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The effect of flood on seasonal dynamics of *Haemaphysalis* (Acari: Ixodidae) tick vectors in Western Ghats forest area of Kerala, South India

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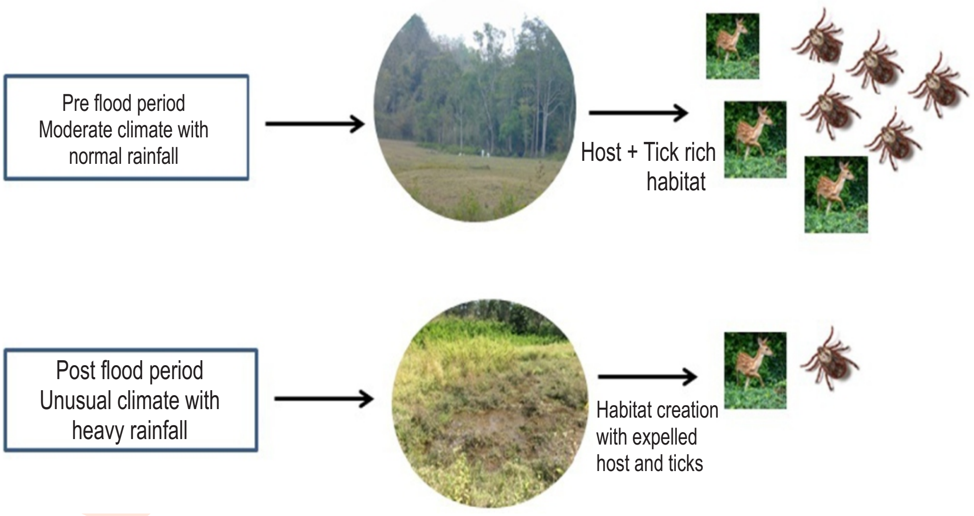
Abstract

Aim: Climate and weather conditions play a crucial role in the dynamics and distribution of ticks and tick-borne diseases. In this study, we explored the influence of a heavy rainfall (flood) occurrence on the seasonal activity and density of host-seeking *Haemaphysalis* tick vectors in Wayanad district, Kerala, India.

Methodology: Wayanad district in Kerala state was selected as the study area. Ticks were collected from December 2017 to May 2019, monthly for five consecutive days by dragging method. Tick density was analyzed with climate data obtained from the meteorological station.

Results: The total number of ticks collected post-flood decreased to 59% in Kurichiyad (site 1) and 63% in Muthanga (site 2), and the seasonal nymphal peak density was shifted. A seasonal peak of tick activity was normally observed from December to February. This peak occurrence was missing after flood in the study areas created with waterlogging and vegetation overgrowth.



Interpretation: The present study revealed the effect of flood events in the study sites with significant differences in the abundance of five *Haemaphysalis* tick species during pre and post-flood periods and forest and wildlife habitats. This difference in the changing climatic conditions and increasing annual flood seasons in the Western Ghats may shift this region's ticks questing activity and tick-borne disease ecology.

Key words: Flood, *Haemaphysalis* sp., Rainfall, Ticks, Western Ghats

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Introduction

Hard ticks (Acari: Ixodidae) play a significant role as vectors of disease to humans and animals by transmitting many important pathogens such as virus, bacteria, protozoa, and helminthes (Estrada-Pena and Jongejan, 1999). The most crucial tick genus in the Western Ghats of India is *Haemaphysalis* spp., vector of Kyasanur Forest Disease. This zoonotic disease is endemic along the Western Ghats (Balasubramanian *et al.,* 2019a). Thus, the abundance of these ticks is a major public and animal health issue. Key abiotic factors such as temperature, rainfall, and humidity influence the presence, development, activity, and longevity of these ticks (Knap *et al.,* 2009; Mrljak *et al.,* 2017). Extreme events, such as heavy rain and subsequent flood, may affect the environmental distribution and abundance of ticks in their natural habitats (North and Hurteau, 2011; Steel *et al.,* 2015). The response of ticks to these factors may increase or decrease tick abundance and their distribution in the forest and wildlife (Mac Donald, 2018). Furthermore, heavy rainfall events have many indirect effects on the presence and survival of ticks, such as destruction of host animals or habitats, host migration, and spectacular changes in the undergrowth of vegetation (Overbeek *et al.,* 2008).

The geographic distribution of ticks is related to climate factors such as humidity, temperature, rainfall, vegetation type, land use, and disturbance (Jore *et al.,* 2014). Global warming is expected to alter vector development, vector physiology, vectors' geographic distribution, and vector-host-pathogen interactions (Parham *et al.,* 2015). Several recent publications have demonstrated how climate change can alter the distribution of vector-borne diseases transmitted by ticks, sandflies and mosquitoes. These studies investigate how changes in spatial distribution of arthropod vectors may influence future spatial distributions of vector-borne pathogens (Balasubramanian and Nikhil, 2015; Balasubramanian *et al.,* 2019b; Balasubramanian *et al.,* 2021; Medlock and Leach, 2015; Marques *et al.,* 2020). Previous studies have shown that the season of the year and the field environment in which the ticks oviposit are important extrinsic factors as ticks were observed to produce a more significant number of eggs during peak and retreating of rains and when placed in the shade (Danielova *et al.,* 2006). The success in oviposition was aided by moisture provided by light-to-moderate rainfall; excessive moisture in terms of heavy rain adversely affected tick oviposition and distribution (Olwoch *et al.,* 2003).

Generally, the larvae of *Haemaphysalis* spp. ticks make their first appearance soon after the monsoon in September. The nymphs of *Haemaphysalis* spp. start appearing in October and reach peak in January. Both larvae and nymphs are scarce or absent during monsoon. If post-monsoon continues till October or November, this scarcity of ticks continues up to November, and it is only in December that fair number begin to appear. Seasonal distribution of adults begins during monsoon months, and a host preference is specific to their life stage: larval and nymphal ticks feed primarily on small vertebrate hosts, while adult ticks seek large mammal hosts (MacDonald and Briggs, 2016). Therefore, biotic and abiotic factors such as vegetation, host fauna, soil, topography, and climate are interrelated, and extremes of any one element may adversely affect the ticks for survival (Bounoua *et al.,* 2013). In previous studies (Murray and Vestjens,1967; Daniel and Gerry, 1967) the complete absence of ixodid ticks has been reported from certain habitats during excessive wetness. Sutherst (1971) in his study on the effect of flooding on the ixodid tick *Boophilus microplus* in Australia found that eggs and larvae of *B. microplus* were more resistant to submersion than engorged female and that their survival increased at low temperatures and in water with high oxygen content. Further, the egg production of *B. microplus* reduced significantly only after submersion for 24 hr. In addition, Martin *et al.* (2017) revealed the impact of a major flood event on tick abundance and activity in north of Vienna, Austria and reported lower number of ticks with periodical flood events.

In the years 2018 and 2019, Kerala state experienced a severe flood. In August 2018, the Western Ghats received the maximum rainfall of 700 - 1000 mm. Moreover, the frequency of flood and their extent are expected to increase in India under projected climate change (Kieran and Arathy, 2020). These flooding events are likely to impact the abundance and distribution of tick population by indirect effects on the tick habitat (Mac Donald *et al.,* 2018; Li *et al.,* 2019). Expelling of hosts, dramatic changes in vegetation, and differences in the leaf litter can affect the presence and survival of ticks (Overbeek *et al.,* 2008). Although the impact of climate change on temperature and humidity can have immediate effects on tick activity and survival, and may also affect the flooding events in forests by changing the tick environmental habitats (Hvidsten *et al.,* 2020; Ginsberg *et al.,* 2017).

In view of the above, the objective of this study was to investigate the effect of significant flooding on the tick abundance associated with forest habitat. Therefore, in this study, two flooded areas along the Wayanad forest, similar geology, vegetation, geographical position, and animal fauna were investigated.

Materials and Methods

Study Area: The present study was conducted in the forest areas of the Wayanad district. Wayanad is a hill district of the Western Ghats in North eastern Kerala, covering a total area of 2,131 sq. km. The altitude varies from 700 – 3,100 m above sea level. This area experiences a modest, semitropical climate with average temperature of 18°C in winter and 35°C in summer and average rainfall of 2,786 mm. The yearly average humidity was above 60 - 65%. Waynad occupies 83.3% of the forest cover. Providing suitable environmental conditions for reproduction and multiplication of ticks due to diverse vegetation, domestic and wild fauna. The study was performed at two different sites in this district.

The study area receives maximum rainfall under the influence of south-west monsoon and minimum rainfall during north east monsoon. However, between 1st to 19th August 2018, this area received 164% more rainfall than normal. The site was selected based on the flood events reported and suitable ecological and geographical forest features that favor the activity of questing ticks proved from the previous year's tick survey at the same sites. The first study site was a mixed forest area with a teak plantation (11°47' 0.2"N, 76°16'52"E, 2,800 feet) in the Kurichiyad forest range. The second study site was a mixed forest area with eucalyptus plantation in the Muthanga forest range (11°40'00.3"N, 76°23'30.2"E, and 2, 821 feet). The study was conducted from December 2017 to May 2018 (pre-flood period), and from December 2018 to May 2019 (post-flood period), ticks were collected monthly following dragging method.

Collection of ticks: Questing ticks were collected by dragging a 1.5 m long×1.0 m wide flannel cloth attached to a wooden stick and a 5 m long nylon rope attached to each end of the stick. The flannel cloth was dragged over vegetation, stopping at an interval, and 2 hrs were spent dragging at each site. All nymphs and adults from each transect were collected and kept in separate vials labeled with date, locality, and collection area. Sampling was performed on rain-free days, avoiding early morning and midday hours to minimize the potentially confounding effects of heavy dew and extreme heat on sampling efficiency.The collected ticks species were identified using morphological identification keys with the help of a stereo zoom microscope (Olympus - SZ-61, Japan) (Geevargese and Mishra, 2011). A total of 120 surveys were carried out with 60 sampling events in Kurichiyad, 60 in Muthanga in both pre and post-flood periods. There were two parallel 100 m transects dragged in from each of five locations for a total sample area of 1,000 m^2 per site per visit at both places. The number of ticks collected per minute was calculated from this data, comparing sample results. Tick were collected between 10:00 am and 4:00 pm by three collectors.

Climate data: Temperature, humidity, and rainfall details were obtained from the meteorological station of the Regional Agricultural Research Station, Wayanad district, and Kerala Meteorological Department through IMD online source, and these data were used for climatic factor analysis. Total rainfall was determined by totaling the daily total rainfall.

Data analyses: Spearman's Rho correlation analysis was performed on the number of ticks and ran correlations for tick abundance and mean total rainfall for all collection months for both locations on the pre-flood and post-flood periods. A p-value <0.05 was considered statistically significant. Statistical analyses were performed by IBM SPSS statistics 20 software.

Results and Discussion

In the year 2018, the study area recorded three times more rainfall as compared to rainfall in the year 2017 (Fig. 1). Comparisons of *Haemaphysalis* tick species during the pre-flood and post-flood periods between December and May are shown in Table 1. Five *Haemaphysalis* species of *Haemaphysalis bispinosa*, *H. cuspidata*, *H. spinigera*, *H. turturis*, and *H. wellingtoni* were collected. A total of 14,107 ticks were collected from December to May during the pre-flood and post-flood periods of 2017–2019, *i.e.,* 9,595 in the area during the pre-flood season (region I) and 4,512 during the post-flood season (region II). Five species were found: 55.8% *H. spinigera*, 41.7% *H. turturis*, 2.42% *H. bispinosa*, *H. cuspidata*, and *H. wellingtoni*. The highest number of ticks per minute was collected in January before the occurrence the flood. The total ticks collected during six months after the flood decreased by 55.5% in the region I and 44.4% in region II. The occurrence of *H. spinigera* and *H. turturis* in the forest vegetation dropped to 50.7% and 24.7%, respectively. However, the population of *H. bispinosa* ticks increased during the post-flood period from 2.42% to 12.48%; *H. cuspidate* (0.1%) and *H. wellingtoni* (0.2%) species also occurred with a low percentage. The number of ticks was also recorded per minute, dragging to differentiate the rainfall impacts in the two study periods. On average, 4.15 ticks per minute were collected from the flooded area before flooding and 1.49 ticks per minute after flooding (Fig. 1).

Even more distinct reduction of collected ticks per minute was seen post-flood where the rate of tick collection reduced 20-fold from 21 to 0 ticks per minute (Fig. 1). The collection results-focused, from December, directly after the flood, the collection rate on the flooded area decreased from 56 ticks per minute in January to 29 ticks per minute. During pre-flood period of 2017–2018, the larval abundance was mainly observed in

Table: 1: Comparison of *Haemaphysalis* tick species from two sites of Wayanad in pre and post-flood (2017-2019) periods

Tick species	**No. of ticks - Pre - flood**		**Total (%)**	**No. of ticks - Post-flood**		**Total (%)**
	Site - 1	**Site - 2**		**Site - 1**	**Site - 2**	
Haemaphysalis bispinosa (Neumann, 1897)	163	70	233 (2.42)	236	502	738* (12.48)
H. cuspidata (Warburton 1910)	0	0	0	3	3	6 (0.1)
H. spinigera (Neumann, 1897)	3931	1429	5360 (55.8)	1530	759	2289*(50.7)
H. turturis (Nuttall & Warburton, 1915)	1678	2324	4002 (41.7)	737	726	1463* (24.7)
H. wellington (Nuttall & Warburton,1908)	0	0	0	1	15	16 (0.2)
Total	5772	3823	9595	2507	2005	4512

*Correlation significant at 0.05 level (2-tailed)

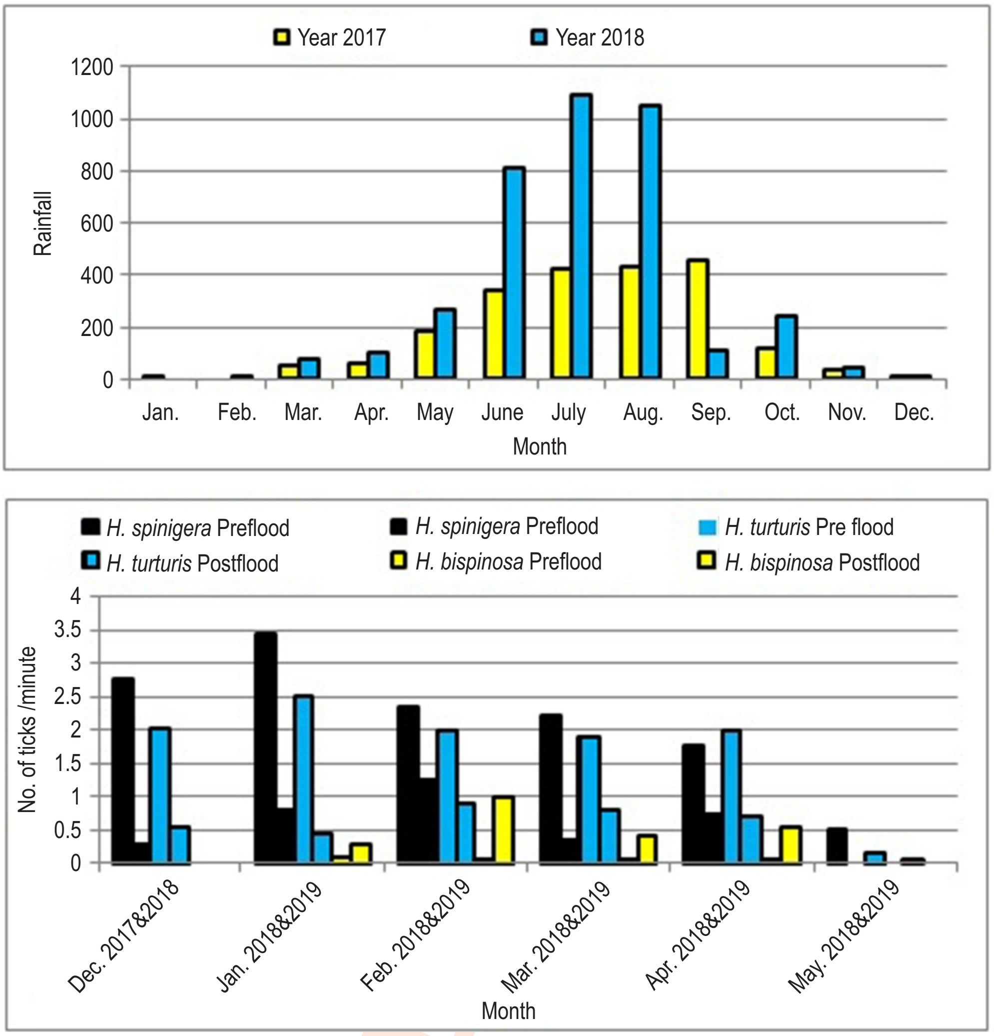

Fig. 1: Effect of rain fall on tick distribution in Wayanad district -2017-2018 (a) Rain fall data of Wayand District 2017-2018 and (b) *Haemaphysalis* tick data from fore at habitat in pre-and post-flood periods.

October and November (more than 5 clusters with >500 larvae/cluster), and nymphal ticks became active in early December 2017 with density peaking in January–February 2018. However, after heavy rains, in 2018–2019, the larval abundance was observed in late December, and peak densities occurred in February–March. The larvae hatching shifted to December due to climatic and geographic effects on host animals and ticks (Martin *et al.,* 2017). The overall abundance dropped after flooding, with a reduction of approximately 50% first pre-flooding estimate to the last estimate. This reduction was statistically significant. *Haemaphysalis bispinosa* reduction was significantly and positively correlated with post-flood (r_{sp} = 0.328, $p < 0.028$) for both locations and *H. turturis* reduction was also positively correlated with post- flood tick reduction (r_{sp} = 0.293, $p < 0.050$). *Haemaphysalis spinigera* abundance was negatively correlated with total rainfall and post flood effects (r_{sp} = −0.943, $p < 0.005$) for both locations. The species diversity of Ixodidae is well known for a small number of genera. At present, 155 *Haemaphysalis* species are known throughout the world, of which 49 have been recorded in India (Geevarghese and Mishra, 2011).

In the present study, only five species were reported, due to limited study sites and periods. The genus *Haemaphysalis* vectoring the causal agent of Kyasanur Forest Disease, Ganjam virus causing Ganjam virus disease, Severe fever with thrombocytopenia syndrome (Casel *et al.,* 2021; Sadanandane *et al.,* 2018). In the present study, the highest prevalence of *H. spinigera* and *H. turturis* was collected which is in agreement with the observation of Sadanandane *et al.,* (2018). Also, Prakasan *et al.* (2015) reported the highest prevalence of *H. spinigera* and *H.*

turturis in Wayanad and Malappuram districts of Kerala. The results of this study on the flood event is in line with the findings of Martin, (2017) who reported that the activity of ticks massively reduced after flood, indicating that there may be important indirect effects of the sediment on the habitat of ticks and host animals. According to Sutherst, (1971), the flood rains cause only a temporary reduction in tick numbers. The long-term effect of rains creates environmental conditions that are highly favorable for tick reproduction. Hinton (1967) described the spiracles of ixodid ticks' structure, especially those that spend much of their life cycle close to the ground, maybe an adaptation that enables them to survive temporary inundations during rainy season. Also, the prolonged preoviposition period of adult ticks species, the flood might be a resting or recovery period following periods of anoxia, as observed in Ixodidae ticks (Sutherst, 1971).

The decrease was most significant post flood, and numbers appeared to increase by March, but there was a delay before numbers increased substantially. The delayed increase of tick density observed in this study suggest that floods were essential for dramatical change in the habitat to benefit ticks or simply delay recruitment. The decrease in density of ticks observed in this study may have been a temporary effect, reflecting the impact of long-absent flooding on this population (Martin *et al.,* 2017). Overall the flood events caused a foremost and long-standing influence on tick abundance. The soil sediments formed by the flood were the main barrier for tick survival; even if some survived, ticks may manage to get away from the deposit, though there was no suitable habitat condition for tick survival in the flooded area. Accordingly, there was an extreme change in the vegetation of flooded area. After heavy rain, forest patches with suitable habitats for tick host animals changed into a marshy land with heavy slush.

This kind of conversion of natural patches destroys the habitats of host animals and retards their free movement toward these sites, thereby decreasing the presence of questing ticks. While many are able to manage, several vertebrate hosts drown, minimizing the number of reproductive hosts of ticks (Nicholas *et al.,* 2021). Differences in rainfall does not fully explain fluctuations in population density; however, other factors such as temperature, humidity, vegetation cover, and host availability have also been suggested (Adejinmi, 2011). *Haemaphysalis bispinosa* was much more abundant during the high rainfall years. In contrast, other tick species were less during this season. *H. bispinosa* maintains population both in the wild as well as under domestic conditions. Unlike other species of ticks infesting cattle in the KFD area, which usually inhabits forest biotope during their non-parasitic phase, *H. bispinosa* inhabits the forest, grazing fields as well as cattle sheds. The other species normally drop while the cattle are grazing in the forest.

This difference in time of engorgement appears to determine the dropping of *H. bispinosa* inside the cattle sheds and other species in the forests. For parasitizing in the field, each stage has to depend on a chance encounter of a host, which is comparatively low. On the other hand, continuous availability of host for all three stages of *H. bispinosa* in the sheds provides maximum chance for each stage to obtain a blood meal. This enables the maximum number of *H. bispinosa* to complete the life cycle in a minimum period, resulting in mass breeding wherever physical factors are favorable. The seasonal abundance of *Haemaphysalis* ticks is typically observed during winter months, with considerably fewer tick densities during dry months (Balasubramanian *et al.,* 2019). This pattern of distribution was missing after heavy rainfall at both the sites. The number of collected ticks per hour reduced four fold directly post flood and remained on a low level for the remaining part of the year (Martin *et al.,* 2017). The reasonably low tick densities during dry months reveal the normal influence of summer season that can be pragmatic every year (Macdonald *et al.,* 2018; Macdonald *et al.,* 2020). Hence, this reduction in tick population could have resulted from lower adult tick survivorship, overgrowth of vegetation, destruction of their habitats, and reproductive hosts being washed away over the flood season (Adejinmi, 2011; Di Luca *et al.,* 2013).

Over all, the climate change is liable to impact the abundance and distribution of tick populations by indirect effects on the habitat qualities that provide refuges for ticks from extremes of weather, and may or may not protect ticks from pathogens and predators (Samish and Alekeev, 2001; MacDonald, 2018; Li *et al.,* 2019). In addition, the abundance of hosts, which may also be linked to habitat changes or by direct effects of climate change on survival (Simon *et al.,* 2014; Dawe and Boutin, 2016). So these types of range expansions/ contractions and changes in densities/species compositions of host and habitat communities will be highly distinctive for different tick species, hence, the extreme weather conditions like flood, changes the geographical distributions of suitable climate, habitat, and host communities for tick survival. It may also effect the changes in tick population ranges depending on the capacity of ticks to be dispersed outside the existing ranges by the hosts.

In summay, this study provides the staged effect of a flooding event on tick abundance and seasonal shifting/change in tick activity. Further, the floods cause only a temporary reduction in tick numbers in short term and create conditions that are favorable for tick reproduction in the long term. Overall, under changing climate conditions and increasing duration of annual flood seasons in the Western Ghats, this temporal mismatch may shift the ticks' questing activity and tick-borne disease ecology in this region.

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