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Distance-dependent effects of electromagnetic radiation from mobile towers on honeybees (*Apis cerena):* a field observation study in Muzaffarpur, Bihar

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Abstract
The rapid expansion of wireless communication has significantly increased radiofrequency electromagnetic field (RF-EMF) emissions, raising ecological concerns (Balmori,2015). Honey bees are particularly vulnerable to RF-EMF exposure, which has been linked to CCD (Colony Collapse Disorder) (Carreck,2014), impaired behaviour (Favre,2011), reduced homing success (Ferrari, 2014), and disrupted floral electric-field sensing (Clarke *et al*.,2013).

This study investigated the influence of proximity to an active mobile communication tower on *Apis cerana* in Muzaffarpur, Bihar. Eighteen healthy colonies were placed at six distances (25,50,100,200,300 and 500m) from the tower atPokhraira while additionalcolonies were maintained at Karja (~18 km away, tower-free) serving as an independent control. Five parameters were recorded weekly over seven observation periods. Spearman rank correlationshowed significant distance-dependent gradients across all parameters ($|\rho| = 0.856–0.964$; $p < 0.001$). Comparison between the Pokhraira 500 m colonies and the Karja control showed no significant difference for most parameters, validating 500 m as a low-exposure reference within the experimental site.

These findings suggest that maintaining apiaries at distances of at least 300–500 m from active mobile communication towers may reduce direct colony-level stress, although foragers ranging over typical flight distances (up to 3 km) may still experience significant EMR exposure during flight.

Keywords: *Apis cerana*, electromagnetic radiation, mobile communication tower, honeybee colony, Bihar

Introduction
Honeybees play a crucial role in the pollination of numerous agricultural crops(Shaden *et al*., 2021) [7].Theyare the most prevalent single pollinator species for crops globally (James Hung *et al*.,2018) [6].In India, *Apis cerana* remains the most widely managed native species, supporting pollination of mustard, litchi, mango, citrus, sunflower, and various pulses across diverse agro-climatic regions.The global decline in honey bee populations threatens agricultural productivity, biodiversity, and ecosystem stability. This decline is caused by multiple interacting stressors, including pesticide exposure (particularly systemic neonicotinoids), pathogens such as *Varroa destructor*, habitat fragmentation, climate change, monoculture farming, nutritional deficiencies, andelectromagnetic radiation (Warner *et al*., 2024) [17]. The combined effects of these stressors reduce pollination services, lowers crop yields, and threatens food security (Chowdhury *et al*., 2025). A growing body of experimental evidence indicates that electromagnetic radiation disrupts key biological functions in honey bees. Sharma and Kumar (2010) [9] reported that *Apis mellifera* colonies exposed to mobile phone radiation showed a marked decline in queen egg-laying rate, reduced colony strength, and lower honey yield. The findings indicate that radiofrequency electromagnetic radiation (RF-EMR) may disrupt magnetoreception, spatial memory, and behavioural regulation in honey bees, contributing to the broader pattern of colony decline observed in regions with intensive mobile communication infrastructure (Shelly Rajput *et al*. 2025) [11]

Field investigations of *Apis cerana* responses to EMR from mobile tower have been reportedby Taye *et al*. (2017) [12], who documented reduced foraging activity and Taye *et al*. (2018) [13], who reported declines in brood area, honey hoarding, pollen stores, and queen prolificacy in colonies placed closer to active towers, along a 100–1000 m distance gradient. No comparable field investigation has been reported from Bihar, a region of intensive small-scale beekeeping and high agricultural dependence on pollination, where local agro-climatic conditions and tower density may differ from those in other parts of India. The present study was designed to examine the effect of distance from an active mobile communication tower on *Apis cerana* colonies under field conditions in Muzaffarpur, Bihar. Specifically, the objectives were: (i) to characterise the relationship between distance from the tower and five key colony-level parameters such as foraging activity, mortality, disoriented flight, brood condition, and colony strengthacross a distance gradient ranging from 25 m to 500 m; (ii) to evaluate the statistical strength and significance of any observed distance-dependent effects using non-parametric correlation and group-comparison tests; and (iii) to validate the interpretation of within-site reference values by comparing the farthest distance treatment with an independent off-site, tower-free control population located approximately 18 km away. We hypothesised that parameters such as foraging activity, brood condition and colony strength would show improvement as the distance from the tower increases (RF-EMR exposure decreases), whereas mortality and disoriented flight would show reduction.

Materials and Methods
Study Area
The research was conducted in Muzaffarpur, Bihar. Two field sites were selected: an experimental site at Pokhraira

village (26°04'16" N, 85°12'12.4" E) in Saraiya block, which contained an operational mobile communication tower, and a control site at Karja village in Marwan block, approximately 18 km away. Both sites were located within the same agro-climatic zone and provided comparable floral resources, including mustard (*Brassica juncea*), litchi (*Litchi chinensis*), and mango (*Mangifera indica*). The Karja control site was visually inspected and verified to be free of mobile communication towers, hence serving as a suitable reference under similar environmental conditions.

Experimental Design

A total of 24 *Apis cerana* colonies were distributed between the two sites. At Pokhraira, 18 hives were arranged along a distance gradient from the mobile tower, with three replicate colonies positioned at each of six distance intervals: 25 m, 50 m, 100 m, 200 m, 300 m, and 500 m. At Karja, six colonies were clustered within the tower-free zone, served as a control reference for colony performance.

All selected honey bee colonies were similar in size and health and kept in identical wooden hives. Standardisation was done by visual assessment and all colonies were taken from the same apiary to minimise genetic or husbandry differences.

Observation Period and Frequency

Observations were recorded during the litchi foraging season, from 9 March 2025 to 23 April 2025. To address the logistical problemsof monitoring both field sites using identical protocols, observations were alternated between the sites on consecutive days. thrpokhraira experimental site was observed on 9, 15, and 23 March and 1, 8, 15, and 22 April 2025. The Karja control site was observed on the day immediately following each observation week: 10, 16, and 24 March, and 2, 9, 16, and 23 April 2025. All observations occurred between 8:00 AM and 11:00 AM to minimise variability due to daily temperature and foraging rhythms.

Parameters Measured

Five parameters were recorded for each colony during each observation visit, with one observation per hive per parameter per date.

Foraging activity: Foraging activity was defined as the number of worker bees departing the hive per minute.

Mortality (dead bees): Mortality was assessed by counting the number of dead adult bees at the hive entrance.

Biological abnormalities (disoriented flight): Disoriented behaviour was defined as: (i) failed landings, where a returning bee required more than two attempts before successful entry, or (ii) hovering near the hive entrance for more than 10 seconds without landing.

Brood condition: Brood condition was assessed through visual inspection of the central brood frames during hive opening. Each colony was rated on a 5-point ordinal scale (0–4). The scoring criteria are presented in Table 1.

Colony strength: Colony strength was assessed during hive openings using a 5-point ordinal scale (0–4). The scoring criteria are presented in Table 2.

Table 1: Scoring criteria for brood condition assessment (0–4 ordinal scale)

Score	Label	Criteria
4	Excellent	Uniform brood pattern; >95% of cells in brood area contain healthy brood; eggs, larvae, and pupae visible in concentric layout characteristic of healthy colonies
3	Good	Mostly uniform brood pattern; 80–95% of cells contain healthy brood; minor irregularities or small gaps
2	Moderate	Patchy brood pattern; 50–80% of cells contain healthy brood; visible empty cells scattered through brood area
1	Poor	Highly patchy brood pattern; 25–50% of cells contain healthy brood; large empty patches within brood area
0	Very Poor	Minimal brood; <25% of cells contain healthy brood; scattered or absent brood pattern; colony failing

Table 2: Scoring criteria for colony strength assessment (0–4 ordinal scale)

Score	Label	Criteria
4	Very Strong	7+ frames densely covered with adult bees; brood frames fully occupied; high activity on combs; vigorous defensive behaviour; abundant nurse bees over brood
3	Strong	5–6 frames well covered with bees; good density on combs; active and healthy appearance; adequate nurse bee coverage over brood
2	Moderate	3–4 frames covered with bees; moderate density; some areas of comb visibly less populated; activity level reduced but functional
1	Weak	2–3 frames sparsely covered; visible thinning of population; reduced comb activity; brood areas inadequately covered by nurse bees
0	Very Weak	1–2 frames or less with sparse bees; severe population decline; brood largely uncovered; minimal comb activity; colony approaching failure

Data Handling and Statistical Analysis

All observations were recorded on sheets and statistical analyses were performed using R software, which has been used in pollinator research (e.g., Traynor *et al*., 2016) [15]. 21 observations (3 hives x 7 weeks) per distance were recorded at Pokhraira and 42 observations (6 hives x 7 weeks) were recorded at Karja.

Spearman rank correlation was used to evaluate distance-dependent effects at Pokhraira and Kruskal-Wallis test was used to compare all six distance groups and determine whether any group differs significantly from others. Mann-Whitney U test was used to compare two groups, Pokhraira 500m colonies and Karja control, and to see whether 500m could be treated as a low-exposure reference. Statistical significance was set up at $p<0.05$.

Results and Discussions

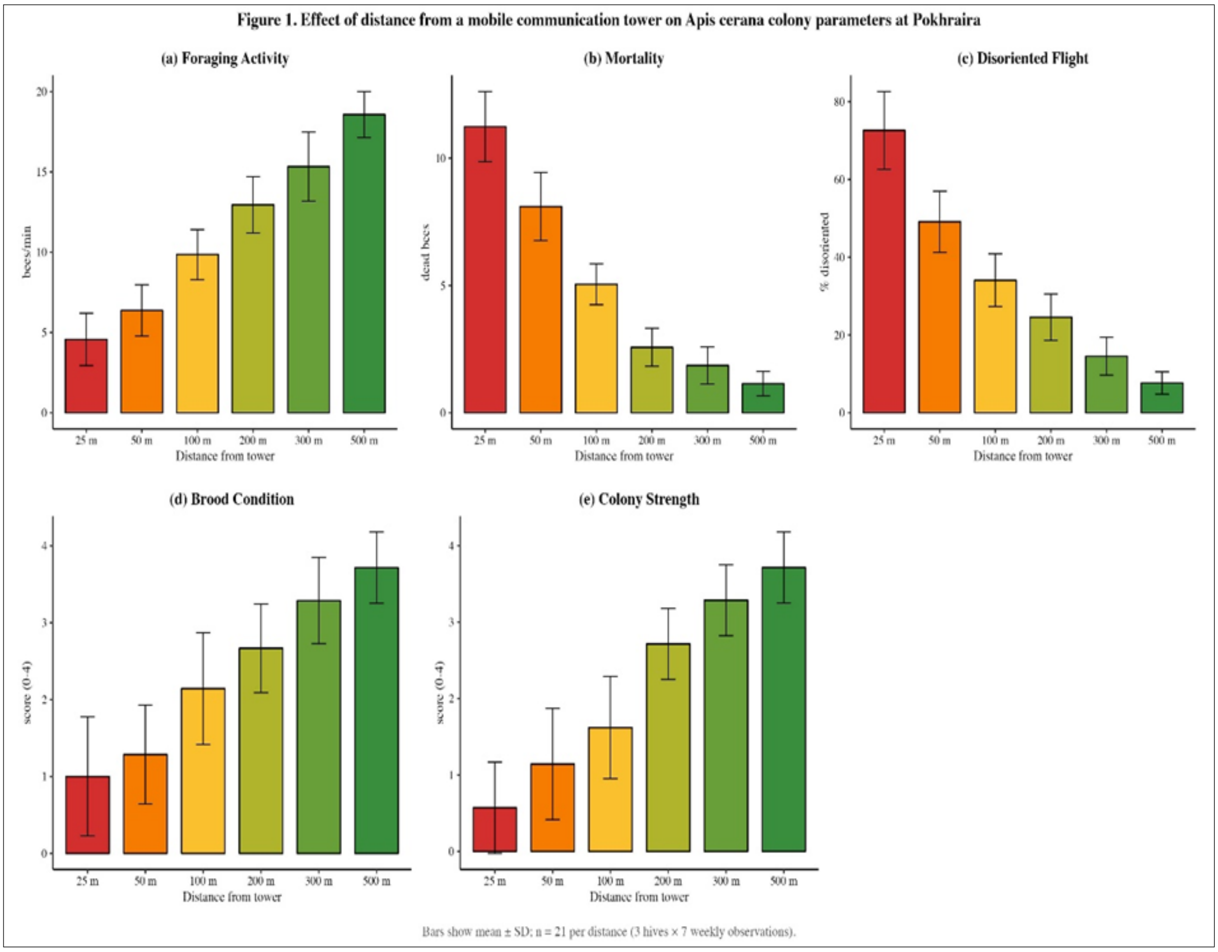
Effect of distance from mobile tower on *Apis cerana* colonies

At Pokhraira, *Apis cerena* colonies showed significant distance-dependent effect from mobile tower. Foraging activity, brood condition and colony strength increased with distance while mortality and disoriented flight decreased. The colonies which were located closest to the tower were mostly affected whereas colonies at 500 m showed similarity to the control colonies.

Table 3: Mean ± SD of five parameters at six distances from the mobile communication tower atPokhraira

Parameter	25 m	50 m	100 m	200 m	300 m	500 m
Foraging Activity (bees/min)	4.57 ± 1.63	6.38 ± 1.60	9.86 ± 1.56	12.95 ± 1.75	15.33 ± 2.15	18.57 ± 1.43
Mortality (dead bees)	11.24 ± 1.37	8.10 ± 1.34	5.05 ± 0.80	2.57 ± 0.75	1.86 ± 0.73	1.14 ± 0.48
Disorientation (%)	72.61 ± 9.99	49.12 ± 7.89	34.08 ± 6.80	24.58 ± 5.93	14.56 ± 4.86	7.68 ± 2.87
Brood Condition (0–4)	1.00 ± 0.77	1.29 ± 0.64	2.14 ± 0.73	2.67 ± 0.58	3.29 ± 0.56	3.71 ± 0.46
Colony Strength (0–4)	0.57 ± 0.60	1.14 ± 0.73	1.62 ± 0.67	2.71 ± 0.46	3.29 ± 0.46	3.71 ± 0.46

n = 21 observations per distance (3 replicate hives × 7 weekly observations). Brood condition and colony strength scored on a 0–4 ordinal scale, with 4 representing the healthiest condition.



Foraging activity at 25 m averaged 4.57 ± 1.63 bees/min, increased approximately fourfold to 18.57 ± 1.43 bees/min at 500 m. Mortality showed an inverse pattern, declining from 11.24 ± 1.37 dead bees at 25 m to 1.14 ± 0.48 at 500m. Disoriented flight, which is the percentage of total returning foragers, decreased from 72.61 ± 9.99% at 25 m to 7.68 ± 2.87% at 500 m. Brood condition and colony strength increased, both showed poor condition (1) near the tower and excellent condition (4) far from the tower.

These distance-dependent effects are similar to recent studies which link RF-EMF exposure to harmful effects on honey bee colonies. Treder *et al*. (2023) [16] showed that RF-EMF exposure disturbs the homing ability of *Apis mellifera* under controlled conditions. molina-Montenegro *et al*. (2023) [8] showed that RF-EMF exposure disturbs pollination of honey bees and alter colony behaviour. Shepherd *et al*. (2019) [10] further showed that even low frequency RF-EMF exposure also have negative effects on honey bees like increased aggression and reduction in aversive learning.

Statistical analysis of distance effects

Spearman rank correlation showed statistically significant relation between distance from the tower and all five parameters (Table 4). Foraging activity, brood condition, and colony strength improved as the distance from the tower increased (ρ = +0.945, +0.856, and +0.896 respectively; all $p < 0.001$), while mortality and disoriented flight decreased as the distance from the tower increased (ρ = −0.954 and −0.964 respectively; both $p < 0.001$). The Kruskal-Wallis test showed significant differences among the six distance groups for every parameter (H ranging from 92.91 to 116.34; all $p < 0.001$), indicating that the observed difference was linked with increasing distance from the tower.

Table 4: Spearman rank correlation and Kruskal-Wallis test results for the relationship between distance from the mobile tower and five colony parameters at Pokhraira

Parameter	Spearman ρ	p-value	Kruskal-Wallis H	df	p-value
Foraging Activity	+0.945	<0.001	112.29	5	<0.001
Mortality	−0.954	<0.001	114.81	5	<0.001
Disorientation (%)	−0.964	<0.001	116.34	5	<0.001
Brood Condition	+0.856	<0.001	92.91	5	<0.001
Colony Strength	+0.896	<0.001	102.43	5	<0.001

n = 126 observations (6 distances × 3 hives × 7 weekly observations). Spearman ρ values close to ±1 indicate near-perfect monotonic relationships.

Thestrong correlationobserved here indicates that the distance from the tower significantly influencehoney bee health and behaviour. The uniformity of the effect across five biologically distinct parameters supports the interpretation of a systemic stressor acting on multiple aspects of colony function. comparable patterns of multi-parameter response to RF-EMR exposure have been noted in previous Indian studies (Sharma and Kumar 2010; Taye *et al*. 2017; Taye *et al*. 2018) [9, 12, 13], though the strength of the dose-response relationship documented here is particularly notable given the shorter distance range examined.

Comparison with off-site tower-free control (Karja)

To validate the use of Pokhraira 500 m hives as a low-exposure reference, all five parameters were compared between the Pokhraira 500 m colonies and the off-site Karja control colonies using the Mann-Whitney *U* test (Table 5). For foraging activity (p = 0.129), brood condition (p = 0.077), and colony strength (p = 0.292), no statistically significant differences were detected between the two reference conditions, supporting the validity of 500 m as a low-exposure reference within the experimental site.

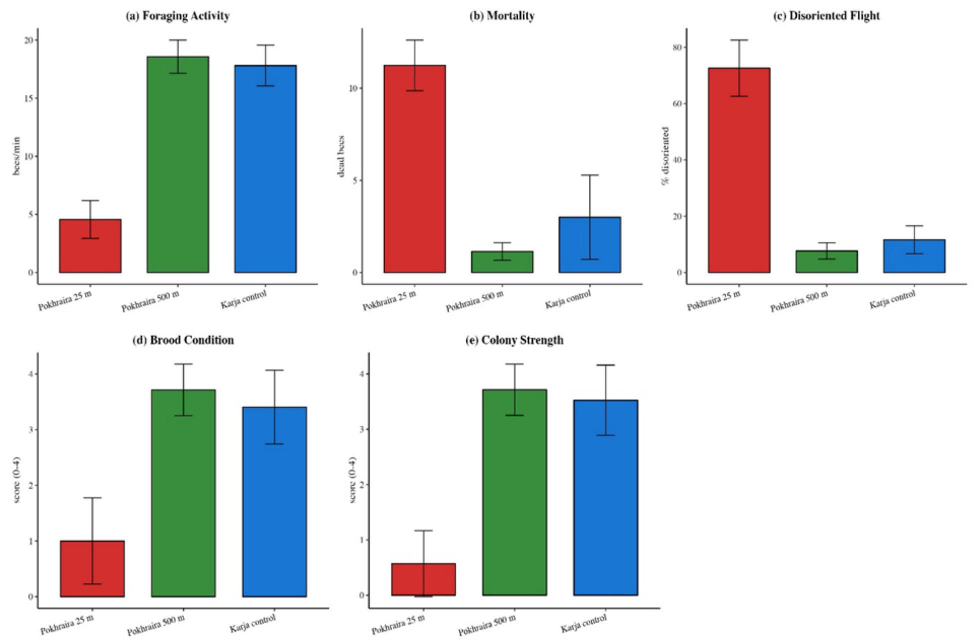
For mortality and disoriented flight, Karja colonies showed slightly higher values than Pokhraira 500 m colonies (p = 0.004 and $p < 0.001$ respectively). However, both reference conditions remained markedly healthier than colonies closest to the tower: Karja mortality (3.00 ± 2.28) was 73% lower than Pokhraira 25 m mortality (11.24 ± 1.37), and Karja disorientation (11.63 ± 4.94%) was 84% lower than Pokhraira 25 m (72.61 ± 9.99%). These differences between Karja and Pokhraira 500 m may be due to factors like beekeeping management practices, environmental conditions, pest pressure, etc.

Table 5: Comparison of five colony parameters between Pokhraira 500 m (within-site reference) and Karja (off-site tower-free control)

Parameter	Pokhraira 500 m (Mean ± SD)	Karja (Mean ± SD)	Mann-Whitney U p-value
Foraging Activity (bees/min)	18.57 ± 1.43	17.81 ± 1.76	0.129
Mortality (dead bees)	1.14 ± 0.48	3.00 ± 2.28	0.004
Disorientation (%)	7.68 ± 2.87	11.63 ± 4.94	<0.001
Brood Condition (0–4)	3.71 ± 0.46	3.40 ± 0.66	0.077
Colony Strength (0–4)	3.71 ± 0.46	3.52 ± 0.63	0.292

n = 21 (Pokhraira 500 m); n = 42 (Karja). Mann-Whitney U test used due to non-normal distribution and small sample sizes.

Figure 2. Comparison of colony parameters between high-exposure (Pokhraira 25 m), within-site reference (Pokhraira 500 m), and off-site control (Karja)



Bars show mean ± SD. Pokhraira 25 m: n = 21; Pokhraira 500 m: n = 21; Karja: n = 42.

The strong distance-dependent effects observed at Pokhraira, the high statistical significance of both correlation and group-comparison tests, and the similarity betweenPokhraira 500m andKarja (control site) indicates that proximity to the mobile tower is linked with measurable adverse effects on *Apis cerana* colony. The two reference groups, Pokhraira 500 m and Karja control, showed better colony performance which indicates that the poor colony performance observed near the tower is mainly due to tower proximity rather than other factors like weather, beekeeping practices, etc.

These findings are important for apiculture and pollinator conservation in India. *Apis cerana* plays an important role in pollination and colony-level declines effects pollination services and crop yield. as mobile communication tower is expanding across rural India, its impact on honey bee population need attention from beekeepers and policy makers. Maintaining hives at some distance from the tower (300-500 m) may reduce direct colony-level stress. However, it may not reduce all possible exposure since foragers fly upto 3 km from the hive. The next step towards research should include direct measurement of electromagnetic radiation, multiple study sites and longer observation period.

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Author contribution statement

BKPS: designed the experiment; Riffat: experimentation and manuscript writing; and BKPS: reviewed and edited the manuscript.

Conflicts of interest

No conflict of interest

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