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How Micro-Habitat of Roosting Sites Governs Insectivorous Bat Diversity? An Insight into the Roosting Ecology of Insectivorous Bats (Mammalia: Chiroptera) in Thar Desert of Rajasthan, India

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Abstract

Bats are using roosting sites for a long time, if not disturbed. Every species has its choice of habitat conditions and more importantly niche preference is quite visible in sympatric species. A better understanding of these simple looking but complex micro-climatic choices makes an interesting field to explore and understand the life of cryptic species like bats, which roosts in dark, damp and remote places and comes out in the darkness of night to rule the night sky everywhere. This selection of roosting sites is based on species specific micro-climatic conditions. The present study was designed to understand their roosting ecology and peculiar site-specific choices. It was observed during the present study that some species are omnipresent in many of the roosting sites, whereas few are having their unique choices. The major variables are humidity, temperature and slight effect of light intensity in the roosting site. If any changes occur in these conditions, they vacate the roost immediately. Out of six insectivorous species studied for 2 years in Western Rajasthan, *Rhinopoma microphyllum*, *Rhinopoma hardwickii* and *Pipistrellus tenuis* found to be more tolerant or resilient from minor changes, on the other hand, *Hipposideros fulvus* showed very specific roost specific microclimate choice. This study also highlights the outer environment and features of roosting sites and highlighting the conservation importance of the second most diverse group of mammals, *i.e.*, bats.

1. Introduction

Order Chiroptera of class Mammalia is a uniquely evolved and one of the most successful mammalian orders as well as the most diverse (Altringham, 2011). Bats are true fliers and used active energy to take flight, which was result of millions of years of evolution. One of the 26 mammalian orders, the Chiroptera includes 1411 species (Burgin *et al.,* 2018) of bats world. Based on molecular phylogeny of the bats (Teeling *et al.,* 2005), genetic data was gathered from all known 21 families of bats were examined and reclassified from old sub-orders namely Megachiroptera and Microchiroptera and explained the radiation migration; as a result Order Chiroptera is reclassified and divided in two new suborders, the Yinpterochiroptera and the Yangochiroptera. Among them, a total of 127 species of bats have been reported from India (Thong et al., 2018) and that makes 90% of total bat diversity of South Asian region (Srinivasulu *et al.,* 2010; Talmale and Saikia, 2018). Order Chiroptera is the second largest order after Rodentia. Rajasthan harbours as many as 25 species of bats (Srinivasulu *et al.,* 2013), total of 16 species of bats has been reported so far from Desert region (Senacha and Dookia, 2013; Srinivasulu *et al.,* 2013). In Thar Desert of Rajasthan, microchiropteran bats have roosts in caves, moist tunnels, dilapidated buildings, historical monuments, step wells and community wells. Due to harsh ecological conditions, extreme temperature and humidity variation over the seasons, their roosting sites holds unique micro-habitat settings. Every species have its choice of micro-habitat and they prefer to live in that micro climatic zone inside roosting site. Roosts are the important aspects of any species. It provides the shelter. Species can breed easily and grow their young ones. Bats choose types of roosting site, choosing of roosts it depends on size and habitat requirement. Many species of bats choose roosts near the foraging area like natural as well as manmade caves, old dilapidated buildings, wall cervices, hollow tree trunk, and tree foliage and beneath the big leaves. Few small species choose unusual roosts like inside the electric box, beneath wooden board or box and door frame. Bats roots are at risk always to human activity (Agosta, 2002). They choose roosting sites using specific criteria such as temperature, light intensity and humidity as an important microclimatic feature in site selection. A detailed thorough study was conducted to understand the relationship between microclimatic parameters and population variations in Thar Desert of Rajasthan between Sept. 2015 to Sept. 2018.

2.. Material and Methods

2.1. Study rea

The Great Indian Desert, or Thar Desert, extends over about 0.32 million km^2 forming approximately 10% of the total geographic area of India. More than 60% of the desert lies in the state of Rajasthan, followed by 20% in Gujarat (Krishnan, 1977). The present study was conduct in two arid most districts of this region; namely, Jodhpur and Barmer, and these districts consist of a large area of arid or semi-arid zone. The study site, Jodhpur (22,850 km^2) and Barmer (28,387 km^2) are situated in the western part of Rajasthan and cover large area of Thar Desert of Rajasthan. Climatically, Rajasthan is a typical hot desert; summer and winter both seasons are very harsh. Temperature in winter is very low in the and as low as up to 0°C. In summer, the temperature escalates and rises up to 49°C. The annual average rainfall is very low between 150 to 300 mm annually. The large area of Rajasthan comes in semi-arid region due to this; high temperature and low humidity are basic characteristics of this landscape. To understand roosting ecology, total six roosting sites were selected, *i.e.,* Daijar cave, Mandore tunnel, Lunawas cave, Mandore gardens cenotaph, Kundal cave and Vairmata ji temple. Among them Daijar, Mandore (both sites) and Lunawas are situated in Jodhpur districts whereas Kundal and Vairmata ji temple are situated in Barmer district (Fig. 1). All these were traditional permanent bat roosting sites and occupied by bats since many years. All roosting sites were away from human habitation, isolated places in hilly region and except one long man-made tunnel all others were deep moist caves.

2.2 Roosting sites

2.2.1. Cave and roosting site feature: Among these six roosting sites, four were caves and two were manmade long tunnels or flood drainage channels with deep dark and high moisture chambers. Among these six sites, Daijar cave (Jodhpur) was having many chambers with complex natural tunnel system that ends inside small chambers, make more complex web of small tunnels inside this cave. This cave was having two wide openings and both were 50 meters apart and parallel to each other. It is fully dark, constant humidity and temperature, makes convenient and more habitable for bats. Kundal cave (Barmer district) is surrounded by medium hill range. This cave has two opening, one is upside and another front side. It has a mega single chamber structure along with a deep cervix, it makes more habitable for bats. Vairmata ji temple (Barmer) cave was a deep 30 metre nature cave like structure, between big monolithic rocks, 100 feet above the ground surface. Lunawas cave (Jodhpur) is situated at top of hill rock with height 200-300 feet from base of hill. This cave is only one side opening and opened with medium chamber with 12-15 feet height and opened in small tunnel chamber. Mandore garden cenotaph (Jodhpur) is situated inside a big old garden and having high ceiling, with moderate darkness even during broad day light, and Mandore tunnel (Jodhpur) is manmade and situated of Mandore garden of Jodhpur city; this tunnel has two openings, one in front and another at back side of tunnel. This is a biggest roosting site of bats among all other roosts. This tunnel has a mega chamber and almost height is 15-20 feet and continuous from one end to another end, it makes a unique site for many species of bats. All these selected roosting sites were housing 6 species of insectivorous bats, namely *Rhinopoma hardwickii, Rhinopoma microphyllum, Taphozous nudiventris, Taphozous perforatus, Hipposideros fulvus* and *Pipistrellus tenuis*.

2.2.2. Microclimatic data collection and morphometric analysis: This survey was done from six above mentioned historical roosting sites of six insectivorous bats. Information on microclimate data of roots like temperature, humidity and light intensity inside the bat's roosts were collected using digital thermo-hydrometer for temperature and humidity and digital lux meter for light intensity. Bat population was counted through wide angle photo of roost with nearest accuracy upto ± 50 bat individuals for both species of genus *Rhinopoma* and upto ± 10 individuals for rest of the species. Since bats of both species of genus *Rhinopoma* lives together in very large number, it is not possible to count them separately, hence their numbers were pooled together.

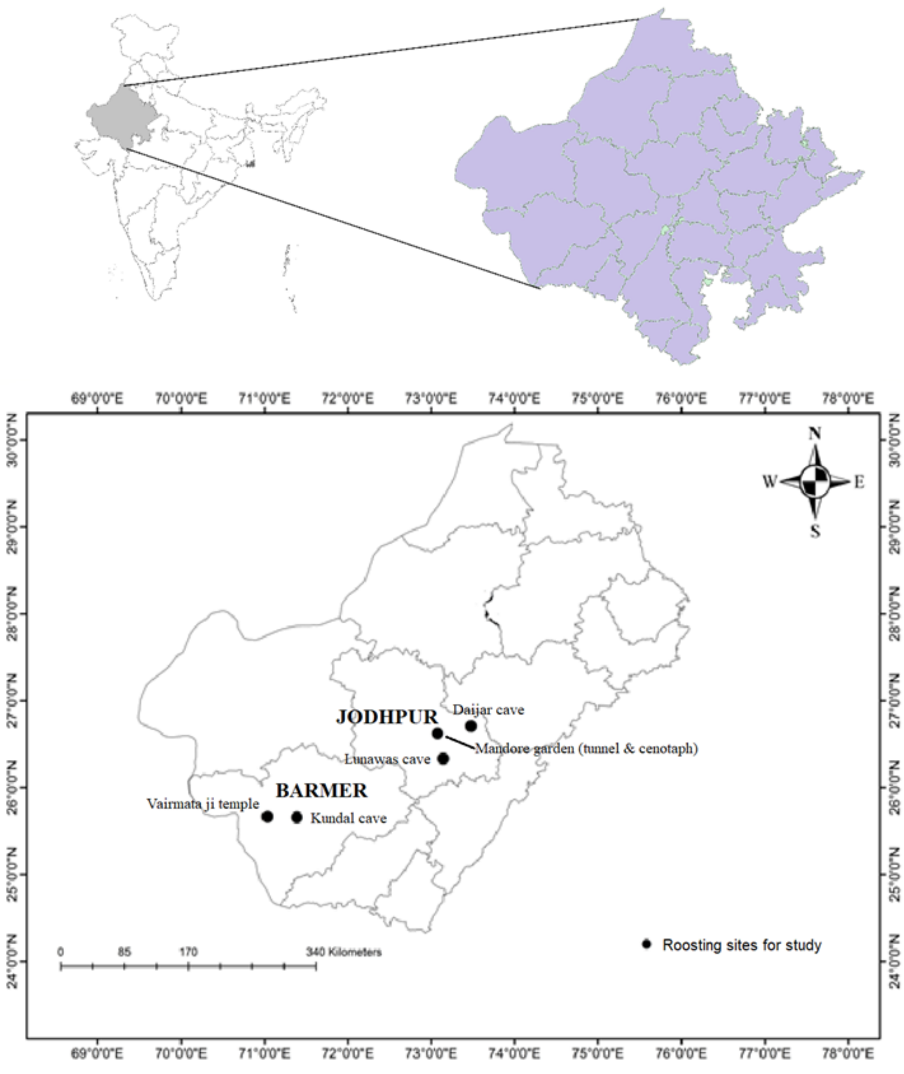

Fig.-1. Bat roosting sites for micro-climatic parameter study in Thar Desert of Rajasthan (two sites in Jodhpur district were very close to each other, hence not visible in this map)

2.3. Statistical analysis

For statistical analysis, non-parametric test was performed to develop interference form collected data. Spearman's rho test was used to measure the strength of association between two variables, i.e., humidity and temperature whereas number of bats inside roost was used as constant variable to understand the preference of micro-habitat conditions.

3. Results

The major climatic conditions of outer environment were quite similar in all these six sites. While looking at the broad habitat, microclimate of roost and cave morphology, it was found that the inner microclimatic conditions were different and showed significant variations. Broadly 5 roosting sites (except Mandore garden cenotaph site) were situated in deep, moist and dark corners of natural cave or man-made tunnels (Table 2.), whereas Mandore cenotaph was a group of cenotaph with very high tomb shaped ceiling. Bats always prefer to roost in high humid chambers from the surrounding, to understand the relationship between the temperature, humidity and number of bats in roosting sites.

Daijar cave, Mandore tunnel and Kundal cave show significant negative correlation between temperature and number of bats (Table 3), when surrounding ambient temperature changes (low as well as high) bat population increases inside the roosting cave, as the inside temperature remain between 22-34°C. Whereas Lunavas cave roost does not show any such correlation between these two parameters. On the other hand, Mandore tunnel roost shows positive correlation (p value 0.05, R value 0.227) between bat population and humidity, means number of bats gradually increases with the humidity (Fig. 2). Other three roosting sites did not show any correlation between bats population and humidity. The observations on temperature, humidity and number of bats in roosting sites were observed for two years and it was calculated that suitable temperature for bats lies between 22^{0}C to 34^{0}C (Fig. 2) and humidity ranged between 65% to 80% (Fig. 2). The peculiar microclimatic temperature and humidity is the major controlling factor for bats in western Rajasthan, because outside temperature and humidity is very much fluctuating over the seasons.

These roosts were also occupied few sympatric bats, *Rhinopoma hardwickii* was common in many of these sites, but always remains in different chambers of the caves or tunnels. Whereas, *Rhinopoma microphyllum* was found in Jodhpur district only, with a specific temperature and humidity condition in comparison with more resilient *R. hardwickii. Taphozous perfortus* was found sharing roost in Mandore tunnel with both species of genus *Rhinopoma* but its preferred micro-habitat was slightly different and it occupied more humid and cooler chamber in comparison with *Rhinopoma* spp. These sympatric species of bats broadly share the roost, but inside the roosting caves, their choices vary. Whereas *Hipposideros fulvus* bat in this arid region required some specific place for survival, like its need to specific environment condition and roosting place for shelter, they preferred deep caves with small tunnel structure with high humidity, complete darkness and low temperature. The habitat choice of *T. nudiventris* was different altogether, it found to occupy a different habitat with high temperature and less humidity zone of open tombs in urban garden.

The Spearman's rho correlation coefficient was calculated and that shows varied degree of significant relationship with temperature and humidity.

3.1. *Rhinopoma* spp. (*R. microphyllum* and *R. hardwickii*), the calculated P value is 0.000, means there is a significant difference between the two variables, i.e., temperature and number of bats (Table 2). Daijar cave, Mandore tunnel and Lunavas cave have positive correlation, which indicates that their numbers increases where cave temperature is high. Kundal cave having negative correlation between the number of bats and temperature, which directly correlate with its geographic location as its on high hilly region, therefore during summer season with the increase in temperature, bat number started declining. Similar result was also found with a calculated P value 0.000 there was a significant difference between the two variables, i.e., humidity and number of bats. Daijar cave, Mandore tunnel, Lunawas cave and Vairmata ji temple cave have significant positive correlation between the variables but in Kundal cave humidity and number of bats negative correlation to each other.

Table No. 1. Features of selected bat roosting sites in Western Rajasthan.

S. No.	Location	Broad habitat (upto 100 mt. radius)	Roosting type	Total depth/length of roosting site	Associated bat species	Humidity (mean %) n=108	Temp. (mean °C) n=108
1	Mandore tunnel, Jodhpur	Underground rainwater drain, situated in urban garden	Old man-made drain, mix roost of 4 species of bats	130 mt long 3-5 chambered rain water drain with high ceiling and small opening at both side	*Rhinophoma microphyllum , R. hardwickii, Taphozous perforatus*	72.9	29.5
2	Mandore garden cenotaph, Jodhpur	Group of cenotaph with very high tomb shaped ceiling, situated in under garden	Centuries old monument, with 6 big tomb	20 ft. high, 25 feet wide and hexagon shaped tomb from base and celling is very high	*T. nudeventris*	52.4	32.5
3	Daijar cave, Jodhpur	Subterranean cave at the root of long hill range, xerophytic scrub vegetation with agriculture fields in front of the cave	Nature cave, near an old temple, with little widening by temple authorities	Multi-chambered and narrow inaccessible gullies, more than 300 ft. long and 12 ft. deep from surface, medium sized two opening	*Rhinophoma microphyllum , R. hardwickii,*	77.2	26.3
4	Lunawas cave, Jodhpur	Natural cave, on north side of a small hillock, 150 ft above the surface, xerophytic scrub vegetation	Natural cave, narrow with deep bifurcated at the end.	More than 100 ft. deep, inaccessible gullies in the end, only one opening	*Rhinophoma hardwickii*	69.8	28.6
5	Kundal cave, Barmer	Natural cave, on a range of hillocks, xerophytic scrub vegetation	Natural cave, wide opening with big chambers in the centre with deep gullies at the end.	More than 80 ft. deep, inaccessible gullies in the end	*Rhinophoma hardwickii*	72.5	25
6	Vairmataji temple cave, Barmer	Deep 92 ft. natural cave like structure, between big monolithic rocks, 100 feet above the ground surface. Scrub xerophytic vegetation in the surrounding with a small seasonal water body nearby	Man-made cave, 7 ft high, 5 ft wide with 200 ft long drainage channel at ground level with wide opening at both sides.	More than 200 ft. long with small gaps in sides and small chambers in the centre with deep, very narrow; inaccessible gullies.	*Rhinopoma hardwickii, R. microphyllum , Taphozous perforatus, Pipistrellus tenuis*	74.2	28.5

3.2. *Taphozous nudiventris,* the calculated P value is 0.000 and there was a significant difference between two variables, i.e., temperature and number of bats. They are negatively correlated with each other, higher the temperature becomes cause of population decline in the roosting site. And between temperature and number of bats, as calculated

P value 0.004 there is significant difference and they were negatively correlated and relationship is moderate, which indicates bats can sustain in fluctuation of humidity levels.

3.3. ***T. perforatus,*** the calculated P value is 0.332 at Vairmata Temple Cave and there was no significant difference between two variables, which indicates that *T. perforatus* is highly temperature tolerant species and their number remain more or less same during the entire study period. On the other hand, between variables humidity and number of bats, calculated P value is 0.000 and there is a significant difference between these two variables. Number of bats and humidity are positively correlated to each other, which means that increase in humidity creates conducive micro-habitat for *T. perforatus* bat in this roosting site. Similar was the case at Mandore tunnel and temperature with number of bats indicates that this is a tolerant species with calculated P value 0.219.

3.4. ***Hipposiderous fulvus,*** calculated P value is 0.000, and 0.001, there is significant difference between the two variables. At Mandore tunnel, there is positive correlation between the bats and temperature. Daijar cave is showing significant difference but correlation between the two variables is not much strong. At Kundal cave 0.036 is non-significant, which may be due to its geographic location, between rocky habitats. For correlation between colony size (number of bats) and humidity, the calculated P value is not significant, means there was no strong correlation with these two variables in any of the roosting sites.

3.5. ***Pipistrellus tenuis,*** calculated P value is 0.000, and 0.005, there is significant difference between the two variables. At Mandore tunnel, there is positive correlation between the bats and temperature. Vairmata ji temple cave is showing significant difference but correlation between the two variables is not much strong. For correlation between colony size (number of bats) and humidity, the calculated P value is not significant, means there was no strong correlation with these two variables in any of the roosting sites.

Table 2. Correlation between the number of bats v/s temperature and humidity.

			Daijar cave	Mandore tunnel	Mandore cenotaph	Lunavas cave	Kundal cave	Vairatramata ji temple
Rhinopoma spp.	Temp.	Co. Coefficient	0.227	**0.708**	-	**0.481**	**-0.601**	-0.114
		p- Value	0.55	0.000	-	0.000	0.000	0.340
	Humidity	Co. Coefficient	0.023	**0.541**	-	0.237	-0.429	**0.745**
		p- Value	0.849	0.000	-	0.045	0.000	0.000
Taphozous nudiventris	Temp.	Co. Coefficient	-	-	**-0.561**	-	-	-
		p- Value	-	-	0.000	-	-	-
	Humidity	Co. Coefficient	-	-	-0.333	-	-	-
		p- Value	-	-	0.004	-	-	-
Taphozous perforatus	Temp.	Co. Coefficient	-	0.219	-	-	-	0.116
		p- Value	-	0.053	-	-	-	0.332
	Humidity	Co. Coefficient	-	**0.703**	-	-	-	**0.618**
		p- Value	-	0.000	-	-	-	0.000
Hipposiderous fulvus	Temp.	Co. Coefficient	-0.381	**0.409**	-	-0.225	-0.247	-
		p- Value	0.001	0.000	-	0.057	0.036	-
	Humidity	Co. Coefficient	-0.114	0.227	-	-0.230	-0.117	-
		p- Value	0.339	0.050	-	0.520	0.326	-
Pipistrellus tenuis	Temp.	Co. Coefficient	-	0.312	-	-	-	0.116
		p- Value	-	0.000	-	-	-	0.005
	Humidity	Co. Coefficient	-	**0.834**	-	-	-	**0.628**
		p- Value	-	0.015	-	-	-	0.005

During study, a general survey was also conducted to find out the general distribution and documentation of roosting sites, in this a total of 362 roosting sites in three districts Jodhpur, Barmer and Jaisalmer were reported. Out of these, only five roosting sites were found to be occupied by *Hipposideros fulvus* in these districts, and the old historical roost (Sinha, 1979) was abandoned by this species. Interestingly, no nose leaf bats (*Hipposideros fulvus*) were found in any old building, well and other possible roost sites. This may be unique feature of *Hipposideros* bats as it lives only in caves of Thar Desert area due to consistent microclimatic conditions inside the cave.

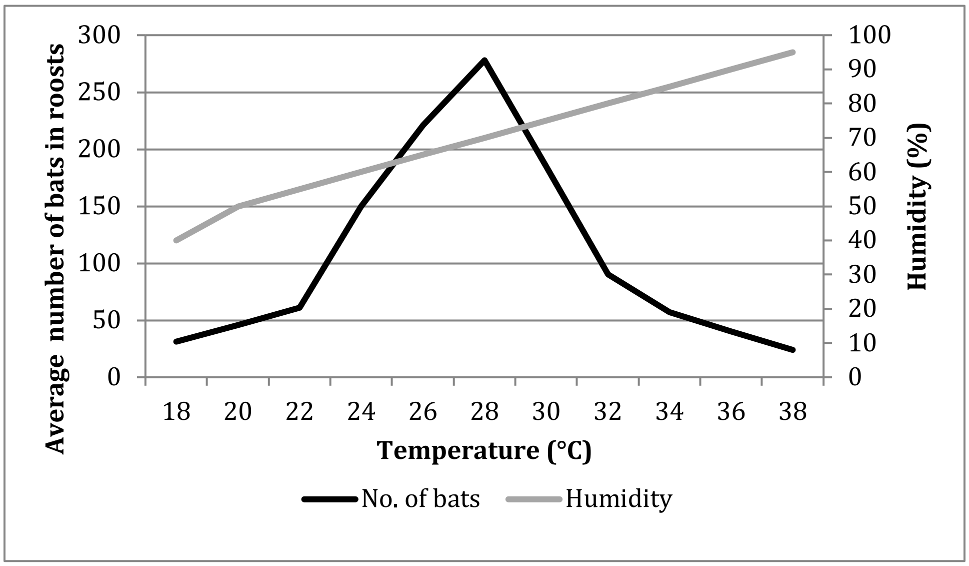

Fig.-2. Correlation between number of bats, temperature and humidity (Spearman's rho test)

4. Discussion

This is a first ever attempt to understand the roosting ecology of bats inside the roosts. Earlier studies on bat diversity in desert region of Rajasthan were conducted by Prakash (1963), Sinha (1979, 1980) and first reported *H. fulvus* from Mandore tunnel locality (Jodhpur) in desert region. After this, various researches were conducted on bats in western Rajasthan (Gaur, 1981; Purohit and Senacha, 2002; Senacha, 2003; Purohit and Gaur, 2005), but none of them focused on the microclimatic conditions inside the roosting sites and how bat species shows their preferred roosting site, where more than one species are present inside the same roost. *H. fulvus* is one of the rare bats for Thar Desert of Rajasthan, as their choices of roosting microclimatic conditions are somewhat different from other species. This was also declared locally extinct from Thar Desert (Senacha, 2003; Purohit and Gaur, 2005) as no record was reported after Sinha (1979). After a gap of around 37 years, it was spotted by Dookia *et al*. (2017) and Singh and Dookia (2019). The desert region of Rajasthan witnessed a huge ecological change over the last 6-7 decades (Sharma and Mehra, 2009), a mammoth irrigation project with huge network of distributaries and perennial availability of water increased humidity as well as rainfall also increased. This has changed the desert ecosystem in many ways (Prakash, 1998). *H. fulvus* is a species largely dependent undisturbed roosting sites with high humidity and consistent temperature in roost, on the other hand both species of Genus *Rhinopoma* is most common bat species and found in variety of habitats.

Variability in weather condition directly impact on the survival and reproductive success in animals (Michener 1973; Racey 1981; Neuhaus *et al.,* 1999; Stokes *et al.,* 2001; Burles *et al.,* 2009). Due to small body size insectivores' bats are vulnerable for any variation in weather conditions, their dependence on small sized insect prey influenced by weather (Humphrey *et al.,* 1977 and Burles *et al.,* 2009). Since all insectivorous bats also consume large number of harmful insects, their role in ecosystem services yet to be analyzed. A proper and comprehensive conservation plan should be developed, where roosting sites of bats can be protected from all future renovation as well as development projects.

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Authors Contribution: *Gajendra Singh (PhD scholar) conducted survey, helped in data collection, its analysis and helped in manuscript preparation. Sumit Dookia (Assistant Professor) conceived the idea, developed study plan, helped in data collection and drafting the manuscript and also the corresponding author.*

Conflict of Interest: The authors declare that there is no conflict of interest.

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