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Application of GIS in Modelling of Dengue Risk based on Socio-Cultural Data: Case of Jalor, Rajasthan, India

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Abstract

Prediction of dengue risk based on socio-cultural factors and its possible spatial relationships was investigated in a dengue endemic area of Jalor. Data were collected personally through interview, a total of 77 households were randomly selected from both, dengue affected samples (DAS) and unaffected samples (UAS). Findings indicated that statistical analysis of sixty socio economic and socio cultural variables, sixteen were found significantly correlated at 0.5 and 0.1 level. These sixteen variables were used in step-wise regression model, only eight variables namely *frequency days of cleaning of water storage containers*, *housing pattern*, *use of water cooler*, *frequency of cleaning water cooler*, *protection of water storage containers*, *mosquito protection measures*, *frequency of water supply*, *frequency of waste disposal* had significant contribution to the incidences of DF/DHF/DSS with a R^2 of 0.958. The paper highlights the statistical and spatial model development based on the analysis of socio-cultural practices adopted by DAS and UAS and from the application of GIS. The paper introduced a new methodology to developed dengue social risk categories in the area. Step-wise regression analysis was found to be an appropriate technique in identifying the significant social risk indicators, contributed to increased transmission of disease. It can be concluded that any step to improve any of the eight social practices identified from step-wise regression analysis would have favorable effects on reducing dengue cases. The results provide valuable information for planning precautionary measures and in controlling the spread of DF/DHF/DSS.

1. INTRODUCTION

Dengue Fever (DF) associated with dengue haemorrhagic fever/dengue shock syndrome (DHF/DSS) has emerged as an important public health problem in the countries of South-East Asia and the Western Pacific region (WHO, 1975). In India dengue fever has been known since the 19th century and epidemics have been reported from almost all part of the country. In Rajasthan, serological studies on outbreaks of dengue fever have been reported from Jaipur in 1973 (Ghosh S.N. and *et. al.*, 1974), and from Ajmer city in 1974 (Padbidri V.S. and *et.al.*, (1973). However, in arid region like Jalor, where the disease has appeared in epidemic form trice during the year 1990 (Chouhan G.S. and *et.al.*, 1990 and Joshi, V. and *et. al.*, 1996). The outbreak of dengue in the Jalor occurred in summer (April-May) in contrast to other parts of India, where such outbreaks are commonly reported after the rains between (August and November). Until now, nearly all research efforts, had focus on biological, entomological and clinical aspects of DF/DHF/DSS separately. Location-specific studies demonstrating integrated use of socio-cultural practices were lacking. This calls for an in depth study of the interrelationship of socio-cultural practices, and identification of the most significant risk indicators under the influence of local conditions using statistical modeling as a analytical tool. This study looked into these issues to evaluate and model the relationships between socio-cultural practices and the incidences of DF/DHF/DSS. It was also aiming at furnishing information to community planners in upgrading the related issues so that the disease incidence would be decreased in the future. Insights gained in the study made shed light on how the socio-cultural practices reflect the occurrence of DF/DHH/DSS.

2. METHODS

2.1 Description of Study Area

Jalor town is one of the eleventh desert districts in Rajasthan and is situated in the south-western zone of the state. It lies between 24°37'and 25° 49' latitude and 71° 11' and 73° 05' east longitudes. The town has a population of about 40,000 and the climate is characterized dry with extremes of high temperature rising as 48 °C in summer months and low temperature is about 10 °C in winter months, sandy terrain and high wind velocity. It is situated at 736 meters above sea level. The average yearly rainfall is 421.6 mm, occurring mainly in July and August.

2.2 Primary and Secondary Data

Primary data were collected through field survey. A structured questionnaire composed of sixty variables; all potentially influenced the occurrence of DF/DHF/DSS were designed to obtain the information through personal interviews and discussions with both dengue affected samples (DAS) and unaffected samples (UAS). The questionnaire collected data about the family details, human dwellings, occupational pattern, awareness and knowledge about dengue, mosquito protection practices, sanitation and waste disposal management, cultural practices regarding storage of water containers and health care were collected. Each individual household, in the study area was defined as a sampling unit. All available dengue patients were taken as sample and an equal number of randomly selected unaffected sample of the study area were also interviewed.

Secondary data included demographic information about town, climate, a list of reported patients and deaths, entomological data of dengue (adult house index, container index), physical environment (land use land cover), topographic and administrative map. These data were acquired with the help of the census book, government /non-government agencies and from published reports.

3. STATISTICAL METHODOLOGY

All the socio-cultural variables were studied through four steps:

1) Based on the literature review, an attempt was made to group the number of variables by combining related variables into one group. Data were therefore arranged into the following six groups: Socio-economic, human dwellings, environment management practices, mosquito protection practices, cultural practices of water storage and technological adoptions.
2) Detection and screening of data outliers to reduce misleading results. In the first screening of the sixty variables, forty eight variables were selected.
3) Second screening of variables was conducted based on a significance Test of the Pearson's correlation coefficient.
4) Development of a regressive-predictive model.

3.1 Correlation of Socio-Cultural Practices with Dengue Incidences

Pearson's correlation coefficient was computed for the forty-eight variables from the six groups with the incidence of DF/DHF/DSS. This statistical technique could identify and isolate sixteen variables that had the strongest positive or negative correlations, tested at 1% and 5% of significance levels.

3.2 Regressive Predictive Model

From the six groups, the sixteen variables that were significantly correlated to the dengue incidence were submitted to multiple regression analysis. The different characteristics of the socio-cultural variables interact together to contribute a combined effect on the dengue incidence. The sixteen variables, which were found to be significantly correlated to dengue incidence, were only used for multiple regression analysis. Step-wise regression technique was employed to explore and identify statistically significant socio-cultural risk indicators and their relative contributions to the occurrence of dengue incidences by eliminating the insignificant variables. Results of step-wise regression analysis revealed that, out of sixteen, only eight independent variables contributed effectively to dengue incidences. The eight variables were used to derive the following regression equation

$$Y = -0.07516 + .928X_1 - .819 X_2 + .757 X_3 + 0.006042 X_4 + .284 X_5 - .647 X_6 - .317 X_7 - .216 X_8$$

Where,

Y = Incidence of Dengue (Dependent variable)
X_1 = Frequency, days of cleaning of water storage containers
X_2 = Housing Pattern
X_3 = Use of water cooler
X_4 = Frequency of cleaning of the water cooler
X_5 = Protection/covering of water storage containers

X_6 = Mosquito protection measures used by the households
X_7 = Frequency of water supply
X_8 = Frequency of waste disposal at community level

The results of step-wise multiple regression analysis indicated that the multiple R and R^2 for the final model were 0.979 and 0.958 respectively. Adjusted R^2 was 0.938 explaining 93.8 % of the total variation in dengue incidence.

3.3 Discussion of the Significant Variables

3.3.1 Frequency, days of cleaning of water storage containers: The model shows that the variable *Frequency days of cleaning of water storage containers* had a positive contribution to dengue incidence. The *Aedes aegypti* mosquito is a domestic breeder and breeding can occur in a water storage containers, which is not emptied and cleaned for sufficiently long periods. The *Aedes aegypti* eggs are normally laid on the damp walls of both artificial and natural containers and they could resist desiccation for several weeks to several months. The eggs hatch when submerged in water. Since water is essential during the first 8 days in the life of mosquitoes, therefore if the frequency of cleaning is more than 8 days, this could lead to an increase in the growth of mosquitoes and, therefore, dengue incidences. Whereas, changing water and emptying water storage containers once or twice a week will greatly reduce risk of dengue fever. It was observed in the study area that people cleaned containers daily, but only those, which were used to store water for drinking purpose. However, those containers, which were used to store water for other domestic purposes, i.e. washing, bathing etc., were cleaned infrequently. These containers were normally cleaned after 10-15 days, or even after one month, thus providing ideal breeding sites for mosquitoes and subsequent sticking of the eggs. They would develop into mosquitoes as soon as ambient temperature and humidity met optimal requirements.

3.3.2 Use of water coolers: The use of the water coolers generally starts with the onset of summer months. In Jalor, the use of coolers was observed to start in the middle of March or early April. Coolers were used until the end of July. Most coolers were found fitted in openings, initially used as windows, whereas, some coolers were of the portable type. Cooler and other containers become excellent places for *Aedes* mosquito breeding and could led to widespread transmission of dengue fever. The cooler plays an important role in the breeding of secondary foci. It was observed that once the cooler was fixed to windows, they remained their. With the onset of the monsoons, the breeding of *Aedes aegypti* larvae spreads from its mother foci to secondary foci which are coolers. Mosquitoes can lay their eggs during rainy seasons or damp periods (use period of coolers). The model indicates the positive relationship of dengue incidence to the *use of water coolers* in Jalor. Studies by Katyal et.al., 1996 indicate that coolers play an important role in mosquito breeding, which seems to support research results.

3.3.3 Uncovered water storage containers: Open stagnant water provides ideal breeding places for *Aedes aegypti* mosquitoes. During the survey it was observed that portable cement tanks, metallic/plastic drums, overhead/underground tanks were used to store clean water within premises. Storing of water within houses is a common practice of the local population during summer months, due to intermittent and erratic water supplies. Most domestic water storage containers were kept uncovered except for underground tanks. This could provide ideal breeding places for *Aedes aegypti* mosquitoes. Different studies indicate that uncovered water containers and pitchers were significantly associated with dengue infection (Koopman, J.S. and et. al., 1991 and Khera, A. and R.S. Sharma. 1992).

The regression model indicates that the presence of uncovered water containers had a positive contribution to dengue incidence. It is interesting to note that the epidemic occurred in the summer months (April-May) when there was scarcity of water. This scarcity could result in an increased storage of water. The practice of not covering the containers, could provide ideal breeding sites to the vector, *Aedes aegypti* in stored water in the houses, thus increasing the risk of dengue incidence and thus holding a positive correlation.

3.3.4 Protection measures against mosquitoes: Use of nets, presence of complete wire screens, creating smoke with *neem* leaves, spraying of insecticides, closing of doors and windows were the common protective measures against mosquitoes. These measures either reduce the number of mosquitoes or provide protection against them and thus reduce the risk of dengue infection. The model shows that the variable *mosquito protection measures* had negative association with dengue incidence, i.e. the more protection measures were used, the less incidence of dengue.

3.5 Housing pattern: A review of literatures indicate that in a crowded area, many people living within the short flight range of the vector from its breeding source could be exposed to transmission even if the house index is low. Therefore, higher population density and interconnection of houses could lead to more efficient transmission of the virus and thus increased exposure to infection. The transmission of the disease is normally limited by the flight distance of *Aedes aegypti* during its lifetime. The flight distance of Aedes aegypti could range from 25 km per day in an open environment (Wolfinsohn, M. and et.al.,1953), to few meters per day (Reiter, P., and et.al, 1995), to less than 25-50 m in an closed urban environment (Morlan, H.B. and Hayes, R.O., 1958). In urban environment, where interconnections are not very common, the independent nature of the house limits flight range of *Aedes aegypti* reduces the transmission of the disease. The prediction model indicates that the variable connectivity of the house (independent =1, connected = 0) had a negative correlation with dengue incidence. This correlation is in line with the results from available studies.

3.3.6Cleaning of water coolers: The model shows that the variable frequency of *cleaning of water coolers* had negative impact on dengue incidence. Generally, the prolonged stay of water in a cooler permits damp space as well as litter formation, thus providing nutrition to larval habitats. This permits growth and transmission of *Aedes aegypti* mosquitoes, thus increasing dengue risk. The negative correlation indicates that if the frequency of cleaning of coolers is high, there would be less chances of dengue infection. This could appear as evidence given the fact that cleaning prevents potential breeding of mosquitoes by removing litter.

3.3.7 Frequency of water supply: The model shows that the variable *frequency of water supply* is negatively correlated to incidences of dengue. Water supplies in most houses, especially during the summer (March to June), was inadequate and not reliable. Water scarcity, resulting in increased and prolonged storage of water for domestic use in various types of containers, subsequently become the breeding places for *Aedes aegypti*. Water storage practices in the area, due to irregular water supplies was a possible cause for higher vector concentration in the sampled houses, increasing transmission. It means the more infrequent the supply of water, the more the practice of water storage, the more the presence of vectors, thus increase in the growth, transmission and increased risk of dengue infection.

3.3.8 Frequency of garbage removal: *Frequency of garbage removal* was the eighth contributing factor, which influences in a negative direction. The presence of waste and garbage, around the household, such as cans, car parts, bottles, old used tires and other junk found in several houses, creates potential breeding sites. Dumping of wastes for long periods of time such as 15-20 days, supported the breeding of *Aedes aegypti* and increased the transmission of disease. If the frequency of the collection of waste disposal by local bodies increases, it would control the *Aedes* breeding and thus would reduce transmission.

4. DEVELOPMENT OF SPATIAL MODEL

Both spatial and socio-cultural parameters could be important in determining disease emergence and transmission. GIS could create possible links between spatial data and their related descriptive information, which could include socio-economic and socio-cultural parameters. The objective of spatial modeling was to determine the applicability of GIS as a tool to identify varying degrees of spatial social risks in Jalor, related to dengue incidence and transmission.

4.1 Weighing of Socio-Cultural Practices

Methods of “weights” was observed to be a suitable technique which would have a combined effect of various social risk factors contributing to the incidence of dengue. To develop a combined social risk category, the eight social risk indicators identified from stepwise regression analysis were selected. Based on review of literature, weights were then assigned to their associated parameters indicating degree of an individual risk indicator. In order to maintain uniformity among all social risk indicators, an equal weighing method was used. Weights of 1-3 were assigned to associated practices. For a given social risk indicator, higher weight (3) was given to the practices with higher risk of dengue incidence, medium weight (2) was assigned to the one, contributing medium risk in the incidence of dengue and a low score (1) was given to the practice with low risk of dengue incidence. For example, in the case of the risk indicator - “frequency of garbage removal”, the lowest value of 1 was assigned to the practice of short duration (once in 1-4 days) garbage removal, 2 to medium duration (once in 5-15 days) and 3 to long duration (more than 15 days) garbage removal practices. The detailed weighing for all the eight risk indicators is presented in Table 2. Since the socio-cultural practices related to the eight social risk indicators, varied from household to household, these scores were assigned separately for each of the 77 households belonging to DAS and UAS groups.

Table 2 Social Risk Indicators and their Weightage

S. No	Social risk indicators	Risk Scores	S. No	Social risk indicators	Risk Scores
1	**Frequency, days of cleaning of water storage containers** a. 1-4 days b. 5-15 days c. >16 days	1 2 3	5	**Protection of water storage container** a. Fully covered b. Sometimes c. Mostly uncovered	1 2 3
2	**Housing pattern** a. Independent house b. Mixed c. Interconnections	1 2 3	6	**Mosquito protection measures** a. Screens b. Insecticides c. close windows d. Smoke/burning herbs *(neem)* e. Mosquito-net	1 1 2 1 2
3	**Use of water cooler** a. 5 days/ month b. 6-10 days/month c. > 15 days/month	1 2 3	7	**Frequency of water supply** a. Everyday b. Alternate c. Every 3 days d. 4-7 days	1 1 2 2
4	**Frequency of cleaning of water cooler** a. 1-4 days b. 5-15 days c. > 16 days	1 2 3	8	**Frequency of waste removal** a. Everyday b. Weekly c. >15 days	1 2 3

4.2 Development of Social Risk Levels

The discriminant analysis approach was used to obtain households wise social risk scores and by using the histogram/box plot technique, social risk scores were translated into social risk levels. The histogram depicts the mean, minimum and maximum values and standard deviation of discriminant scores of the 77 households. To derive risk levels, percentiles technique was used. For example, if five possible risk levels are to be identified, discriminant scores at 20 percentile, 40 percentile, 60 percentile and 80 percentile could be used as the cut-off points. These risk levels were termed as very low, low, medium, high and very high risk level respectively with scores of 1, 2, 3, 4 and 5 for the assigned risk levels respectively. For each household, it is necessary to check the predicted risk levels from discriminant scores, to their actual class. For this, estimates of the classification function coefficients were used. It was observed that the application resulted in 94.8 % correct classification under the risk level categories, very positive from statistical considerations.

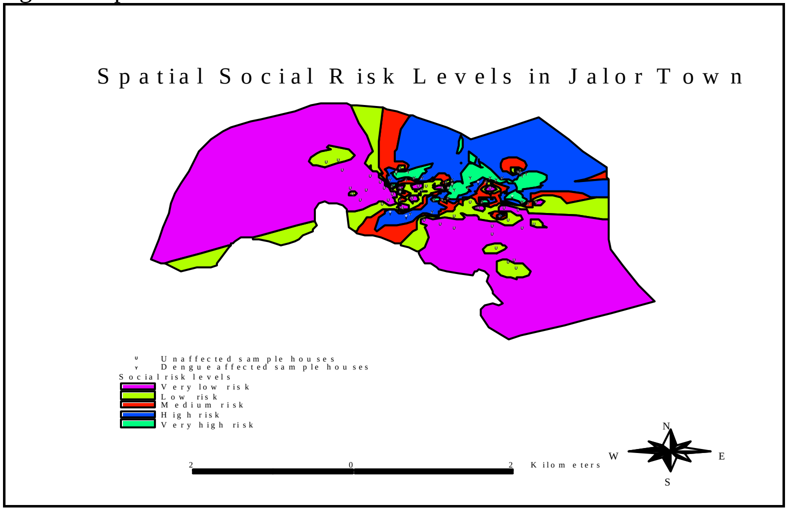
4.3 Development of a Spatial Social Risk Model

As the sample households were spatially distributed and social risk information with regard to these households were collected and analyzed, it could provide spatially distributed social risk levels. The spatial (point data) with their attributes, were input to GIS and a spatial point wise risk level map was developed. This was achieved by digitizing spatial locations of houses of DAS (37 households) and UAS (40 households) samples located in the Jalor administrative map. On the administrative map of Jalor, locations of houses of DAS and UAS were overlayed. GIS database were developed separately for DAS as well as UAS groups having information on social risk levels. Nearest neighborhood technique of extrapolation was used to develop a social risk map of the area. This provided location wise social risks of dengue incidence. Analyzed results are presented in Figure 1. The figure (map) shows the spatial distribution of the five social risk levels, which were identified through discriminate analysis. Analysis indicate that a large percentage of area (61.09 %) had very low social risk, where as 16.90 % of the area had high risk, 12.35 % had low risk followed by 6.58 % area with medium risk. Only a very low area, 3.09 % had very high risk. Overall, little more than 26 % had medium to high social risk

5. Conclusions

Prediction of dengue risk based on socio-cultural factors was investigated in a dengue endemic area of Jalor. The data analysis and modeling revealed that the socio-cultural factors such as the housing patterns, limited use of mosquito protection measures, irregular water supplies, poor management of waste disposal, storage of water on the premises due to inadequate water supplies in summer months, prolonged storage of water for domestic and other purposes significantly affected incidence of dengue. Storing of water in the houses created conditions

Figure 1. Spatial Social Risk Levels in Jalor Town



conducive to the breeding of *Aedes aegypti* mosquitoes and led to more pronounced vector presence. Step-wise regression analysis was found to be an appropriate technique in identifying the significant social risk indicators and contributed to increased transmission of disease. It may, therefore, be concluded that any step to improve any of the above social cultural practices would have favorable effects on reducing dengue cases. Such analysis provides valuable information for planning precautionary measures and in controlling the spread of DF/DHF/DSS.

The objective of the spatial modeling was to create a linkage between households, their socio-cultural practices and dengue incidence. The spatial model is capable of identifying five different very low, low, medium, high and very high risk levels of dengue incidence for the study area. It would contribute significantly to the spatial prediction of social risk levels in Jalor. Further, the approach could assist in focusing and implementing precautionary and preventive strategies to monitor and control incidences of dengue more effectively.

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