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Prediction of dengue potential in Dehradun (Uttarakhand) based on variability of lagged meteorological parameters with *Aedes* species abundance: An insight from statistical analysis

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Abstract
The changes in the correlation between temperature, rainfall and several arboviruses and their vectors have direct impact on population size, maturation period, feeding habits and survival rate of *Aedes* mosquitoes. The present study focusses on the role of meteorological factors contributing towards the fluctuation and magnitude of adult *Aedes* species abundance in order to predict dengue cases in Dehradun (Uttarakhand). Excel spreadsheet 2013 was used to perform the correlation and multiple regression analysis and to validate models, MedCalc software was used. The highest correlation between maximum temperature and *Aedes* population were found at 5-lag week (r=0.68) and for minimum temperature found in 1-lag week (r=0.82). Relative humidity and *Aedes* abundance were in highest correlation in 0-lag week (r=-0.06 for 0719h and r=0.57 for 1419h). Rainfall was also found best correlated with *Aedes* mosquitoes during 0-lag week (r=0.49). The two meteorological variables {minimum temperature 1-lag week and relative humidity (0719h) 0-lag week} that had the highest correlation with mosquitoes (r=-0.57 and r=-0.06, respectively) were selected to create the models. The model 1 predicted values were found more accurate in terms of showing the trends of mosquito abundance over weeks as compared to model 2. The predictive model developed in this study could partly inform decision makers for determining when to initiate control measures to minimize the likelihood of dengue risk.

Keywords: Meteorological parameters, *Aedes*, Bland-Altman agreement plot, Dehradun

Introduction

Mosquito vectors are highly sensitive to meteorological changes which directly reflect to their relationships with diseases which were first time described in the 1920s [1] and later quantified in the 1950s [2]. Now-a-days in the present scenario sensitivity of *Aedes* vectors to meteorological conditions are highly accepted [3-5]. The studies of Focks *et al.* [6] and Yang *et al.* [7] have shown that meteorological parameters have direct impact on population size and maturation period and also on feeding habits and survival rate of *Aedes* mosquitoes. An elaborate study has conducted in Rhode Island to establish the correlation between temperature, rainfall and several arboviruses and their vectors [8]. Another study in French Guiana has observed that the life span of *Aedes* mosquitoes could extend upto 76 days with favourable optimum environmental conditions [9]. Meanwhile, some studies [6, 10] have discussed on increasing *Aedes* mosquito population when temperature rises, as temperature rises from 24 ºC to 32 ºC and more, the reproductive cycle is shorter due to increasing twofold feeding frequency and also the pupal stage reduces to one day from 4 days as temperature increases from 22 ºC to 32-34 ºC. On the other hand, heavy rainfall destroys larvae and reduces survival rate of female mosquitoes but creates abundant breeding sources [9]; whereas extremely low precipitation directly related with ambient increase in temperature that may serve as perfect breeding habitats [11]. Thus, excessive heat and rainfall on one hand kill mosquitoes, but on the other hand within their survivable range, warmer temperatures and low precipitation increase their reproduction and biting activity by many folds which can directly be assembled for increase of pathogen transmission [12]. Many studies have come to find that vectors development increases in warmer temperatures, raising the odds of disease transmission, while the reproduction rates and replication of disease are comparatively slower in cooler temperatures [13-15]. Another important meteorological parameters *i.e.*, relative humidity is directly correlated with rainfall, particularly increases following drought. Relative humidity have reported to have strong impacts over the flight range and subsequently host-seeking behaviour of mosquitoes [16, 17]. From a case study of Jeddah, Saudi Arabia [5], it has postulated that if they could predict the weekly adult mosquitoes population based on meteorological variables in prior, public health officials would be helpful in planning control strategies of mosquitoes and mosquitoes borne diseases.

In district Dehradun, the dengue infection is well established from the year 2006 onwards with epidemic reported in 2010 (2889 cases) and 2013 (3018 cases) by Uttarakhand Health Department (unpublished data). Thus the present study mainly focusses on understanding the role of meteorological factors contributing towards the fluctuation and magnitude of *Aedes* mosquitoes abundance to predict dengue fever transmission in Dehradun (Uttarakhand).

Materials and Methods

Study area: Dehradun city (latitude 30º19'N, longitude 78º04'E) is located on the northern provinces of India merely in the foothill of Himalayas at an elevation of 435m (1,427 feet). The city has somewhat semi-cold-arid climate with mean annual maximum / minimum temperature, relative humidity and rainfall of 28.59 ºC / 14.81 ºC, 68.86% and 197.55 mm respectively. The climate of Dehradun city represents four distinct seasons *viz*., summer (March-May), monsoon (June-August), post monsoon (September-November) and winter (December-February).

Meteorological data: Meteorological data were procured from the Ecological Division, Forest Research Institute (FRI), New Forest Dehradun for the time period 2013-2014. The factors like daily maximum temperature, daily minimum temperature, daily relative humidity (at 0719h and 1419h) and daily rainfall of Dehradun city were retrieved during the time period. The daily observations of these variables were used to calculate average weekly maximum and minimum temperatures and the average weekly relative humidity and weekly rainfall for inclusion in regression and descriptive analyses.

Adult *Aedes* species collection: Mosquitoes were collected from outskirts of Dehradun city using UV rays enabled mosquito traps *viz.*, Terminator-I and Terminator-II. In the laboratory daily filtering and sorting of mosquitoes were done not only according to species using appropriate keys and catalogues [18-20] but also according to sex, date, location coordinates and trap wise number of mosquitoes. Since the study was designed on *Aedes* species as main vector of transmitting dengue fever, this research and analysis were based on average weekly adult *Aedes* specimens only.

Data analysis: Pearson's correlation analysis was used to verify the associations between adult *Aedes* species and the meteorological parameters as it shows only the degree of linear relationship between two variables and thus can be utilized to determine the highest correlations between the studied variables for using them in multiple regression analysis. In order to avoid multicollinearity the correlations between average weekly adult *Aedes* species and the weekly values of the meteorological parameters at different weekly lags (0, 1, 2, 3, 4, 5, 6, 7 and 8) were carried out before performing the multiple regression analysis.

The correlation analysis and multiple regression analysis were performed in excel spreadsheet 2013. In order to validate the models 1 and 2, the actual weekly *Aedes* species data from 2014 was used in MedCalc software to align the average of each pair (X-axis) versus the difference between each pair of the predicted and actual weekly values (Y-axis) in order to access the agreement between these values based on method developed by Altman and Bland [21] as because the correlation alone might not be adequate for the assessment.

Results

A total of 937 adult mosquitoes specimens belonging to 4 genera (*Aedes*, *Anopheles*, *Armigeres* and *Culex*) were encountered during the study period. Among the collected mosquitoes species *Culex* shared maximum number followed by *Aedes*, *Anopheles* and *Armigeres* in succeeding order. Overall 13 species of *Aedes* mosquitoes were reported *viz*., *Ae. aegypti*, *Ae. albopictus*, *Ae. pseudotaeniatus*, *Ae. vittatus*, *Ae. thomsoni*, *Ae. albolateralis*, *Ae. gilli*, *Ae. suffuses*, *Ae. greeni*, *Ae. w-albus*, *Ae. unilineatus*, *Ae. dissimilis* and *Ae. edwarsi*.

The highest correlation between maximum temperature and *Aedes* were found at 5-lag week (r=0.68) and for minimum temperature found in 1-lag week (r=0.82). Relative humidity and *Aedes* were in highest correlation in 0-lag week (r=-0.06 for 0719h and r=0.57 for 1419h). Rainfall was also found best correlated with *Aedes* during 0-lag week (r=0.49) (Fig. 1). The multiple regression analysis was conducted using the five variables at these time lags to create the first model (Table 1). Then the two meteorological variables {minimum temperature 1-lag week and relative humidity (0719h) 0-lag week} that had the highest correlation with mosquitoes (r=-0.57 and r=-0.06, respectively) were selected to create the second model since they could better explain the variance in average weekly mosquitoes (Table 2). However, in the multiple regression the average of the meteorological parameters and *Aedes* species of 2013 were used and then predicted the weekly mosquito values for 2014 based on the result of this analysis.

A correlation coefficient of 0.84 was observed between the actual and predicted average *Aedes* numbers (resulting from model 1), even though the scales are different *i.e.*, lower in actual mosquito numbers and higher in the predicted values (Fig. 2). However, in model 2 comparatively lower correlation coefficient of 0.63 was observed between actual and predicted values with narrower bands (Fig. 3). In this study, model values predicted in model 1 were found more accurate in terms of showing the trends of mosquito abundance over weeks as compared to model 2 (Fig. 2 and 3).

The limits of agreement were calculated from d±1.96s, where 'd' is the mean of difference between each pair of predicted and actual values, and 's' is the standard deviation of the difference between these pairs. The calculation results showed that the upper and lower limits of agreements of model 1 were 26.77 and 1.76, respectively, and the upper and lower limits of agreements of model 2 were 13.63 and -3.36, respectively.

Fig. 4a shows that 31.21% of datasets of model 1 are within the upper and lower limits of agreement, indicating a strongest concordance between the predicted and actual average of weekly adult *Aedes* species. In contrast, Fig. 4b shows that 13.38% of datasets of model 2 are within the limits of agreements, indicating the least concordance between the values.

Discussion

Significant relationships were revealed between minimum temperature, relative humidity (1419h) and average adult *Aedes* species with a lag of 1-week and 0-week respectively. A decrease in *Aedes* species abundance could be forecasted by a decrease in meteorological variables like minimum temperature, maximum temperature relative, humidity (1419h) and rainfall as coefficient values were found positive and on the contrary decrease in vector species abundance could be forecasted by an increase in weekly relative humidity as coefficient of relative humidity (0719h) was found negative, supported by the findings of the study conducted in North Queensland, Australia [4] which suggest that any decrease to around 18°C can lead to increase in the mosquito abundance because it increases the humidity and offers the best conditions for mosquito to survive.

Model 1 explains more accurate effects of weather on *Aedes* species abundance, so, we can select it as the better model compared to model 2. It was found to be comparatively more sensitive (31.21%) in predicting sharp alteration of mosquito numbers showing the condition that would allow mosquito control measures to be initiated before the sharp increases happens. Different studies have used similar analyses of meteorological factors and mosquitoes in and Argentina [3], Australia [4] and Saudi Arabia [5]. The *Aedes* mosquito survival rate can increase at higher temperatures (not more than 38 °C), and our study indicates the weekly temperatures and relative humidity are supporting variables for survival of adult *Aedes* mosquitoes and transmission of dengue [6]. Similar results have been presented by Githeko *et al.* [10], who found that temperature ranges from 14 °C to 18 °C at the lower end and 35 °C to 40 °C at the upper end could lead to higher dengue vector transmission.

The models presented here explain the variation in the mean number of adult *Aedes* per week and sharp increase and reduction of the mosquitoes in some weeks. Other considerable supporting factors might be human population growth rate and carrying capacity (*e.g.*, breeding container density) for dengue vectors as stated in Yang *et al.* [7]. Khormi *et al.* [22] found that the variations in annual meteorological variables indicated that certain factors other than biological characteristics of adult *Aedes* mosquitoes determine dengue fever transmission. The other factors are human population such as social status, population immunity and economic status also have a significant influence on dengue transmission and its vector [5]. The model developed in this study based on prediction could preliminary inform decision makers for determining when to initiate the appropriate control strategies of the mosquito and its borne diseases.

Table 1: Meteorological parameters with most significant correlations vs average number of adult *Aedes* species (Model 1).

Met. parameters	Co-efficient	SE	P-value	CI_{95}
Max. Temp (5-lag week)	-0.653	0.362	0.074	-1.372 – 0.065
Min. Temp (1-lag week)	0.939	0.326	0.004	0.291 – 1.587
RH (0719h) (0-lag week)	0.298	0.106	0.005	0.088 – 0.509
RH (1419h) (0- lag week)	-0.004	0.103	0.967	-0.208 – 0.200
Rainfall (0-lag week)	0.099	0.066	0.136	-0.032 – 0.231

Model 1: Average Aedes sp. = (-0.653)* Max. Temp (5-lag week) + 0.939* Min. Temp (1-lag week) + 0.298* RH (0719h) (0-lag week) + (-0.004)* RH (1419h) (0- lag week) + 0.099* Rainfall (0-lag week)

Table 2: Significant Meteorological parameters with the highest correlations vs average number of adult *Aedes* species (Model 2).

Met. parameters	Co-efficient	SE	P-value	CI_{95}
Min. Temp (1-lag week)	0.939	0.326	0.004	0.291 – 1.587
RH (1419h) (0- lag week)	-0.004	0.103	0.967	-0.208 – 0.200
Model 2: Average *Aedes* sp. = 0.939*Min. Temp (1-lag week) + (-0.004)* RH (1419h) (0- lag week)				

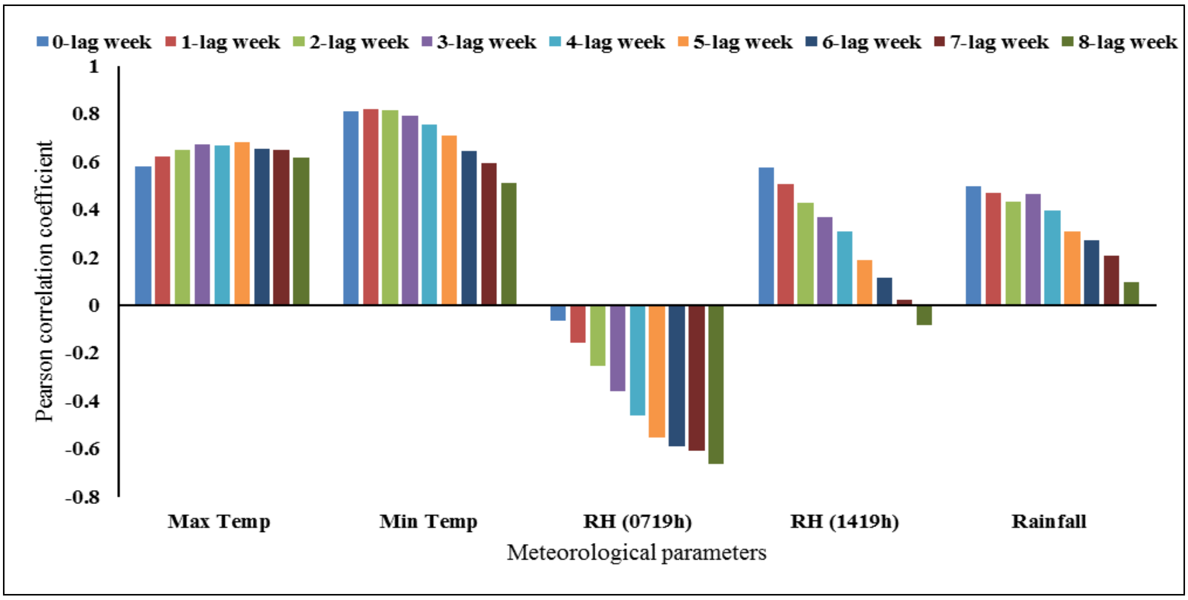


Fig 1: Correlation coefficients between meteorological parameters and adult *Aedes* species using different lag periods.

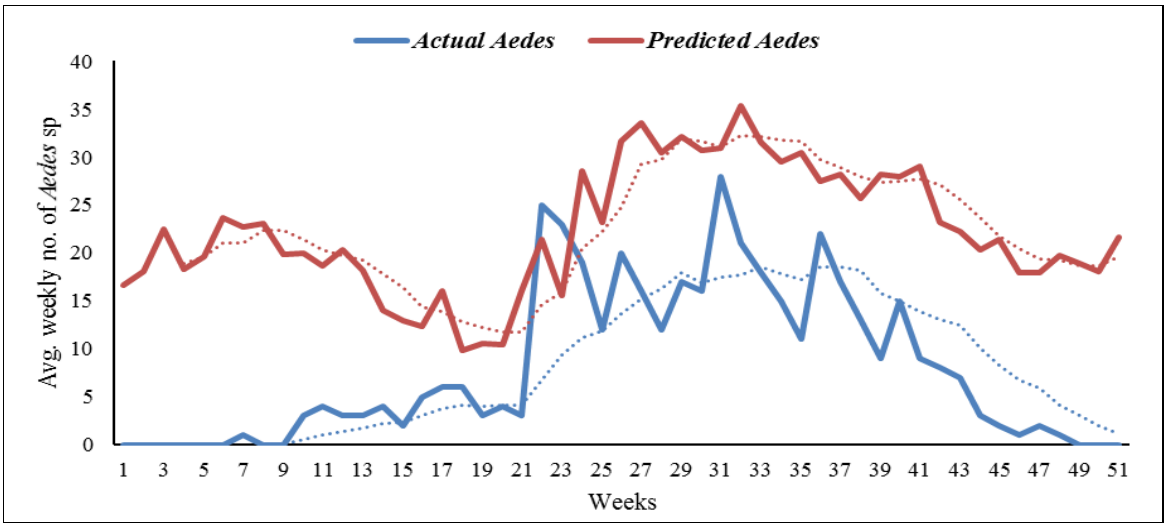


Fig 2: Values of predicted average adult *Aedes* species per week as calculated from model 1.

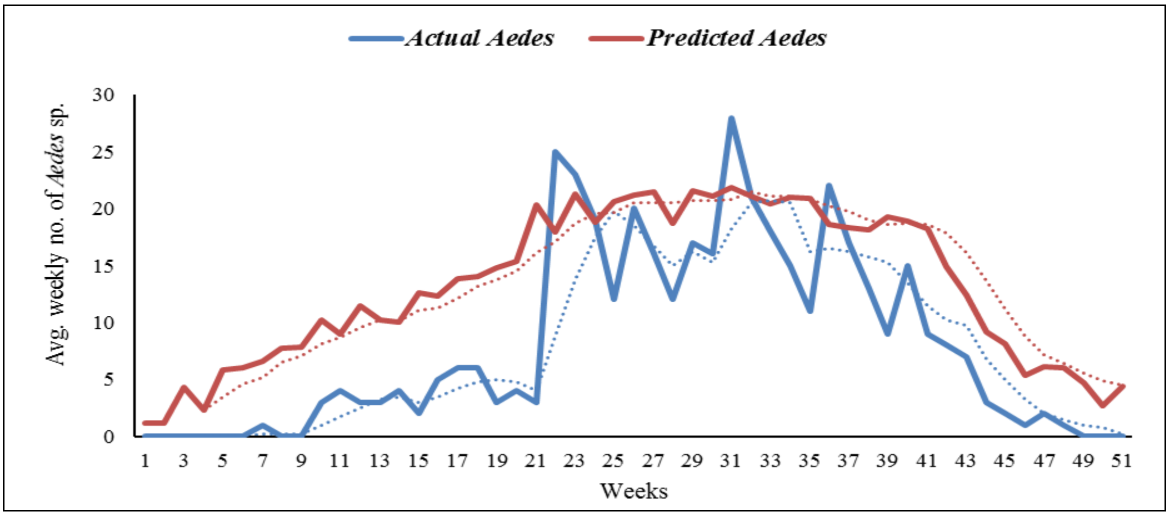
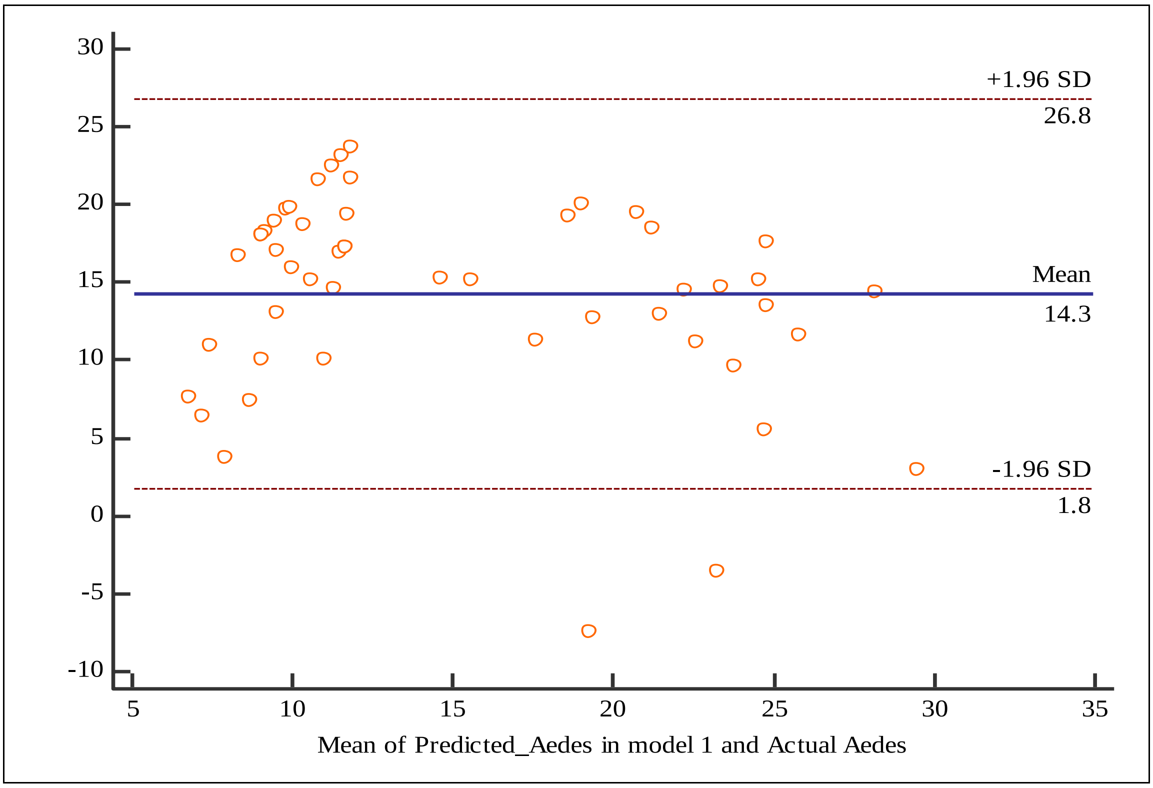
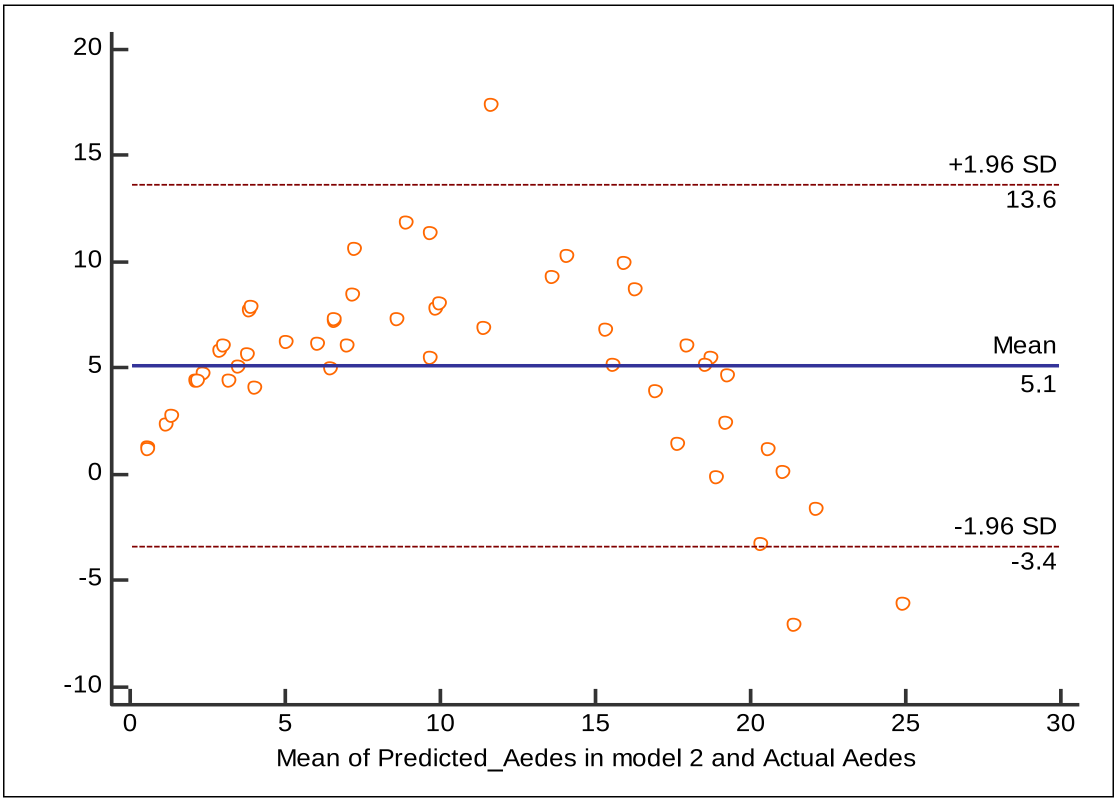


Fig 3: Values of predicted average adult *Aedes* species per week as calculated from model 2.



A



B

Fig 4: Bland-Altman agreement plot showing the difference between each pair of average predicted and actual weekly *Aedes* sp. (horizontal axis) plotted against the difference between predicted and actual weekly *Aedes* sp. (vertical axis). A. = Model 1; B. = Model 2

Conclusion

In consideration of population growth rate and carrying capacity (*e.g.*, breeding container density) for dengue vectors the predictive model developed in this study could partly inform decision makers for determining when to initiate these control measures in order to minimize the likelihood of dengue risk. The other factors also have a significant influence on dengue transmission which include human population factors also such as abundance, social status, population immunity and economic status.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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