Journal of Advances in Biology & Biotechnology

Volume 27, Issue 9, Page 140-146, 2024; Article no.JABB.121115
ISSN: 2394-1081

Spatial Modeling of the Distribution of *R. microplus* and *Haematobia* sp. Flies in Maharashtra State though Inverse Distance Weighting

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Authors' contributions

This work was carried out in collaboration among all authors. Author GB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors BWN and GMC managed the analyses of the study. Authors SDM and SRR managed the laboratory investigations and graphics. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i91283

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/121115

Original Research Article

Received: 14/06/2024
Accepted: 16/08/2024
Published: 21/08/2024

ABSTRACT

Aims: Spatial model of distribution of two important veterinary pest *viz. Rhipicephalus microplus* ticks and *Haematobia* sp. flies in Maharashtra state was prepared.
Study Design: An Inverse Distance Weighting approach was employed for the data obtained through primary survey of insects under study.

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Cite as: *Bhangale, Gajendra, B.W. Narladkar, G.M. Chigure, S.D. Moregaonkar, and S.R. Rajurkar. 2024. "Spatial Modeling of the Distribution of R. Microplus and Haematobia Sp. Flies in Maharashtra State Though Inverse Distance Weighting". Journal of Advances in Biology & Biotechnology 27 (9):140-46. https://doi.org/10.9734/jabb/2024/v27i91283.*

Place and Duration of Study: The study was carried out during January 2023 to June 2023 covering entire state of Maharashtra in India.

Methodology: Total 143 location points for *R.microplus* ticks and 31 locations for *Haematobia* sp. flies in the Maharashtra state were finalized and included in the modeling exercise. These location points were converted to spatial dataframe and imported in R software and processed for Inverse distance weighting by using the precipitation and temperature bioclimatic raster files for the state.

Results: The *R. microplus* distribution studied using inverse distance weighted interpolations, the model's negative correlation of -0.061 was found to have an acceptable AUC of 0.746, indicating a decent fit of the IDW model. On the other hand, the IDW model was shown to be non-significant with a minimal AUC value of 0.579 in the case of *Haematobia* sp. flies. Nonetheless, the zonal statistics indicated that around 30% of the state's total area was unsuitable for *R. microplus* and that 57% was unsuitable for *Haematobia* sp. flies.

Keywords: Rhipicephalus; inverse distance weighting; GIS; Maharashtra; haematobia.

1. INTRODUCTION

Ticks and tick-borne diseases are one of the important medical, veterinary and economic problems globally. Ticks have a strong vector capacity and a blood-sucking behaviour. Ticks are the most significant vectors of disease-causing pathogens in both domestic and wild animals, ranking second only to mosquitoes as worldwide disease vectors due to their capacity to inflict direct and indirect harm on their hosts [1]. Production loss is directly linked to tick infestations and is expected to cost several million dollars globally [2]. The management cost of ticks and tick-borne diseases (TTBDs) in India has been estimated to be approximately US $498.7 million annually, according to Minjauw and McLeod [3]. Considering the importance of ticks in livestock husbandry, its prevalence estimates through spatial and temporal distribution is a major tool for implementing control strategies. Since lot of works have been carried to study the prevalence of ticks on livestock as well as farm premises, the inclusion of geographic information systems for the same is scare in India. Maps depicting the distribution of ticks are frequently used to represent the spread of human diseases or as a proxy for transmission exposure risk; nevertheless, the majority of tick-borne infections have poorly defined vector ranges.

Several evidences suggest the usefulness of Geographic Information Systems (GIS) and Remote Sensing (RS) techniques in the prediction and monitoring of vector-borne diseases of livestock, based on the spatial distribution pattern of livestock insect pests [4,5] (Kalluri et al., 2007). The distribution of livestock pests, such as insects and ticks, is largely influenced by the bio-physical characteristics of the area, making it possible to improve estimation using these sophisticated tools [6]. The utilization of maps is vital for conveying potential exposure risks and visualizing spatial data related to diseases. Within the field of public health, disease maps have been extensively employed to illustrate the spread of vector-borne diseases, varying in complexity from basic plotted cases or dot maps to advanced risk forecasts generated through machine learning algorithms.

Mapping products, no matter how complicated, depend on geo-referenced datasets being available. We considered that the most of livestock tick and fly species have not been thoroughly mapped in India as on today. Therefore the present study was planned to use one of the geographic information system (GIS) tools *viz*. Inverse Distance Weighting approach for mapping of *R. microplus* ticks and *Haematobia* sp. flies based on the occurrence records collected through an entomological survey.

2. MATERIALS AND METHODS

This study was based on the presence and occurrence points of the *Rhipicephalus microplus* ticks of cattle and *Haematobia* sp. flies in the Maharashtra State. Ticks identified as *Rhipicephalus microplus* from 143 locations were geo-referenced in a *".csv"* file based on the latitude-longitude records collected at the time of samples collections itself. For the location data of *Haematobia* sp. flies, samples identified from 18 number of locations and it was also added with the data from earlier work done by Gudewar [7] which remained to 31 points after removal of duplicates. Therefore, having the above tick presence data, geo-referenced locations, or occurrence points that represent *Rhipicephalus microplus* ticks of cattle and *Haematobia* sp. flies were recorded in terms of coordinate pair as decimal latitude/longitude in the WGS84 system where the cattle was sampled for ticks using a GPS app in a smartphone (*NoteCam*). However, the coordinate pair data for the locations for occurrence points from a study by Gudewar [7] were obtained from GoogleEarth. These geo-coordinate data was transformed into Latitude and Longitude in WGS 84 Global Projection System in QGIS software. This GIS analysis was limited to the occurrences records for Maharashtra state for both tick and fly distribution. The location file was then saved in *".csv*" format to be later used for GIS modeling.

The GIS modeling was performed by using *dismo* package (version 1.3-8) in R environment [8]. The approach used was Inverse Distance Weighting *i.e.* IDW; a spatial interpolation method. IDW interpolation assumes that things which are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The distribution was predicted based on the 3 basic climatic attributes *viz.* annual mean temperature, annual precipitation and elevation. These climatic covariates were obtained from WorldClim database (https://www.worldclim.org/) in the form of raster files which were then cropped to Maharashtra state boundary in QGIS before using in the analysis.

In RStudio, the analysis was first started with loading the required packages *viz*. dismo, raster and sp which helps perform modeling algorithm, read, process and analyze raster files, spatial analysis and producing graphical outputs of data respectively [9,10,11]. After loading these library, the data on occurrence records were inputted by *read.csv* command. In next step, the spatial covariates *i.e.* raster files of annual mean temperature, annual precipitation and elevation were called and entered into the RStudio environment. These raster files were then stacked as a RasterStack object. Both these dataset objects were assigned a common projection system *i.e.* WGS84. Subsequently pseudo absence records or background points were obtained by *RandomPoints* commands referring to any of raster files and occurrence location file. Subsequently, having all these objects in hand, the model was run with help of *geoIDW* command, an algorithm in *dismo* package. This run provided a model object whose results were obtained through simple *summary* command. The summary was then interpreted and presented in table format while the model object was then subjected to form the prediction through a *predict* command and this predicted model was then imported in QGIS for visualization for final model. In QGIS, the predicted model files were loaded and categorized in to five classes assigning the suitability for the presence and spread of the vector species under study.

3. RESULTS AND DISCUSSION

The Inverse distance weighted interpolations for the studying the distribution of *R.microplus* (Fig. 1) revealed that the model negative correlation of -0.061 showed an acceptable AUC of 0.746 which indicated moderate fitting of IDW model (Table 1). However the results for *Haematobia* sp. flies revealed that the IDW model was non-significant with a minimal value of AUC *i.e.* 0.579. The zonal statistics however pointed out towards nearly 30% as non-suitable for *R.microplus* and 57% of total area of the state as non-suitable for *Haematobia* sp. flies (Table 2/ Fig. 2).

Table 1. The IDW model output for *R. microplus* and *Haematobia* sp. flies in Maharashtra

R. microplus		***Haematobia* sp. flies**	
class	: ModelEvaluation	class	: ModelEvaluation
n presences	: 143	n presences	: 31
n absences	: 500	n absences	: 50
AUC	: **0.74679**	AUC	: **0.5793548**
cor	: -0.061757	cor	: -0.0516856
max TPR+TNR at : 0.378463		max TPR+TNR at : 0.2855463	

Table 2. Zonal statistics for *R.microplus* ticks and *Haematobia* sp. flies in Maharashtra by IDW method

Suitability	***Rhipicephalus microplus***		***Haematobia* sp. flies**	
	Area in sq km	**Percent**	**Area in sq km**	**Percent**
Absence	80476.649	22.97	76493.124	21.84
Non Suitable	27033.06	7.72	124624.63	35.58
Low Suitable	151133.54	43.14	45468.13	12.98
Mod Suitable	55473.05	15.84	53670.84	15.32
High Suitable	36185.60	10.33	39476.30	11.27

In order to estimate the geospatial distribution of both the vectors under this study, an Inverse Distance Weighting approach was employed as a simple GIS tool. Inverse distance weighted (IDW) interpolation is widely used spatial interpolation method in Geographic information systems analysis. It is a deterministic approach that estimates the value of a variable at an un-sampled location based on the values of the surrounding sampled locations. The basic principle behind IDW is that the influence of a known data point on the interpolated value decreases as the distance from the known data point increases (Malieka et al., 2020). IDW assumes that the variable being interpolated is more similar between closer points than between distant points. It gives higher weights to closer points and lower weights to more distant points when estimating the value at an un-sampled location [12].

The estimated value at an un-sampled location is calculated as a weighted average of the known data points within a specified neighboring area. The weight assigned to each known data point is inversely proportional to the distance between the known data point and the un-sampled location.

The formula for IDW interpolation is:

$$Z(x,y) = \Sigma(Wi * Zi) / \Sigma(Wi)$$

Where:

Z(x,y) is the estimated value at the un-sampled location (x, y)
Zi is the known value at the i^{th} data point
Wi is the weight assigned to the i^{th} data point, calculated as:

$$Wi = 1 / d^p$$

Where:

d is the distance between the unsampled location and the i^{th} data point
p is the power parameter, typically set between 1 and 3, controlling the rate of decline in the weight as the distance increases.

The power parameter (p) in the IDW formula determines the rate of decline in the weight as the distance increases. A higher power parameter (*e.g.,* p=3) gives more weight to the closest points and reduces the influence of distant points. A lower power parameter (*e.g.,* p=1) results in a more gradual decline in the weight as the distance increases, leading to a smoother interpolated surface [13]. IDW can be influenced by spatial autocorrelation, and it may be necessary to account for this effect, for example, by adjusting the power parameter or the search radius used in the interpolation.

The Inverse Distance Weighting (IDW) approach is frequently employed in spatial analysis when dealing with data points that possess measurable attributes rather than binary characteristics, as noted by Auchincloss et al. [14]. Despite this, its application in models that focus on the presence or absence of certain phenomena is rarely documented. Nevertheless, in select research endeavors that concentrate on examining spatial relationships among occurrences of diseases, the IDW method has yielded dependable results. An illustrative case is the investigation conducted by Sharma et al. [15], which delved into the spatial sero-epidemiology of bovine trypanosomiasis in the low-lying regions of Punjab, India. The researchers highlighted that the prevalence of bovine trypanosomiasis exhibited a significant correlation with various environmental factors influencing the prevalence of *Trypanosoma evansi*, such as the mean temperature, precipitation levels, potential evapotranspiration rates, and cloud cover. Subsequent to this analysis, the data was subjected to interpolation through IDW, revealing a clustering of infective zones within Punjab. Similarly, a study by Sumbria et al. [16] within the same region of Punjab discovered that the prevalence of *Theileria equi* was notably higher in the southwestern areas compared to other zones. The prevalence pattern identified through nested PCR testing demonstrated a robust correlation with temperature, while displaying an inverse association with precipitation and cloud cover. These consistent findings underscore the significance of employing the IDW approach in delineating the regions where *Rhipicephalus microplus* is present, as evidenced by the current research. Additionally, the interpolation maps for *Haematobia* sp. species flies exhibited a distinct "bulls-eye" pattern, possibly attributed to the limited number of presence points. However, the efficacy of utilizing this method to analyze species distribution in relation to environmental variables was deemed insignificant, as indicated by the Area Under the Curve (AUC) values hovering around the 50s, suggesting that the model's outputs were essentially random predictions [17,18].

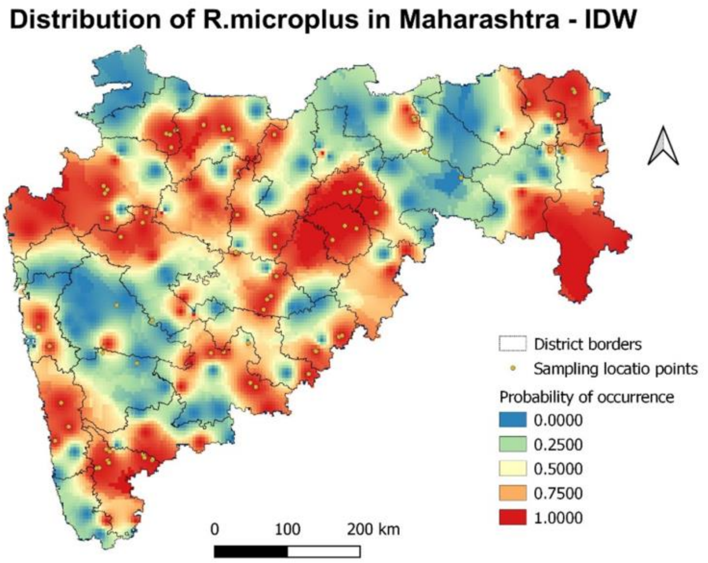

Fig. 1. Distribution of *R.microplus* ticks inn Maharashtra State, India

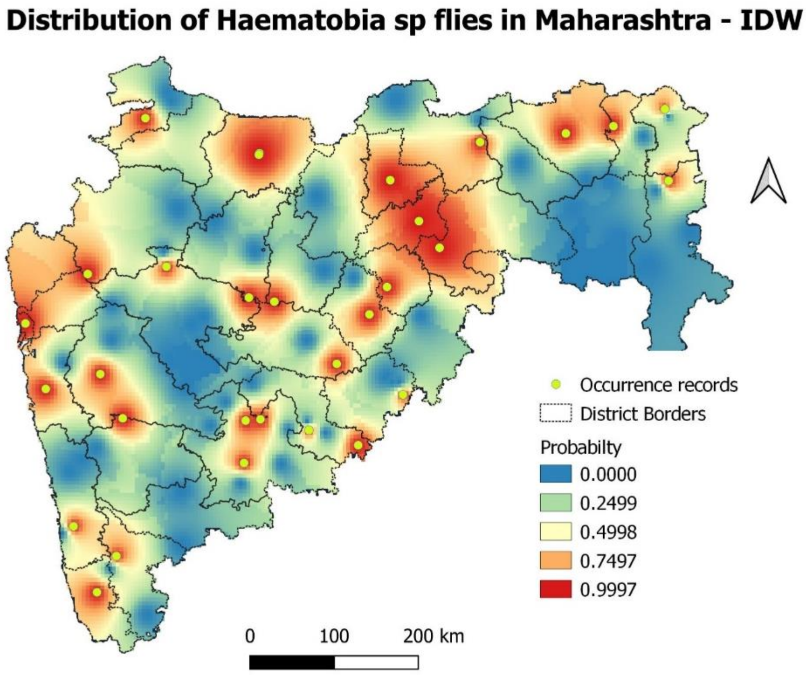

Fig. 2. Distribution of Haematobia sp. flies in Maharashtra State, India

4. CONCLUSION

It was concluded that for determining the geographical spread of *R.microplus* in Maharashtra the Inverse Distance weighting is a suitable approach and for *Haematobia* sp. flies, it has trivial outcomes. It is therefore recommended to use the resultant projected maps of *R.microplus* obtained through this research for its further study in the state. These findings are helpful for devising the control strategies for ticks and tick borne diseases of cattle by planning the cluster wise interventions based on the level of suitability as described under this study.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

ACKNOWLEDGEMENTS

This study has not received any external grants however the logistics and administrative support provided by the authorities of College of Veterinary and Animal Sciences Parbhani and MAFSU, Nagpur is duly acknowledged.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/121115