples provide excellent, clear, and detailed definition and illustration of the various forms with system process. The summary and conclusion of this study provide information on the application of remote sensing and GIS to public health epidemiology with clear illustrations and examples of the research projects and works published by the individuals and the author for more than 40 years, and has become essentially important to public health for mapping the geographical aspects of the prevalence of vector-borne disease at the district level in the country, biodiversity of vectors, viral diseases, parasites, bacterial diseases, and studying the geo-environmental risk factors associated with disease occurrences at the block or ward level as well as at the national level(the micro-level case studies in the metropolitan of Visakhapatnam city and disease management in the cosmopolitan urban settlement of Pondicherry. GIS is not only used for mapping the spatial distribution of disease prevalence but also is an essential tool for disease surveillance, predicting the disease transmission, and most importantly, incorporating the geospatial epidemiological analysis of proximity, similarity, geometry, and incidence of cognitive disease, and socioeconomic and ecological variables. The integrated hybrid remote sensing and GIS techniques must be used to map the vector breeding potential areas vulnerable to risk of disease transmission and could provide the possible information on reliable estimates of and mapping of malaria, filariasis, JE, and dengue vector breeding habitats, and facilitate to estimate the people at risk of vector-borne disease transmission. It is also used for geospatial epidemiological research, and hence, derived guidelines for decision making for vector-borne disease control and management at the local and national level (filariasis, malaria, JE, dengue and chikungunya, and visceral leishmaniasis epidemic control and management). It is used for national disease control programs, disease surveillance, spatial modeling, and disease transmission, beyond mapping. And it has no limit with field of restriction. Therefore, unquestionably, the subject of remote sensing and GIS is classified as the applied public health spatial epidemiology.

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