Climatic Determinants of Japanese Encephalitis in Bihar State of India: A Time-Series Poisson Regression Analysis

Pravin M Pisudde¹, Praveen Kumar², Pradhan Parth Sarthi³, Pradeep R Deshmukh⁴

Abstract

World’s 60% population lives in regions endemic for Japanese Encephalitis (JE), which affects approximately three billion people. Southeast Asia, especially India, is also not an exception to JE. The present study was carried out to know about the climatic determinants that affect occurrence and transmission of JE cases. The data on maximum temperature, minimum temperature, average temperature, relative humidity, and rainfall was retrieved for the period from 2009 to 2014. Similarly, JE surveillance data was also retrieved for the same period. Time-series Poisson regression analysis was used to quantify the association between climatic conditions and JE incidences. Among the predictors, time was negatively associated, number of JE cases during last month, relative humidity (1-month lag) and rainfall (2-month lag) were positively associated while average temperature (3-month lag) has no significant association with JE incidence. This will help in early forecasting of the JE incidences, if future climate over the area are known in advance.

Keywords: Rainfall, Temperature, Relative humidity, Climate, Japanese Encephalitis, Bihar, Poisson regression analysis

Highlights

• The optimal lag for climatic variables with JE cases in Bihar is analyzed
• Number of JE cases during last month, relative humidity (1-month lag) and rainfall (2-month lag) were positively associated
• The Poisson regression model fits well, as the predicted and observed and number of JE cases match significantly during reporting months

Introduction

World’s 60% population lives in regions endemic for Japanese Encephalitis (JE), which affects approximately three billion people. It is estimated that approximately 68,000 people suffer from this disease every year, causing approximately 10,000–15,000 deaths in more than 20 countries, including Asia and the Pacific region.¹,² Rural and suburban areas are more affected.³-⁵ It also poses a great threat to human beings in Southeast Asia and the Western Pacific region, with case fatality rate up to 30%. According to annual (2014-15) report of National Vector Borne Disease Control Program (NVBDCP), India has reported 3600 cases of JE in years 2010 to 2013 with mortality of approximately 18%. Bihar State
has contributed significant amount of cases during the same duration. This contribution is increasing with increase in number of JE cases reported every year.\textsuperscript{6}

Many surveillance studies have attributed global climate change and the modulation of agriculture for outbreak of JE.\textsuperscript{7} Impact of climate variability on the transmission of JE virus is principally influenced by temperature and precipitation for the growth of the mosquitoes and the JE virus.\textsuperscript{8} There are a few studies conducted on the influence of rainfall, temperature and relative humidity on the density of mosquitoes, which ultimately affect occurrence of diseases like JE.\textsuperscript{9,10} During 2011-12, JE outbreaks occurred in many parts of north-eastern states including Bihar State and North West Bengal. In one of the reports, it is mentioned that the impact of climate variability on the transmission of JE virus is principally influenced by temperature and precipitation for the growth of the mosquitoes and the JEV.\textsuperscript{8}

In India, hardly any study has reported the effect of climatic conditions on JE incidence and especially for Bihar State. The climatic determinants for the transmission of JE in Bihar State are quite unknown and have not been studied by earlier researchers. Hence, the current research aims to find out the role of climatic variables (temperature, rainfall and relative humidity) in the occurrence/transmission of JE in Bihar State, India. This will help in better understanding the impact of climatic variables on JE transmission. The major findings from the current research would be valuable in making policy decisions on improved JE surveillance, prevention and control in Bihar State.

**Importance of the Study**

It should be known that the ecology of JE is very complex and the affected one suffers badly. Studying various determinants, especially environmental, will help policy makers and stake holders to keep surveillance on disease occurrence indirectly as the amount of contact between human beings and vectors, as well as environmental condition influence the transmission of the disease. These types of studies at local level will help health service providers to be prepared for the forthcoming disease burden and necessary curtailment of the disease incidence.

**Materials and Methods**

**Study Area**

Present cross-sectional study was carried out for Bihar state (between 83°-30’ to 88°-00’ longitude and 24°-20’ to 27°31’ latitude), located in the eastern part of the country. It is a tropical and sub-tropical state. It lies mid-way between the humid West Bengal in the east and the sub-humid Uttar Pradesh in the west, which provides it with a transitional position in respect of climate, economy and culture. It is bounded by Nepal in the north and by Jharkhand in the south. The Bihar State plain is divided into two unequal halves by the river Ganga that flows from west to east. Bihar State has a population of 10.38 crore with 17% of population falling in 0–6 year age group in 38 districts. Literacy rate of Bihar State is 63.82% and decadal growth is 25%, thus Bihar State is a complex state for healthcare services in terms of resources and accessibility.\textsuperscript{11}

It is vulnerable to the health impacts of climate change, because of its geographic location, poor health sector infrastructure, poor accessibility to health services, growing population and dependence on a traditional way of life.

The climate of Bihar State is a part of the climatic pattern of the Indian subcontinent. It enjoys a continental monsoon type of climate owing to its great distance from the sea. The Himalayan Mountains in the north have a significant bearing on the distribution of monsoon rainfall in Bihar State. It has four seasons namely: cold weather season – December to February; hot weather season – March to May; southwest monsoon – June to September; and retreating southwest monsoon – October to November.\textsuperscript{12}

**Meteorological Data**

The study period was 2009 to 2014. We retrieved data on maximum temperature, minimum temperature, average temperature, relative humidity, and rainfall for the above mentioned period. We obtained data on rainfall, maximum surface temperature and minimum surface temperature from India Meteorological Department (IMD), while the data for relative humidity was obtained from National Centres for Environmental Prediction (NCEP). The data was retrieved in the Network Common Data Form (NetCDF) format, further processed using the Grid Analysis and Display System (GrADS) and area averages were carried out on daily basis for each of the climatological variables. Monthly averages for Bihar State districts were used for analysis purpose after required transformations.\textsuperscript{13-15}

**JE Surveillance Data**

For surveillance of JE, government of Bihar has established designated surveillance sites (SSSL) at tertiary healthcare facilities. Each SSSL has a designated nodal officer for coordination of JE/Acute Encephalitis Syndrome (AES) surveillance activities. In SSSL, medical officers (MOs), pediatricians, and other physicians, nurses who see patients with AES inform the designated nodal officer immediately upon presentation of an AES case. The case is further subjected to laboratory investigations for JE; the nodal officer immediately notifies the district malaria officer (DMO) or the designated officer in charge of AES/JE surveillance in the district. The SSSL regularly generates and transmits information on encephalitis, confirmed JE cases, and the outcome. There is case investigation and line listing of suspected cases of JE in order to track these cases back.
to their villages to take appropriate control measures. From DMO office, line-listed cases of AES and JE are reported to the state malaria officer (SMO).16 Epidemiological data on monthly basis for JE for the past 6 years (2009–2014) was collected from the SMO office with prior necessary permission.

**Results**

**Statistical analysis of Data**

Correlation between monthly incidence of Japanese Encephalitis (JE) and monthly mean climatic variables (temperature, relative humidity and rainfall) was studied using Spearman’s rho. Highest correlation (rho) was used to identify the optimal lag of the climatic condition.

Time-series Poisson regression analysis was used to quantify the association between climatic conditions and disease incidence. Number of incident cases of JE was assumed to follow Poisson distribution. Three time-series Poisson regression models were developed each adjusted for autocorrelation, secular trend, and lagged effects. However, the model with average temperature yielded least AIC (403.284), hence we described the same model. Dependent variable was number of Japanese Encephalitis in month t. The model has been expressed as follows:

\[
\ln(y_t) = \beta_0 + \beta_1 \text{Time} + \beta_2 \ln(y_{t-1}) + \beta_3 \text{Tempaverage lagged 3 months} + \beta_4 \text{Humiditylagged 1month} + \beta_5 \text{Rainfalllagged 2 months}
\]

Where, \( y_t \) is number of Japanese Encephalitis cases in month t, \( \beta \) are coefficients of regression while subscripts of climatic variables show appropriate month that correlated most with number of JE cases.

**Description of JE cases with climatic conditions**

Fig. 1 displays incident cases of JE along with climatic conditions over the study period. It can be noted that there is a seasonal pattern in climatic conditions and incident cases of JE. There is a peak of JE cases in October of every month. Rainfall starts 2 months before the peak, temperature starts rising 3 months before the peak, and peak of humidity almost coincides or lags by a month with that of peak of JE cases.

![Figure 1. Japanese Encephalitis and Climatic Conditions over the Study Period (2009–2014)](image_url)

**Optimal Lag of Climatic Conditions**

Table 1 shows correlation of incident cases of JE with climatic conditions and the optimal lag of climatic conditions. The correlation ranged from 0.713 to 0.787 and all the correlations were statistically significant. The least lag was observed for the relative humidity. It was one month, while maximum lag of 3 months was observed for maximum and average temperatures. Minimum temperature and rainfall had a lag of 2 months.

| Variable (Monthly Averages) | Spearman’s RHO | p-Value  | Lag Months |
|-----------------------------|----------------|----------|------------|
| Maximum temperature         | 0.717          | <0.001   | 3          |
| Minimum temperature         | 0.787          | <0.001   | 2          |
| Average temperature         | 0.747          | <0.001   | 3          |
| Relative humidity           | 0.729          | <0.001   | 1          |
| Rainfall                    | 0.713          | <0.001   | 2          |

![Table 1. Correlation of Climatic Variables with Incident Cases of JE and Optimal Lag of Climatic Variables](table_url)
Climatic Determinants

Among the predictors, time was negatively associated, number of JE cases during last month, relative humidity (1-month lag) and rainfall (2-month lag) were positively associated while average temperature (3-month lag) has no significant association with JE incidence. With time, risk of JE decreased (RR=0.985, 95%CI: 0.979–0.991). Number of JE cases during a month increased the risk of JE during next month (RR=1.611, 95% CI: 1.454–1.784). Similarly, relative humidity in the previous month and rainfall (2-month lag) increased the risk of JE significantly (Table 2). Figure 2 shows fit between reported and predicted number of JE cases and it can be observed that there is a good fit.

Table 2. Climatic Determinants of Japanese Encephalitis (JE) Using Time-Series Poisson Regression Model

| Variables (Monthly Average) | Relative Risk | 95% CI       | p-Value |
|-----------------------------|---------------|--------------|---------|
| Time in months              | −0.985        | −0.979–−0.991| <0.001  |
| Natural log of number of cases in previous months | 1.611 | 1.454–1.784 | <0.001  |
| Humidity (1 month lag)      | 1.059         | 1.043–1.075  | <0.001  |
| Rainfall (2 months lag)     | 1.002         | 1.001–1.004  | 0.049   |
| Average temperature (3 months lag) | 0.909 | 0.825–1.002 | 0.057   |

Discussion and Conclusion

The significant climatic determinants of JE in Bihar State were found to be time, number of JE cases in previous month, relative humidity (1-month lag) and rainfall (2-month lag).

The disease was endemic in 179 districts of 21 states, of which Assam, Bihar, Tamil Nadu, Uttar Pradesh and West Bengal have been reporting more than 80% of disease burden. During 2011, 8249 cases and 1169 deaths and during 2012, 8344 cases and 1256 deaths due to AES were reported. During 2013, 7825 cases and 1273 deaths due to AES have been reported. During 2014, 9693 AES cases and 1490 deaths have been reported. This shows an increasing trend of JE and AES in India despite India having increased the efforts in recent past for control of JE by the National Vector Borne Diseases Control Program (NVBDCP). Vaccines have been introduced in all JE-prevalent states. Still, 1661 cases of JE were reported in the year 2014 from 15 states and union territories, out of which 293 (17.6%) died. According to Bi et al. there are many risk factors in the disease transmission. These include rainfall, temperature, population, immunity, virus infection among reservoirs, the mosquito situation and its control measures and the level of social and economic development such as housing conditions. Vaccination also plays an important role in the transmission of JE. Vaccination was introduced in 2014 and it is less likely to affect the study. The climatic conditions affect the development of the mosquitoes and the virus, as well as people’s behavior as per Bi et al. They reported temperature and relative humidity have positively affected the transmission of JE in Bihar state.

Higher temperatures (within limits) lead to more rapid development of larvae, shorter times between blood meals, and faster incubation times for viral infection within mosquitoes. As a result, increases in temperature allows mosquito populations to reach higher levels faster, and to be maintained for longer, thereby increasing the opportunities for viral transmission. It has been reported that only 14% of mosquitoes were infected with JE virus when temperatures were 18–22°C, but the figure reached 80% when temperatures were 26–30°C. In China, for

Figure 2. Observed vs. Predicted JE Cases
locations with annual average temperatures below 20°C, there were only few cases of JE; between 25 and 30°C, there was the possibility of an epidemic of the disease; and for locations with over 30°C, the epidemic peak appeared. But, our study failed to document any association between average temperature and JE incidence.

Rainfall and relative humidity also play an important role in the transmission of JE as mosquitoes require water to support the larval and pupal stages of development. The positive association with rainfall is consistent with findings of other studies that have examined environmental factors and JE disease incidence elsewhere in Asia and other mosquito-borne diseases. For example, summer rainfall was found to be a good predictor of increased risk of JE in country areas of China, Japan and India. In our study, relative humidity with one month of lag period also had a positive impact on the transmission of JE. Relative humidity influences longevity, mating, dispersal, feeding behavior and oviposition of mosquitoes. At higher humidity, mosquitoes generally survive for longer and disperse further. Therefore, they have a greater chance of feeding on an infected animal and surviving to transmit a virus to humans or other animals. Relative humidity also directly affects evaporation rates from mosquito breeding sites. At 25°C and 80% relative humidity, females survived two-fold more and produced 40% more eggs. In the same conditions, mosquito tends to live for 11 more days than the normal. It should be noted that relative humidity is a combined effect of rainfall and temperature.

To conclude, rainfall (2-month lag) and relative humidity (1-month lag) were important climatic determinants of JE incidence and track of these two environmental factors may help abort impending JE epidemic and prevent related morbidity and mortality. This will help to provide inputs to local health authorities for prevention and containment of JE in Bihar State, India. Further, the current research would be valuable in making policy decisions on improved JE surveillance, prevention and control in Bihar State.

Conflict of Interest: None

References

1. Campbell G, Hills S, Fischer M et al. Estimated global incidence of Japanese encephalitis: Bull World Health Organ 2011 Oct 1; 89(10): 766-74.
2. Erlanger TE, Weiss S, Keiser J et al. Past, present, and future of Japanese Encephalitis. Emerg Infect Dis. 2009 Jan; 15(1): 1-7.
3. Shresta S, Awale P, Neupane S et al. Japanese Encephalitis in children admitted at Patan Hospital. J Nepal Paediatr Soc. [Internet]. 2009 Jan 30 [cited 2016 Jul 31]; 29(1). Available from: http://www.nepjol.info/index.php/JNPS/article/view/1595.
4. Kabilan L, Rajendran R, Arunachalam N et al. Japanese encephalitis in India: An overview. Indian J Pediatr. 71(7): 609-15.
5. Potula R, Badrinath S, Srinivasan S. Japanese encephalitis in and around Pondicherry, South India: A clinical appraisal and prognostic indicators for the outcome. J Trop Pediatr. 2003 Feb; 49(1): 48-53.
6. Government of India, NVBDCP, Directorate General of health services, Ministry of health and family welfare. National Vector Borne Disease Control Program. Annual Report 2014-15 [Internet]. New Delhi: Available from: http://www.nvbdcp.gov.in/Doc/Annual-report-NVBDCP-2014-15.pdf.
7. Tewari SC, Thenmozhi V, Arunachalam N et al. Desiccated vector mosquitoes used for the surveillance of Japanese encephalitis virus activity in endemic southern India. Trop Med Int Health 2008 Feb 1; 13(2): 286-90.
8. Jmor F, Emsley HCA, Fischer M et al. The incidence of acute encephalitis syndrome in Western industrialised and tropical countries. Virol J. 2008; 5: 134.
9. Solomon S. Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change, editors. Climate change 2007: The physical science basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge ; New York: Cambridge University Press 2007; 996.
10. Field C, Barros V, Dokken D et al. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change, editor. United Kingdom and New York: Cambridge University Press 2014; 1132.
11. Government of Bihar. State Profile [Internet]. [cited 2015 Oct 4]. Available from: http://gov.bih.nic.in/Profile/default.htm.
12. Government of Bihar. Climate Profile of Bihar [Internet]. [cited 2015 Oct 4]. Available from: http://gov.bih.nic.in/Profile/climate.htm.
13. Kalnay E, Kanamitsu M, Kistler R et al. The NCEP/NCAR 40-Year Reanalysis Project. Bull Am Meteorol Soc. 1996 Mar 1; 77(3): 437-71.
14. Pai DS, Sridhar L, Rajeevan M, Sreejith OP, Satbhai NS, Mukhopadyay B. Development of a new high spatial resolution ( 0.25 ° x 0.25 ° ) Long Period ( 1901-2010 ) daily gridded rainfall data set over India and its comparison with existing data sets over the region. Mausam. 2014;65(1):1-18.
15. Parth Sarthi P, Kumar P, Ghosh S. Possible future rainfall over Gangetic Plains (GP), India, in multi-model simulations of CMIP3 and CMIP5. Theor Appl Climatol. 2016;124(3-4):691-701. doi:10.1007/s00704-015-1447-5.
16. Government of India. Guidelines for surveillance of
acute encephalitis syndrome (with special reference to Japanese Encephalitis). Directorate of National Vector Borne Diseases Control Programme, Directorate General of Health Services, Ministry of Health and Family Welfare. 2006.

17. Bagcchi S. India intensifies Japanese encephalitis immunisation. The Lancet Infectious Diseases 2014 Aug; 14(8): 682.

18. Vashishtha VM, Ramachandran VG. Vaccination policy for Japanese encephalitis in India: Tread with caution! Indian Pediatr. 2015; 52(10): 837-39.

19. Bi P, Zhang Y, Parton KA. Weather variables and Japanese encephalitis in the metropolitan area of Jinan city, China. J Infect. 2007 Dec; 55(6): 551-56.

20. Russell RC. Ross River virus: Ecology and distribution. Annu Rev Entomol. 2002; 47: 1-31.

21. Geng G. Epidemiology. 2nd edn. Beijing: People's Medical Publishing House 1996; 2.

22. XU Z. Vector borne infectious diseases. Ningxia People's Publishing House 1990.

23. Bi P, Tong S, Donald K et al. Climate variability and transmission of Japanese encephalitis in Eastern China. Vector-Borne Zoonotic Dis. 2003 Sep 1; 3(3): 111-15.

24. Khan SA, Narain K, Handigue R et al. Role of some environmental factors in modulating seasonal abundance of potential Japanese encephalitis vectors in Assam, India. Southeast Asian J Trop Med Public Health 1996 Jun; 27(2): 382-91.

25. Sakai T, Takahashi K, Hisasue S et al. Meteorological factors involved in Japanese encephalitis virus infection in cattle. Nihon Juigaku Zasshi Jpn J Vet Sci. 1990 Feb; 52(1): 121-27.

26. Hales S, de Wet N, Maindonald J et al. Potential effect of population and climate changes on global distribution of dengue fever: An empirical model. The Lancet 2002 Sep 14; 360(9336): 830-34.

27. Tong S, Bi P, Donald K et al. Climate variability and Ross River virus transmission. J Epidemiol Community Health 2002 Aug 1; 56(8): 617-21.

28. Parton KA, Ni J. Climatic variables and transmission of malaria: a 12-year data analysis in Shuchen County, China. Public Health Rep. 2003; 118: 65.

29. McMichael AJ. World Health Organization, editors. Climate change and human health: Risks and responses. Geneva: World Health Organization 2003; 322.

30. Costa EAP de A, Santos EM de M, Correia JC et al. Impact of small variations in temperature and humidity on the reproductive activity and survival of Aedes aegypti (Diptera, Culicidae). Rev Bras Entomol. 2010; 54(3): 488-93.