An Integrated Approach for Development of a Decision Support System for Early Surveillance of Japanese Encephalitis: a Remote Sensing-based study in Conjunction with Epidemiological Scenario in Assam, India

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Abstract

Japanese Encephalitis (JE) is one of the serious mosquito borne viral diseases mostly prevalent in India and many of the South Asian countries. A comprehensive study was conducted in Dibrugarh, a JE endemic district of Assam taking into the account of the environmental and social factors that determine the outbreak of the disease. Effect of environmental and climatic factors on mosquito vector densities was investigated using geospatial tools and techniques. Wetlands were found to be the most preferred habitat type for most of the JE-transmitting mosquitoes followed by paddy-growing areas and ponds. The villages abundant with these habitats or located nearby were found to be more vulnerable to JE risk. Based on the spatial distribution of habitat types, villages in the district were divided into three categories of vector abundance and hence the risk of JE. It is found that rainfall (intensity as well as duration) is the most significant determinant in the modulation of mosquito density followed by temperature. It is also observed that the derived models could explain about 61% to 73% variation in mosquito density due to change in weather variables as indicated by R^2 values of the Models. Among socio-economic determinants, pig rearing habit of the villagers was found to be most significant. JE risk map was prepared by integrating vector abundance map with the map of host abundance in GIS domain. Attempts were also made to forecast the intensity of JE cases based on a time series analysis of historical morbidity pattern, whereas forecast for onset of the disease was based on the modulation of weather variables in the study area. A web-based decision support system (DSS) developed by integrating the forecasts of JE onset, intensity and JE prone villages has been provided to the concerned health authorities to take timely intervention measures. The JE early warning system developed for Dibrugarh district was extended to two more JE prone districts viz, Sibsagar and Tinsukia as validation sites and observed that the accuracy of forecast was within the range of 69% to 77%. DSS on JE has opened up new opportunities to study similar vector-borne diseases of the JE serogroup *viz*., West Nile.

1. Introduction

Japanese Encephalitis (JE) is a serious vector (mosquito) borne viral disease mostly prevalent in India and many of the Asian countries. Virus from wild birds through vector mosquitoes spread to peri-domestic and domestic birds (reservoirs) and then to mammals like pigs (amplifier), and eventually spills over to humans. JE Virus has been isolated from about 30 species of mosquitoes worldwide which fall under 5 genera viz., *Culex, Anopheles, Aedes, Armigeres* and *Mansonia*. However, only a few species meet the requirements to be classified as important vectors (Vythilingam et al., 1996). Since the first record of JE case in India in 1955 in Tamil Nadu followed by isolation of JE virus from wild-caught mosquitoes in 1956, in the last couple of decades, epidemics of JE have occurred in the states of West Bengal, Assam, Manipur, Nagaland, Uttar Pradesh, Bihar and Goa in addition to South India. JE cases have attained alarming proportions to pose as a major public health problem in India, more so due to its very high case: fatality ratio (Borah et al., 2011)

1.2 Geospatial technology in health research

Remote sensing (RS) combined with Geographical Information System (GIS) has emerged as an effective tool for surveillance of mosquito vector habitats and risk assessment. The risk of contracting mosquito borne diseases is a function of the spatial and temporal pattern of vector breeding habitats and also of the interaction between vector and people and vector and the reservoir (pigs in case of JE).

The advent of remote sensing 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 (Dhiman, 2000). Since 1985, the Centre for Health Care Application of Aerospace Related Technologies (CHAART) has taken projects on the application of Remote Sensing and GIS technology to human health problems in China. There have been significant research studies on JE and other vector-borne diseases in the country (Huang et al., 2018 and Liu et, al., 2022). GIS has been used in surveillance of vector-borne disease by many workers (Barnes & Cibula, 1979, Hugh Johnes, 1989, Beck et al., 1994, Glass et al., 1995, Hendrickxy et al., 1999, Verdonschot et al., 2014, Sallam et al., 2016 &2017, Longbottom et. al., 2017, Ha et al., 2021, Furlong et al., 2022). Abelardo et al., (2000) described application of GIS in determining Eastern Equine Encephalitis (EEE) virus transmission. Jeganathan et al., (2001) characterised malaria vector habitats using remote sensing and GIS in the districts of Lakhimpur and Dibrugarh in Assam. Nageswara Rao et al, (2004) investigated the physiographic disposition of areas that are affected by multiple health problems in Kasargod district of Kerala using remotely sensed data. Application of remote sensing and GIS in characterizing JE affected areas of Assam has been described by Handique et al., (2005, 2011). Status of spatial delimitation, forecasting and control of JE in India has been discussed in detail by Sabesan (2008), Handique et al. (2014) and Palaniyandi et al. (2017).

2. Materials and method

2.1 Study area

The study was carried out in Dibrugarh district of Assam located in the north eastern part of India considering the severity of impact of JE and its perennial occurrence (average annual case load in Assam during the last few decades since 1980 has been 295 – the average annual incidence per million population being 12.5. Dibrugarh district alone shared a burden of 37 cases per million population) in the area. The district covering a geographical area of 7023.9 sq km lies between 27° 15′ N - 28° N Latitude and 94° 45′ E - 96° E Longitude (Figure 1). The district is divided into six Primary Health Centres (PHCs) *viz.* Barbaruah, Lahowal, Panitola, Tengakhat, Khowang and Naharani for monitoring and providing health care services in the district.

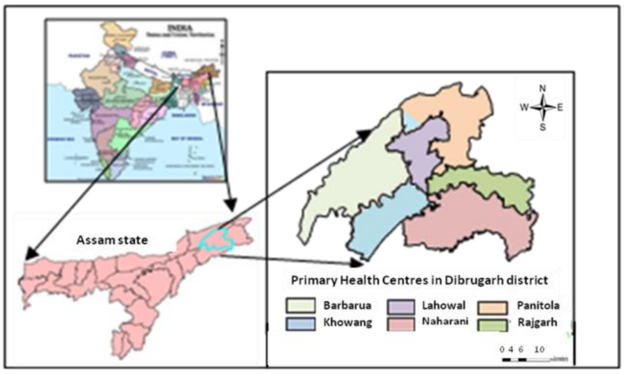

Figure 1. Location map of the study area

GIS layers of road transport and health centre locations of the district have also been prepared.

2.2 Mosquito collection and serological studies

Adult mosquito collections were conducted at fortnightly intervals from each PHC i.e. once a month from each of the eight collection sites. One cattle shed housing 6-8 cattle in each village was pre-identified for the adult mosquito collection and collection commenced 30 minutes after sunset and continued for one hour. The collected mosquitoes were brought to the laboratory in Barraud cages of 12 cubic inches size wrapped in moistened muslin cloth. Mosquitoes were identified live under a binocular stereoscope by trained personnel following standard identification keys after inactivating them on a Chill Tray (American Biophysics Corp, USA) at low temperatures (0-2ºC). Mosquitoes were pooled species-wise and stored in 2ml centrifuge vials limiting the numbers to 50 in a pool. The vial caps were tightened and secured by adhesive tape, labelled and stored in liquid nitrogen cans for JE virus incrimination studies. Mosquito densities were expressed in Man Hour Densities (MHD) (mosquito collected per man per hour, i.e. total collection of a particular dusk hour divided by number of persons engaged in collecting).

Immature mosquito collections were conducted simultaneously with the adult collections. Standard white plastic dippers with 200ml water holding capacity fixed to an extendable aluminium handle were used for the purpose. Dips were made in all probable mosquito breeding habitats like paddy fields, fallow fields, irrigation canals, ponds, wetlands, etc. and the mosquito larvae and pupae thus collected were stored separately habitat-wise in plastic containers. The containers were labelled and each of the larvae/pupae was link-reared in the laboratory. Emerged adults were identified and recorded.

Vector incrimination was done by Xeno-diagnosis (Rosen and Gubler, 1974). ELISA test was conducted on the samples by using JE virus-specific and arbovirus-specific monoclonal antibodies (supplied by National Institute of Virology, Pune). Serological studies were conducted by ICMR-Regional Medical Research Centre NER, Dibrugarh following standard procedures.

2.3 Meteorological parameters

Meteorological observation centres were set up at Madhupur under Barbaruah PHC and Kuwarigaon under Naharani PHC for recording meteorological parameters like rainfall, temperature (min/max) and relative humidity (morning and evening) on daily basis. To compensate for the weather data for the Lahowal PHC area and also as a reference, daily meteorological data was obtained from the Indian Meteorological Department (IMD) and recording centre at Mohanbari. Last 25 years weather data of the study area on daily basis from 1985 onwards has been obtained from IMD, Pune.

2.4 Delineation of mosquito breeding habitats using remote Sensing data

Satellite imageries of different sensors (IRS LISS III and LISS IV) were acquired from National Remote Sensing Centre (NRSC) Data Centre, Hyderabad, India ensuring cloud-free condition. After acquisition of satellite data, it was subjected to various pre-processing techniques in order to obtain geographically referenced data.

Multi-spectral images are primarily subjected to digital image classification using supervised approach to find out the land-cover class based on the response in spectral reflectance. Supervised classification based on maximum likelihood algorithm was operated upon the image using these purified signature sets. Different habitat types such as river, stream, wetland, pond, water-logged areas, agricultural land, tea garden, forested area, settlements, etc. were identified.

2.5 Collection of JE case data

Data pertaining to JE cases were collected from the office of the Joint Director of Health Services in Dibrugarh district and from the Office of the Directorate of Health Services, Guwahati, Assam. Average disease incidence per unit population was calculated based on the PHC wise census records collected from the respective PHCs compiled under National Centre for Vector Borne Disease Control (NCVBDC). Data on socio-economic status; poultry, cattle and pig farming practice; flood proneness of the areas and personal protection measures adopted for prevention of mosquito bites, etc. were collected through a socio-economic survey.

2.6 Data analysis

Different analyses in GIS domain have been performed using ARC GIS 9.3 and 10.2.1 Software. Statistical analyses have been done using Microsoft Excel and SPSS 15.0 and 20.0.

A methodology flow chart is depicted in Figure 2 with linkages attributed to Japanese Encephalitis (JE) Forecasting Model.

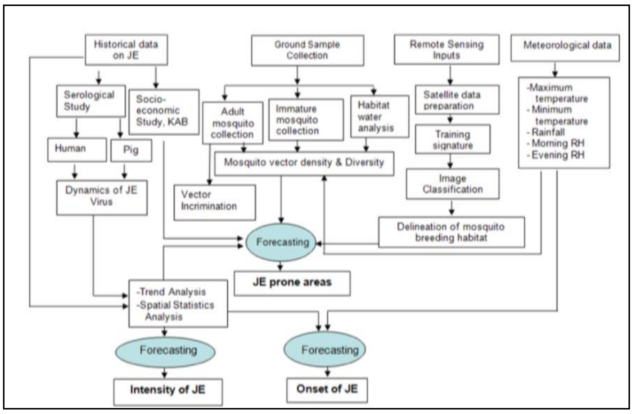

Figure 2. Japanese Encephalitis (JE) Forecasting Model

A web-based decision support system (DSS) developed by integrating the forecasts of JE onset, intensity and JE prone villages have been provided to the concerned health authorities to take timely intervention measures.

3. Results and discussion

3.1 Determination of vector habitat preference

Habitat preference of different mosquito species was measured by plotting the relative frequency of occurrence of different mosquito species in available habitat sites of sample collection points. It was observed that species like *Cx. vishnui, Cx. gelidus, Cx. quinquefasciatus, An. hyrcanus, An. annularis,* have high occurrence in almost all the habitat types. High number of occurrence of most of the mosquito species in wetlands shows it to be the most preferred habitat, particularly for species like *Cx. vishnui, Cx. gelidus, Cx. bitaeniorhynchus. An. hyrcanus* is observed to be available in all habitats in high numbers (particularly in wetland and pond), except in habitats like sewage canal, and ground pool. From the vector diversity analysis, it is seen that wetland contributes the maximum diversity, and it is seen from the graph that it also supports high occurrence of the vectors.

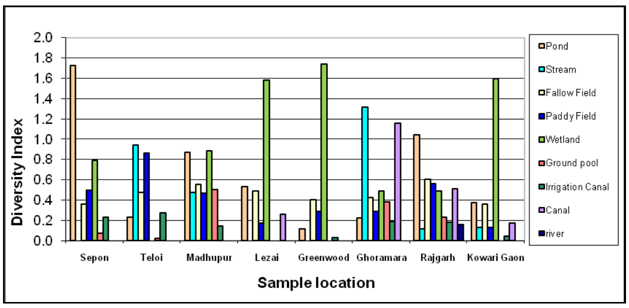

Figure 3. Shannon Weiner Diversity Index of vectors Mosquito at different sample location points.

In order to see the habitat preference of mosquito species or in other words to ascertain the species richness of a particular breeding habitat in the study area, Shannon Weiner Diversity Index was calculated, which has been given in Figure 3.

Wetlands were found to be the most preferred breeding habitat in majority of the sample collection points. Ponds and deep water paddy areas followed closely as other preferred breeding sites for a number of mosquito species as indicated by the diversity indices. As the area under paddy cultivation is the largest, they are the major contributors in building up of vector density in the study area.

3.2 Categorization of villages based on vector abundance

Different JE-transmitting mosquito species exhibit varying preferences for different habitats. This behaviour was studied by correlating the change in land cover pattern with the change in abundance of mosquito species. Satellite imageries were classified to observe the temporal and spatial variation in terms of land cover pattern, particularly for the known mosquito habitat types.

Categorization of the villages into a relative scale of High, Medium and Low mosquito density areas was done based on the correlation of different vector habitats with mosquito abundance and this has been used as one of the indicators of risk of JE occurrence.

3.3 Effect of weather parameters on vector density

A set of weather variables believed to have affect on the building of the vector population has been considered for the study. These affects was studied with the help of multiple regression models. Following are the set of the weather variables considered:

a) Maximum temperature in ºC (T_{max}) b) Minimum temperature in ºC (T_{min}) c) Rainfall in mm (Rf)
d) Morning Relative Humidity in % (RH_m) e) Evening Relative Humidity in % (RH_e)
MHD can be standardized by pooling the density and then taking log of 10 man hour density. Mosquito density has been standardized by taking log (10MHD + 1). The best fitted equation found to be-

$$Log\ (10MHD+1) = 5.459-0.009log\ (10Rf+1)-0.401T_{max} + 0.293T_{min} - 0.045RH_m - 0.023RH_e\ (R^2=0.732, SE=0.471) \quad (1)$$

It was observed that the models could explain about 58% to 71% variation in mosquito density (MHD) due to change in weather variables as indicated by the R^2 values of the models. Among individual weather parameters, rainfall was found to have a significant effect ($p<0.05$) on MHD in all the PHCs except Naharani. Temperature (both maximum and minimum) showed significant effect on MHD in all the PHCs. Effect of morning and evening relative humidity was observed to be the least among weather variables.

3.4 Categorization based on host abundance

Pig-rearing habits of different communities in the study area were assessed along with the socio-economic survey carried out in the villages near ground sample collection points. Tribal communities viz. *Sonowal Kachari, Boro Kachari, Deori* and *Mising* communities were found to have highest pig population followed by communities like *Ahom, Chutia, Moran, Motok, Mesh* etc. Communities like *tea tribe, Nepali and Bengalis* had relatively less pig-rearing habit. Lowest population of pig was observed among general castes like *Kalita, Brahmin, Kumar* etc. Information on village-wise community distribution was collected from the office of the respective Block Development Officer. Based on the village's community distribution pattern, all the villages were categorized into three pig population categories viz. High, Medium and Low pig population areas. This indicated the abundance of JE virus reservoir and hence the risk of JE the village.

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3.5 Categorization of villages based on retrospective data on disease intensity

Villages of the district were categorized according to the intensity of caseload since 1985. Villages having a caseload of 5 and above reported over the years were categorized as High JE intensity villages. Villages having caseload 1 - 4 were categorized as Medium JE intensity area. Villages that never reported any JE case since 1985 were categorized as Low JE intensity areas.

3.6 Preparation of JE risk map

Integration of vector abundance map with map of host abundance and map of disease intensity lead to preparation of final map of JE risk viz. High, Medium and low JE risk villages. Figure 4 depicts the map of JE risk for Dibrugarh district for the year 2017.

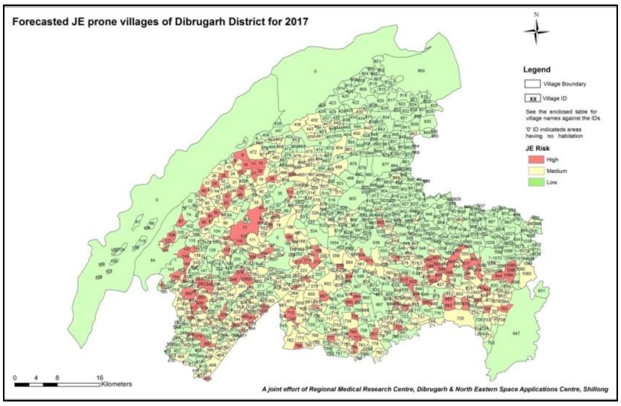

Figure 4. JE risk for Dibrugarh district for the year 2017.

3.7 JE-prone villages and reported JE cases in 2017

List of villages in the Dibrugarh district were categorized into 3 categories of JE risk (High, Medium and Low) as per the methodology described in Section 3.6. Out of total 109 cases, 71 cases (65.14%) were reported from High prone areas, 17 cases (15.6%) from Medium JE prone areas and 21 cases (19.27%) were reported from Low JE prone areas identified in the study. We need to observe the cases reported from the low JE-prone areas. Causes for spreading the disease to newer areas call for detailed geospatial analysis in these areas.

3.8 Forecasting of onset of Japanese Encephalitis (JE) during 2008-17

Prediction made with analysis based on meteorological parameters of the 9th and 11th Standard meteorological week (SMW) determines onset of JE in a disease season. Analysis of 28 years (1985 to 2012) meteorological observation shows that meteorological parameters of these SMW are having significant correlation with onset of JE in the selected districts.
Table 1 gives forecasted disease onset vis-a-vis actual occurrence for four years (2014-17) in the selected three districts.

District	Year	Forecasted onset	Actual Occurrence
Dibrugarh	2014	Early	Normal
	2015	Early	Very Early
	2016	Normal	Normal
	2017	Early	Early
Sivsagar	2014	Early	Early
	2015	Early	Very Early
	2016	Normal	Normal
	2017	Early	Early
Tinsukia	2014	Early	Normal
	2015	Early	Very Early
	2016	Normal	Normal
	2017	Early	Early

Table 1. Forecasted and actual onset of JE

3.9 Validation of JEWS

The JE early warning system developed for the district of Dibrugarh was extended to two other JE prone districts in the state of Assam viz., Sibsagar and Tinsukia in the subsequent years. It was continued for 3 years (2018 to 2020).

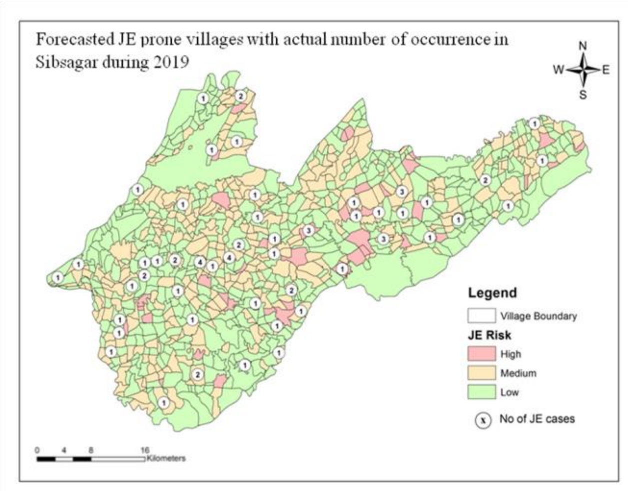

Figure 5. Forecasted JE prone villages with actual number of occurrence in Sibsagar district during 2019

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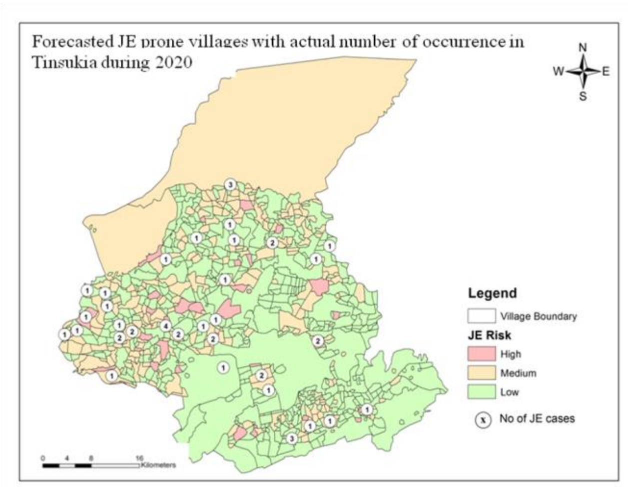

Figure 6. Forecasted JE prone villages with actual number of occurrence in Tinsukia district during 2020

It was observed that the model performed equally good in both the districts with about 74% of the JE cases reported from the High risk villages identified in the district of Sibsagar and 71% cases reported from the High risk villages identified in the district of Tinsukia. Comparatively higher accuracies were observed during the year 2019 in Sibsagar (77%) and in the year

2000 in Tinsukia (75%). Maps showing the Forecasted JE prone villages along with the actual number of JE cases reported for these two years are depicted in the Figures 5 and 6.

4. Conclusion

A web-based decision support system (DSS) developed by integrating the forecasts of JE onset, intensity and JE prone villages have been provided to the concerned health authorities in a user-friendly format based on the facilities available with the State/District health office. Landing page of the web based DSS is given in Figure 7.

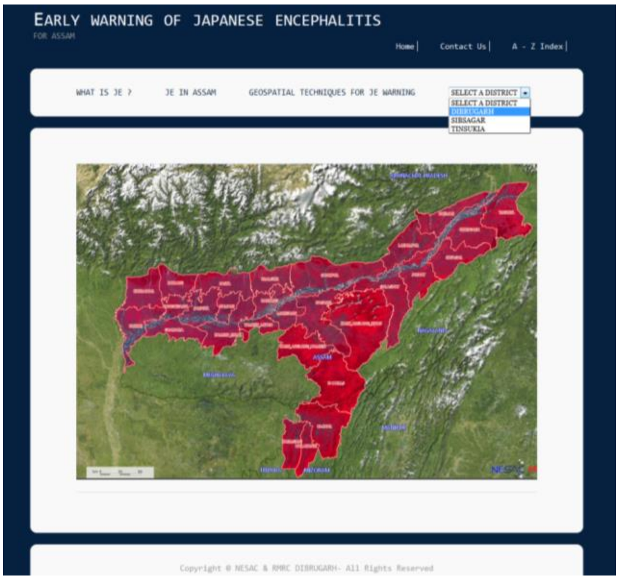

Figure 7. Landing page of JE Early Warning System (JEWS)

The successful development of DSS for JE has lead to study the a similar virus viz., West Nile (WN), which is another important vector-borne disease in India belonging to the JE-serogroup (Pauli et al., 2013, Paramavisan, et al. 2003). In India, mosquitoes belonging to the genus *Culex* were found to transmit the WN virus. These include *Culex vishnui*, *Cx. quinquefasciatus*, *Cx. tritaeniorhynchus*, *Cx. pseudovishnui and Cx. whitmorei* (Khan et al., 2017). An early-warning system for WN has been designed using Dynamic Continuous-Area Space-Time (DYCAST) system in California (Carney et al., 2011). In some studies, dead bird surveillance and weather data and demographic data have been used as an early warning of WN virus (Eidson et al., 2001, Manore et al., 2014, Mostashari et al., 2003).

In India, one study found that sentinel chickens could be an indicator of WN virus activity (Khan et al., 2017). These indicate that further studies on the eco-epidemiology and surveillance of the WN virus in India is required. The data generated can be used to develop a DSS early warning system for WN similar to that of JE.

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References

Abelardo, C., Moncayo, John, D. Edman and John, T. Finn. 2000. Application of geographic information technology in determining risk at Eastern Equine Encephalomyelitis virus transmission. *T Am. Mosq. Cont. Assoc*. 16(1): 28-25.

Barnes, C.M. and Cibula, W.G. 1979. Some implications of remote sensing technology in insect control programmes including mosquitoes. *Mosquito News*. 39:271-282.

Beck, E.L., Roddriguez, M.H., Dister, S.W., Rodriguez, A.D., Rejmankova, E., Ulloa, A., Meza, R.A., Robert, D.R., Paris, J.F., Spanner, M.A., Washino, R.K., Hacker, C. and Legters, L. 1994. Remote sensing as a landscape epidemiological tool to identify village at high risk for malaria transmission. *Am J Trop Med Hyg*. 51(3): 271-280.

Borah J., Dutta P., Khan S.A., Mahanta J., 2011. A comparison of clinical features of Japanese encephalitis virus infection in the adult and paediatric age group with Acute Encephalitis Syndrome. *J. Clin. Virol*, 52, 45-49.

Carney RM, Ahearn SC, McConchie A, Glasner C, Jean C, Barker C, Park B, Padgett K, Parker E, Aquino E, Kramer V. 2011. Early warning system for West Nile virus risk areas, California, USA. *Emerg Infect Dis*. 17(8):1445-54. doi: 10.3201/eid1708.100411. PMID: 21801622; PMCID: PMC3381548.

Dhiman, R. C. 2000. Remote sensing: a visionary tool in malaria epidemiology. *ICMR bulletin*. 30(11):1-2.

Eidson M, Kramer L, Stone W, Hagiwara Y, Schmit K., 2001. New York State West Nile Virus Avian Surveillance Team. Dead bird surveillance as an early warning system for West Nile virus. *Emerg Infect Dis*. 7(4):631-5. doi: 10.3201/eid0704.010405. PMID: 11585524; PMCID: PMC2631773.

Furlong, M., Adamu, A., Hickson, R.I., Horwood, P., Golchin, M., Hoskins, A. & Russell,T., 2022. Estimating the Distribution of Japanese Encephalitis Vectors in Australia Using Ecological Niche Modelling *Trop. Med. Infect. Dis*, 7(12), 393; https://doi.org/10.3390/tropicalmed7120393.

Glass, G.E., Schwartz, B.S., Morgan, J.M. III, Johnson, D.T., Noy, P. M. and Israel, E. 1995. Environmental risk factor for lyme disease identified with Geographic Information System. *Am. J. Pub. Health*. 85:944-948.

Ha, T.V., Kim, W., Nguyen,T.T., Lindahl, J.,Nguyen,V.H., Thi,N.Q., et al. 2021. Spatial distribution of Culex mosquito abundance and associated risk factors in Hanoi, Vietnam. *PLoS Negl Trop Dis* 15(6): e0009497. https://doi.org/ 10.1371/journal.pntd.0009497.

Handique, B. K., Khan S. A., Chakraborty, K., Goswami, J. and Sarma, K. K., 2011. Spatial Statistical Analysis of JE Occurrence and Identification Disease Hotspots-Case Studies in a JE Endemic District in North East India, *International Journal of Geoinformatics*, 7(1), 7-14.

Handique, B. K., Khan S. A., Goswami, J., Chakraborty K., Bora R. and Sarma, K. K., 2005. Characterization of JE Prone Areas of Dibrugarh District of Assam using Remote Sensing and GIS. *Proceeding of the 25th ISRS Annual Convention and National Symposium,* 6-9 Dec, 2005, Ranchi, India.

Handique, B. K., Khan, S. A., Mahanta, J., & Sudhakar, S. 2014. Forecasting Japanese encephalitis incidence from historical morbidity patterns: Statistical analysis with 27 years of observation in Assam, India. *Journal of Vector Borne Diseases*, 51(3), 172-178.

Hendrickxy, G., Napala, A., Dao, B., Batawuli, D., DeDeken, R., Vermilien, A. and Stingenberg, J.H.W. 1999. A systematic approach to area wide tsetse distribution and abundance maps. *Bull. Ent. Res*. 89:231-244.

Huang, X.X., Yan, L., Gao X. Y., Ren, Y.H., Fu. S. H., Cao, Y.X., He, Y., Lei, W. W., Liang,G.D., Wang,S.W., Wang,H.Y., 2018. The relationship between Japanese encephalitis and environmental factors in china explored using national surveillance data. *Biomedical and Environmental Sciences*, 31(3), 227-232.

Hugh Jones, M. 1989. Application of remote sensing to the identification of the habitats of parasite and disease vectors. *Parasitology Today* 5(8): 244-25.

Jeganathan, C., Khan, S. A., Ramesh, C., Singh, H., Srivastava, V. and Raju, P. L. N., 2001. Characterisation of Malaria Vector Habitats using Remote Sensing and GIS. *Journal of the Indian Society of Remote Sensing,* 29(2), 31-36.

Khan, S. A., Chowdhury, P., Choudhury, P., & Dutta, P. 2017. Detection of West Nile virus in six mosquito species in synchrony with seroconversion among sentinel chickens in India. *Parasites & Vectors,* 10, 1-7.

Liu, M.D., Li, C.X., Cheng2, J.X., and Zhao, T.Y., 2022. Spatial statistical and environmental correlation analyses on vector density, vector infection index and Japanese encephalitis cases at the village and pigsty levels in Liyi County, Shanxi Province, China, *Parasites & Vectors*, 15,171 https://doi.org/10.1186/s13071-022-05305-8.

Longbottom, J., Browne, A. J., Pigott, D. M., Sinka, M. E., Golding, Nick., Hay, S. I., Moyes, C. L. & Longbottom, J., Shearer,F. M., 2017. Mapping the spatial distribution of the Japanese encephalitis vector, Culex tritaeniorhynchus Giles, 1901 (Diptera: Culicidae) within areas of Japanese encephalitis risk, *Parasites & Vectors* 10,148.

Manore, C. A., Davis J.K., Christofferson, R.C., Wesson D.M., Hyman J.M., Mores C.N., 2014. Towards an early warning system for forecasting human west nile virus incidence. *PLoS Curr*. PMID: 25914857; PMCID: PMC4398566.

Mostashari F., Kulldorff M., Hartman J. J., Miller J.R., Kulasekera V. 2003. Dead bird clusters as an early warning system for West Nile virus activity. *Emerg Infect Dis.* 9(6):641-6. doi: 10.3201/eid0906.020794. PMID: 12781002; PMCID: PMC3000152.

Nageswara Rao, P.P., Elango, H.R., Rajmohan, H.R. and Krishna Murthy, V. 2004. Satellite-based assessment of physiographic disposition to health problems in Kasargod district, Kerala, India. *Journal of the Indian Society of Remote Sensing*, 32(1): 75-79.

Palaniyandi, M., Anand, P.H. & Pavenda, T., 2017. Environmental risk factors in relation to occurrence of vector borne disease epidemics: Remote sensing and GIS for rapid assessment, picturesque, and monitoring towards sustainable health. *International Journal of Mosquito Research*, 4(3), 09-20.

Paramasivan, R., Mishra, A. C., & Mourya, D. T. 2003. West Nile virus: the Indian scenario. *Indian Journal of Medical Research*, 118, 101-108.

Pauli G, Bauerfeind U, Blümel J, Burger R, Drosten C, Gröner A, Gürtler L, Heiden M, Hildebrandt M, Jansen B, Montag-Lessing T, Offergeld R, Seitz R, Schlenkrich U, Schottstedt V, Strobel J, Willkommen H. 2013. West nile virus. *Transfus Med Hemother.* 40(4):265-84. doi: 10.1159/000353698. Epub 2013 Jul 4. PMID: 24179475; PMCID: PMC3776406.

Sabesan S., Konuganti, H. K. R. and Perumal, V. 2008. Spatial delimitation, forecasting and control of Japanese Encephalitis: India –a case study. *The Open Parasitology Journal*, 2, 59-63.

Sallam M.F., Fizer C., Pilant A.N., Whung Pai-Yei, 2017. Systematic Review: Land Cover, Meteorological, and Socioeconomic Determinants of Aedes Mosquito Habitat for Risk Mapping. *Int. J. Environ. Res. Public Health*, 14, 1230.

Sallam, M.F., Xue, R.-D., Pereira, R.M., Koehler, P.G., 2016. Ecological niche modeling of mosquito vectors of West Nile virus in St. John’s County, Florida, USA. *Parasites Vectors*, 9, 371.

Verdonschot P.F.M, Besse-Lototskaya A.A., 2014. Flight distance of mosquitoes (Culicidae): A metadata analysis to support the management of barrier zones around rewetted and newly constructed wetlands. *Limnologica*, 45, 69-79.

Vythilingam, I., Mahadevan, S., Tan, S. K., Abdulla, G. and Jeffery, J. 1996. Host feeding pattern and resting habits of Japanese encephalitis vectors found in Sepang, Selangor, Malaysia. *Tropical Biomedicine*. 13: 45-50.