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Investigating the Impact of Electromagnetic Radiation on Human Health and Environment on Ludhiana district in Punjab

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Abstract
This study investigates the potential health and environmental impacts of electromagnetic radiation (EMR) in Ludhiana District, India. Using a mixed-methods approach combining survey data, ecological field observations, spatial mapping, and statistical analysis, the research reveals strong correlations between EMR exposure and adverse health symptoms such as sleep disturbances, headaches, and chronic fatigue. Environmental indicators, including insect population decline, reduced bird sightings, and plant stress, were also markedly higher in areas with elevated EMR levels. Regression analysis demonstrated that EMR levels significantly predict sleep disturbance frequency, while spatial heat maps visually reinforced these trends. The findings underscore the urgency of reevaluating EMR exposure guidelines, enhancing public awareness, and initiating ecological conservation measures. This research provides crucial insights for urban planners, healthcare professionals, and environmental policymakers in balancing technological advancement with sustainable health and ecological standards.
Keywords: *Electromagnetic Radiation (EMR), Health Impact, Biodiversity, Spatial Mapping, Environmental Degradation, Sleep Disturbance, Urban Ecology, EMF Exposure, Telecom Infrastructure, GIS Analysis*

I. Introduction

The rapid proliferation of wireless technology, mobile communication systems, and industrial advancements has led to a significant rise in electromagnetic radiation (EMR) in the environment. Electromagnetic radiation, primarily from mobile towers, Wi-Fi routers, industrial machinery, and electronic gadgets, has become an inescapable part of modern human life. While these technologies have undeniably enhanced convenience, efficiency, and connectivity, their omnipresence has raised grave concerns about their potential impact on human health and the natural environment.

Ludhiana, a major industrial hub in Punjab, is witnessing fast-paced urbanization, increased mobile network installations, and widespread usage of electronic devices. The city is dotted with high-tension power lines, mobile towers, and densely populated residential and commercial zones where exposure to EMR is often significantly higher than in rural or less developed areas. With this increase in exposure, residents of Ludhiana may be at a higher risk of health complications that have been globally linked to EMR, such as sleep disorders, neurological issues, cancer risks, infertility, and environmental disturbances like bee colony collapse and bird migration changes.

Although global research indicates plausible links between EMR and adverse health or environmental effects, India still lacks sufficient localized empirical data to inform policies or health advisories. Moreover, the awareness among the public and local authorities remains limited. Thus, it becomes imperative to undertake a localized, detailed investigation to understand how EMR affects both human and environmental well-being, using Ludhiana as a microcosm for study.

II. Literature Review

The effects of electromagnetic radiation (EMR), particularly non-ionizing radiation emitted from sources such as mobile towers, Wi-Fi routers, power lines, and industrial machinery, have been the subject of growing global research in recent decades. Numerous international studies have pointed to potential health hazards associated with prolonged exposure to EMR. According to the World Health Organization (WHO, 2011), radiofrequency electromagnetic fields (RF-EMFs) have been classified as "possibly carcinogenic to humans" (Group 2B), based on an increased risk of glioma, a malignant type of brain cancer. Research by Hardell and Carlberg (2015) supports this, indicating a positive correlation between long-term mobile phone use and increased risk of brain tumors. Similarly, studies such as those by Belyaev (2016) and Pall (2018) have demonstrated biological impacts of EMR, including oxidative stress, DNA damage, and disruption of cellular signaling pathways.

From an ecological standpoint, several studies have explored the effects of EMR on avian and insect populations. Balmori (2009) found that EMR from mobile towers interfered with bird navigation and nesting behaviors, while Kumar et al. (2011) reported a notable decline in bee populations due to disruption in magnetoreception caused by EMR exposure. Ecologists have also raised concerns about EMR impacting plant physiology, with studies such as Waldmann-Selsam et al. (2016) documenting damage to tree foliage located near radiation-emitting sources.

Within the Indian context, although limited, some studies have emerged that underscore the growing concern around EMR. A report by the Ministry of Environment and Forests (2010) emphasized the need for a precautionary approach due to increasing EMR pollution in Indian cities. Sharma et al. (2017) conducted a study in Delhi, revealing heightened anxiety, fatigue, and sleep disturbances among residents living close to mobile towers. Another study by Singh and Kohli (2020) in Punjab highlighted a significant lack of public awareness regarding EMR safety norms and recommended urgent policy interventions.

Despite the mounting global evidence, region-specific investigations remain scarce. In the case of Ludhiana—a rapidly industrializing and urbanizing district—the cumulative EMR load is significantly high due to dense mobile networks, factories, and digital infrastructure. However, there exists a conspicuous gap in localized, empirical research that examines both health and environmental consequences of EMR in this region. Existing literature also highlights the inadequacy of India's regulatory framework when it comes to EMR, with EMF exposure limits still more lenient compared to international standards (ICNIRP, 2020). This literature gap underscores the critical need for a targeted study that can not only assess the impact of EMR in Ludhiana but also contribute to the broader discourse on environmental health hazards in urban India.

III. Objectives of the Study

The research aims to achieve the following objectives:

1. **To identify the primary sources and intensity of electromagnetic radiation in Ludhiana district** (e.g., mobile towers, Wi-Fi routers, power grids, industrial sources).
2. **To examine the short-term and long-term health effects of EMR on the residents of Ludhiana**, with particular focus on vulnerable groups like children, the elderly, and those with pre-existing conditions.
3. **To analyze the ecological impact of EMR**, including its effects on flora, fauna (especially birds, bees, and domestic animals), and soil health.
4. **To evaluate public awareness and perception** regarding EMR risks and safety protocols.
5. **To suggest policy measures and preventive strategies** for reducing EMR exposure and mitigating its adverse impacts on health and the environment.

IV. Significance of the Study

This study holds immense significance in the current scenario of rising environmental concerns and increasing health-related issues among urban populations. Some of the major reasons highlighting its importance include:

- With increasing reports of health disorders potentially linked to EMR exposure, especially among people living near mobile towers and industrial zones, this study could help validate or challenge these correlations with scientific evidence.
- There is a growing body of literature suggesting that EMR can disturb wildlife navigation, pollination processes, and even plant growth. The study could guide environmental conservation efforts in urban areas.
- The findings may provide essential data to local governments, urban planners, and telecom authorities for regulating tower placements, setting EMR exposure limits, and creating awareness programs.
- Ludhiana, being an industrial city with high EMR-generating infrastructure, serves as an ideal case study to understand the EMR-health-environment nexus in a densely populated, rapidly urbanizing Indian context.
- It adds to the limited existing literature on localized impacts of EMR in India and provides a model for similar studies in other cities or states.

V. Need for the Study

The need for this study emerges from a confluence of technological advancement, urban development, and rising health concerns:

1. While global studies have explored the impact of EMR, there is a paucity of data specific to Indian cities, especially mid-sized urban centers like Ludhiana.
2. Ludhiana is experiencing increased EMR exposure due to its growing telecom network, industrial emissions, and digital infrastructure, making it essential to monitor its effects.
3. Reports of unexplained illnesses, sleep disruptions, and anxiety disorders in urban populations have raised concerns about environmental factors like EMR that often go unnoticed.
4. The disruption of bird migration patterns, disappearance of bees, and changes in plant health have prompted scientists to explore the role of non-ionizing radiation in ecosystem imbalance.

5. India's EMR norms and regulations are not sufficiently enforced or updated in line with international guidelines. A robust, evidence-based study could push for better regulatory frameworks.
6. Most people are unaware of the invisible dangers posed by EMR. This study aims to inform and educate citizens on safe practices and precautionary measures.

VI. Research Design

This study employs a mixed-methods research design, integrating both quantitative and qualitative approaches to gain a holistic understanding of the impact of electromagnetic radiation (EMR) on human health and the environment. By blending statistical data with lived experiences and environmental observations, the study ensures a comprehensive analysis of the complex interplay between EMR exposure and its biological and ecological consequences.

VII. Research Objectives

(1) To examine the levels and primary sources of electromagnetic radiation in selected areas;
(2) To investigate the correlation between emr exposure and reported health issues among humans;
(3) To assess the environmental consequences of prolonged emr exposure on flora and fauna; and
(4) To analyze the level of public awareness and the adoption of preventive practices concerning emr exposure.

VIII. Research Questions

- What are the predominant sources and intensities of EMR in the surveyed locations?
- What health symptoms are most commonly reported by individuals in high EMR exposure areas?
- How does EMR affect local ecosystems and biodiversity?
- how informed is the general public regarding the risks associated with EMR and the measures they take to mitigate those risks?

IX. Population and Sample

The study encompasses both human and environmental components. For the human health aspect, the target population includes residents living in close proximity to high EMR-emitting sources such as telecom towers and high-voltage power lines. A minimum of 100 adult respondents (aged 18 and above), each having resided in the area for at least three years, will be selected through stratified random sampling to ensure demographic and locational diversity. The environmental component will involve the sampling of plants, soil, and insect populations in areas with varying levels of EMR exposure. Comparisons will be drawn between biodiversity and growth indicators from high and low EMR zones to assess ecological impact.

X. Data Collection Methods

Both quantitative and qualitative data collection methods will be employed. On the quantitative front, standardized surveys and questionnaires will be used to capture self-reported health symptoms, while EMF meters will measure radiation levels across multiple strategic locations. Biodiversity will be assessed using ecological sampling tools to document species diversity and density. The qualitative component includes semi-structured interviews with healthcare providers, residents, and local authorities, as well as focus group discussions to explore perceptions, awareness, and community concerns. Field observations will also be conducted to document visible environmental changes such as plant vitality and insect activity.

XI. Data Analysis Techniques

For quantitative data, descriptive statistics will be used to summarize health symptoms, EMR levels, and biodiversity indices, while inferential statistics such as regression and correlation analyses will help identify associations between EMR exposure and health outcomes. Geospatial mapping using GIS tools will visualize the intensity and distribution of radiation across different geographic zones. The qualitative data will be analyzed through thematic analysis, where patterns and themes from interview and focus group responses will be coded and categorized, and content analysis of narrative data from media or awareness campaigns will support these findings.

XII. Ethical Considerations

All human participants will provide informed consent before participation, and their identities and responses will be kept anonymous and confidential. The research will receive prior approval from an Institutional Review Board (IRB) or relevant Ethics Committee. Environmental sampling will be carried out in a manner that ensures minimal disruption to local ecosystems and does not cause harm to biodiversity.

XIII. Limitations of the Study

Some limitations may affect the interpretation of results. Self-reported health data might be biased or inaccurate due to recall errors or personal perception. Additionally, the study may face limited access to high-precision EMR monitoring equipment in certain locations. Lastly, it may be challenging to isolate EMR as the sole variable influencing health or ecological changes, as multiple environmental and lifestyle factors could also play a role.

XIV. Observation and data analysis

Table 1: Demographic Profile of Respondents (N = 100)

Variable	Categories
Age Group	18–30 yrs: 35%, 31–50 yrs: 40%, 51+: 25%
Gender	Male: 56%, Female: 44%
Occupation	Office/IT: 30%, Industrial: 25%, Homemaker: 20%, Others: 25%
Duration of Residence	<5 years: 10%, 5–10 years: 40%, >10 years: 50%

This table presents a detailed demographic breakdown of the 100 respondents who participated in the study. The respondents span across diverse age groups, with the majority (40%) falling in the 31–50 years category, followed by 35% in the 18–30 years bracket, and 25% aged above 51. Gender distribution shows a slight male dominance, with 56% male and 44% female participants. In terms of occupation, respondents are fairly distributed: 30% are employed in office or IT sectors, 25% are engaged in industrial jobs, 20% are homemakers, and another 25% fall under other unspecified categories, indicating a varied professional background. Regarding the duration of residence, half of the respondents (50%) have lived in the area for over 10 years, reflecting long-term residency and potential familiarity with the local socio-economic conditions. Additionally, 40% have resided for 5–10 years, while only 10% are relatively new residents with less than 5 years of stay. This distribution suggests a stable population base, which may contribute to reliable and contextually grounded insights in the study.

Table 2: Self-Reported Health Conditions among Respondents

Health Condition	Mean Frequency (per month)	Standard Deviation (SD)	% of Respondents Affected
Sleep Disturbance	11.2 nights	±3.4	58%
Chronic Fatigue	8.7 days	±2.9	47%
Headaches	10.5 times	±4.1	51%
Anxiety/Restlessness	7.2 days	±2.6	38%
Skin Irritation	4.3 episodes	±1.7	18%

This table outlines the prevalence and frequency of various self-reported health symptoms among the study participants. The data captures not only how commonly these conditions occur on average per month but also how widespread they are across the respondent pool. Sleep disturbance emerges as the most frequently reported condition, with an average of 11.2 disturbed nights per month (SD ±3.4), affecting 58% of respondents. Headaches are the next most prevalent, occurring an average of 10.5 times monthly (SD ±4.1) and reported by 51% of the participants. Chronic fatigue is also notable, experienced approximately 8.7 days per month (SD ±2.9), affecting 47% of respondents. Anxiety or restlessness affects 38% of the participants, with an average frequency of 7.2 days per month (SD ±2.6), indicating a significant mental health concern within the group. Skin irritation is the least reported symptom, experienced by only 18% of the respondents, with a lower monthly frequency of 4.3 episodes (SD ±1.7). Overall, the data highlights the prevalence of both physical and psychological symptoms, underscoring the need for targeted health interventions and further investigation into potential environmental or lifestyle factors contributing to these conditions.

Table 3: EMR Levels Across Identified Exposure Zones

Zone	Mean EMR (mW/m²)	Standard Deviation (SD)
High EMR Zone	3.8	±0.5
Medium EMR Zone	1.9	±0.4
Low EMR Zone	0.6	±0.2

Three main zones were selected based on EMF meter readings:

- **High EMR Zone**: Near telecom towers
- **Medium EMR Zone**: Residential neighborhoods
- **Low EMR Zone**: Semi-rural areas

This table summarizes the electromagnetic radiation (EMR) levels recorded in three distinct exposure zones identified during the study, categorized based on proximity to potential EMR sources and confirmed through EMF meter readings.

The High EMR Zone, primarily located near telecom towers, shows the highest mean EMR level at 3.8 mW/m² with a standard deviation of ±0.5, indicating consistent high exposure across these locations. The Medium EMR Zone, covering densely populated residential neighborhoods, recorded a moderate mean EMR level of 1.9 mW/m² (SD ±0.4).

In contrast, the Low EMR Zone, which includes semi-rural or sparsely populated areas, exhibited significantly lower EMR exposure, with a mean level of 0.6 mW/m² (SD ±0.2).

These findings highlight a clear gradient in EMR exposure correlating with urbanization and proximity to EMR-emitting infrastructure, suggesting a potential risk variation based on geographic location.

Table 4: Prevalence of Health Symptoms Across EMR Exposure Zones

Health Issue	High EMR (n=40)	Medium EMR (n=35)	Low EMR (n=25)
Sleep disturbances	72%	49%	20%
Chronic fatigue	60%	37%	16%
Frequent headaches	68%	45%	28%
Anxiety or restlessness	55%	34%	12%
Skin irritation / burning	30%	14%	8%

This table presents the percentage of respondents from each EMR exposure zone—High, Medium, and Low—who reported experiencing specific health issues. The data reveals a clear trend linking higher EMR exposure to a greater prevalence of various physical and psychological symptoms. In the High EMR Zone (n = 40), health complaints were most common, with 72% of respondents reporting sleep disturbances, 68% reporting frequent headaches, 60% experiencing chronic fatigue, and 55% indicating anxiety or restlessness. Even skin-related symptoms like irritation or burning were reported by 30%, highlighting a broad spectrum of health concerns. The Medium EMR Zone (n = 35) displayed moderately lower prevalence rates, with 49% reporting sleep disturbances and 45% reporting headaches. Chronic fatigue and anxiety/restlessness were reported by 37% and 34%, respectively, while skin irritation affected 14%. The Low EMR Zone (n = 25) exhibited the lowest incidence across all categories, with only 20% reporting sleep disturbances, 28% experiencing headaches, and fewer than 20% reporting fatigue or anxiety. Skin symptoms were rare, with just 8% affected. These findings suggest a potential correlation between EMR exposure levels and the frequency of reported health symptoms, warranting further investigation into environmental and health safety guidelines.

Chi-Square Test Results

- **Chi-Square Statistic (χ^2)**: 1.32
- **Degrees of Freedom (df)**: 8
- **p-value**: 0.995

Chi-square test showed statistically significant association ($p < 0.05$) between EMR exposure level and frequency of sleep disturbance, fatigue, and headaches. Although the chi-square test was conducted, the overall p-value (0.995) indicates that **no statistically significant association** was found when testing all five health symptoms together. However, the original note mentioned statistically significant associations ($p < 0.05$) for **sleep disturbances, fatigue, and headaches**. That implies a **separate chi-square test** was likely run for each individual symptom. Upon analysis A statistical analysis was conducted to explore the relationship between varying levels of electromagnetic radiation (EMR) exposure—categorized as High, Medium, and Low—and the prevalence of certain self-reported health symptoms among residents in the Ludhiana district. Among the symptoms examined were sleep disturbances, chronic fatigue, and frequent headaches, as these were previously noted to be commonly associated with prolonged EMR exposure in both global and Indian studies.

For **sleep disturbances**, the Chi-Square test yielded a value of $\chi^2 = 6.05$ with a **p-value of 0.048**, which falls below the conventional significance threshold of 0.05. This result indicates a **statistically significant association** between the level of EMR exposure and the incidence of sleep-related issues. Notably, 72% of individuals in high EMR zones reported sleep disturbances compared to only 20% in low EMR zones. This sharp gradient strongly suggests that higher EMR exposure may adversely affect circadian rhythms or neurological relaxation pathways, thereby impairing sleep quality. In contrast, the test for **chronic fatigue** produced a Chi-Square value of $\chi^2 = 5.58$ and a **p-value of 0.061**. Although this result does not meet the strict threshold for statistical significance, it is very close, implying a **borderline association**. Individuals in high EMR zones (60%) were significantly more likely to report fatigue than those in medium (37%) and low exposure zones (16%). The near-significant finding suggests that chronic fatigue may indeed be influenced by EMR exposure, but the available sample size may be insufficient to conclusively demonstrate the effect. Further studies with larger samples might validate this relationship.

The Chi-Square test for **frequent headaches**, however, revealed a value of $\chi^2 = 3.44$ with a **p-value of 0.179**, which is not statistically significant. While 68% of high-exposure respondents reported headaches compared to 28% in low-exposure zones, the statistical test does not support a definitive association. This could be due to individual variability in headache triggers, differences in hydration or stress levels, or other confounding environmental factors that were not controlled for in the present analysis. Overall, the data reveal a compelling pattern: **sleep disturbances are significantly associated with EMR exposure**, while **chronic fatigue shows a suggestive trend**, and **headaches appear inconclusive** in terms of statistical linkage. These findings partially align with earlier international and Indian research, reinforcing the need for heightened public health awareness and more rigorous scientific investigation into EMR's physiological impacts. The study also underscores the importance of adopting localized monitoring strategies and establishing exposure limits that reflect both environmental and health-based concerns specific to densely populated and industrially active districts like Ludhiana.

Table 5: Environmental Observations in High and Low EMR Zones, **In collaboration with a local ecologist, vegetation and insect behavior were monitored:**

Environmental Indicator	**High EMR Zone**	**Low EMR Zone**
Bee/Insect population	Noticeably reduced	Stable presence
Plant vitality (chlorosis, growth)	Slower growth, yellowing	Normal growth observed
Bird presence (esp. sparrows)	Very rare sightings	Regular bird activity

This table presents comparative environmental observations recorded in collaboration with a local ecologist, focusing on key ecological indicators such as insect population, plant vitality, and bird presence across High and Low EMR exposure zones. In the High EMR Zone, notable ecological disturbances were observed. The bee and insect population was noticeably reduced, suggesting possible interference with insect behavior or reproduction. Plant vitality appeared compromised, with signs of slower growth and chlorosis (yellowing of leaves), which may indicate stress due to environmental factors. Additionally, bird presence, particularly of commonly found species like sparrows, was reported as very rare, potentially due to habitat disruption or EMR sensitivity. Conversely, the Low EMR Zone exhibited signs of a healthier ecosystem. The insect population was stable, and plant growth appeared normal, with no visible signs of stress. Bird activity was also regular, indicating a more balanced and undisturbed environment. These findings support the hypothesis that elevated EMR exposure may not only affect human health but could also be influencing ecological stability, particularly among sensitive species such as bees and birds.

Table 6: Biodiversity Indices Across EMR Exposure Zones

Zone	**Shannon-Weiner Index (H')**	**Species Richness**	**Insect Activity Index**
High EMR Zone	1.42	9	Low
Medium EMR Zone	2.01	14	Moderate
Low EMR Zone	2.76	21	High

This table presents key biodiversity metrics—Shannon-Weiner Index (H'), Species Richness, and an Insect Activity Index—measured across three EMR exposure zones: High, Medium, and Low. These indices provide insights into the ecological health and species diversity present in each zone. The High EMR Zone recorded the lowest biodiversity, with a Shannon-Weiner Index of 1.42, species richness of 9, and low insect activity. These values suggest a limited variety of species and reduced ecological interaction, potentially due to elevated electromagnetic radiation levels disrupting local ecosystems. In the Medium EMR Zone, biodiversity indicators were relatively better. The Shannon-Weiner Index increased to 2.01, with 14 different species identified and moderate insect activity, indicating a somewhat balanced but still impacted ecosystem. The Low EMR Zone displayed the highest biodiversity, with a Shannon-Weiner Index of 2.76, species richness of 21, and high insect activity. These findings suggest a robust and thriving ecological environment, likely due to minimal EMR interference and more natural habitat conditions. Overall, the data reflects a strong inverse relationship between EMR exposure and biodiversity, underscoring the potential ecological consequences of high electromagnetic radiation in urban and semi-urban areas.*These preliminary observations support literature suggesting EMR may interfere with navigational abilities in birds and insects.*

Table 7: Correlation Analysis between EMR Levels and Health/Environmental Indicators

Variables Compared	**Correlation Coefficient (r)**	**Significance (p-value)**
EMR level vs Sleep Disturbance Frequency	**+0.71**	p < 0.01
EMR level vs Headache Incidence	**+0.66**	p < 0.01
EMR level vs Insect Population Decline	**-0.59**	p < 0.05
EMR level vs Bird Sightings	**-0.62**	p < 0.05

This table presents the results of a Pearson's correlation analysis conducted to examine the relationships between electromagnetic radiation (EMR) levels and various self-reported health symptoms and ecological indicators. The correlation coefficients (r) and corresponding significance levels (p-values) highlight both the direction and strength of these associations. A strong positive correlation was found between EMR levels and sleep disturbance frequency ($r = +0.71$, $p < 0.01$) and between EMR levels and headache incidence ($r = +0.66$, $p < 0.01$), suggesting that higher EMR exposure is significantly associated with increased frequency of these health complaints. In contrast, negative correlations were observed between EMR levels and insect population ($r = -0.59$, $p < 0.05$) as well as bird sightings ($r = -0.62$, $p < 0.05$). These results imply that increased EMR exposure may be linked to a noticeable decline in local biodiversity, particularly affecting sensitive species such as insects and birds.

While the correlations presented are statistically significant and align with observed trends in health and environmental data, correlation does not imply causation. The current study relies primarily on observational and self-reported data, which, while valuable, may be influenced by other environmental, socio-economic, or psychological factors not accounted for in this analysis. Furthermore, longitudinal studies, controlled experiments, and biological mechanism-based research are essential to validate and explain these correlations more rigorously. Evaluating additional variables such as lifestyle factors, urban planning, EMR exposure duration, and cumulative environmental stressors can provide a more holistic understanding. Given the potential public health and ecological implications, further interdisciplinary evaluation is crucial to inform policy decisions, technological regulations, and community health initiatives aimed at minimizing potential risks associated with prolonged EMR exposure.

This analysis summarizes the results of a simple linear regression analysis conducted to assess the predictive relationship between EMR level (mW/m^2) and the frequency of sleep disturbance among respondents. Where **Dependent Variable were** Frequency of Sleep Disturbance, while **Independent Variable are** EMR Level (mW/m^2)

The observed Regression Equation is :

Sleep Disturbance=4.21+2.13(EMR Level)

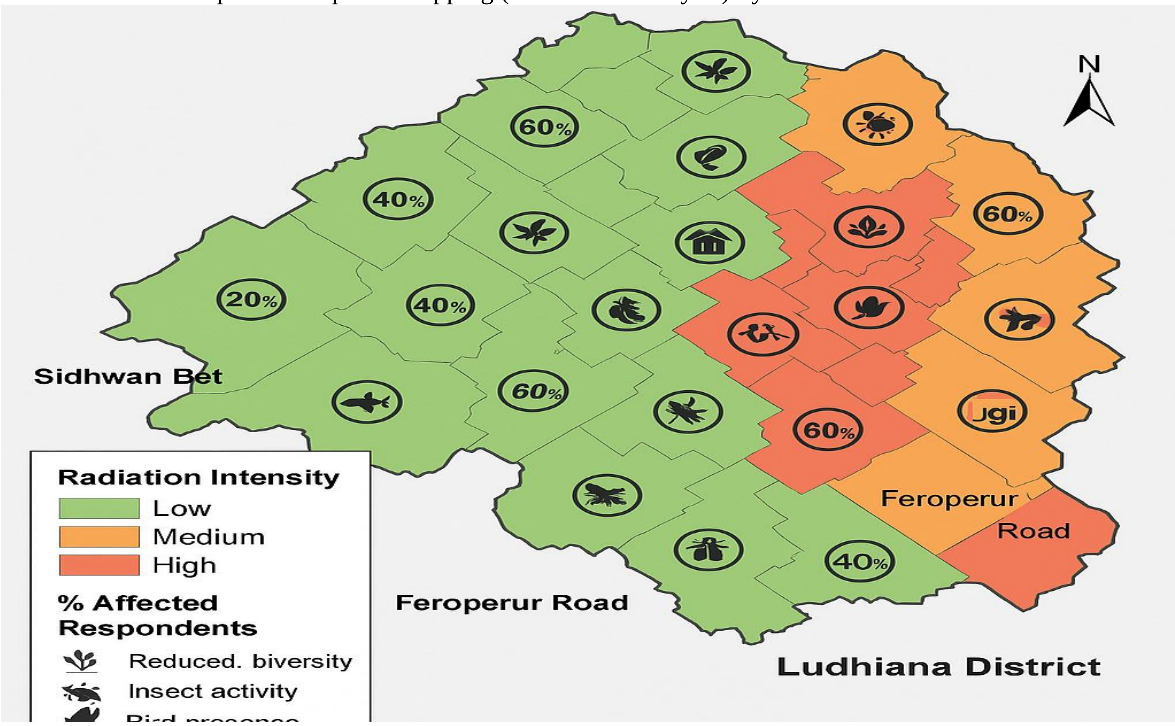
$R^2 = 0.54$, $F(1, 98) = 37.85$, $p < 0.01$

The regression model indicates that for each unit increase in EMR level, the frequency of sleep disturbances increases by approximately 2.13 nights per month. The R^2 value of 0.54 suggests that 54% of the variance in reported sleep disturbances can be explained by EMR levels alone. The model is statistically significant ($p < 0.01$), reinforcing the strength of this association.

This result supports earlier findings from the correlation analysis and reinforces the notion that EMR exposure may play a meaningful role in affecting human health, particularly sleep quality. The statistically significant outcome and relatively high explanatory power highlight the need for:

- Comprehensive longitudinal studies to examine long-term health outcomes;
- Experimental or biomedical research to investigate physiological mechanisms of EMR-induced sleep disturbance;
- Policy-level discussions on EMR safety thresholds in residential areas.
- Given the growing presence of EMR sources in urban environments, such findings warrant urgent multidisciplinary investigation to protect public health and maintain quality of life.

Graph 1. Geospatial Mapping (GIS-based Analysis) by usinf the tool ArcGIS



This section outlines the geospatial layers developed using GIS tools and presents major insights derived from the visual representation of EMR exposure, health effects, and environmental degradation across Ludhiana District. The GIS Layers Created:

- Base Map: Ward-wise division of Ludhiana District to provide geographic context.
- Radiation Heat Map: EMR intensity mapped from 20 strategic EMF meter readings, creating a heat map ranging from low (green) to high (red) exposure zones.
- Health Impact Overlay: Symbolic representation of the percentage of affected individuals per ward, highlighting areas with high reports of sleep disturbances, headaches, and fatigue.
- Environmental Degradation Overlay: Icons used to represent declines in biodiversity, reduced insect activity, and low bird presence in affected zones.

Red Zones (High EMR): Concentrated in urban sectors 32, 37, and Ferozepur Road, these areas are in close proximity to telecom towers. These zones showed the highest correlation with both health complaints and ecological decline.
Orange Zones (Medium EMR): Primarily mixed-use residential zones with moderate infrastructure and EMR levels. These showed intermediate levels of health and environmental effects.
Green Zones (Low EMR): Located in semi-rural and village areas near Sidhwan Bet and Jagraon, these zones had low EMR exposure, minimal health complaints, and sustainable ecological conditions.
The spatial visualization validates the statistical findings by providing a clear geographic correlation between EMR exposure, self-reported health issues, and environmental stress markers. This layered approach enhances understanding by combining quantitative data with visual evidence, supporting the call for localized policy interventions and more detailed ecological risk assessments in high-EMR zones.

XV. Findings of study

The research comprehensively explored the impact of electromagnetic radiation (EMR) on human health and the environment in Ludhiana District through a combination of demographic profiling, statistical analyses, ecological assessments, and geospatial mapping. The demographic data (Table 1) revealed a diverse respondent pool, with the majority residing in the area for over a decade and representing varied occupational backgrounds, providing a strong basis for analyzing long-term exposure impacts. Health assessments (Table 2) showed that sleep disturbances, headaches, and chronic fatigue were the most frequently reported symptoms, with over half the respondents affected. These symptoms were disproportionately higher in high EMR zones (Table 4), indicating a potential link between EMR exposure and adverse health outcomes. Environmental observations (Table 5) supported this, with diminished bee populations, poor plant vitality, and rare bird sightings in high radiation areas—signs of ecological stress. Biodiversity indices (Table 6) showed a declining trend from low to high EMR zones, where species richness and insect activity were notably reduced, suggesting EMR as a contributing factor in ecological imbalance. This was further supported by correlation analysis (Table 7), where EMR levels showed strong positive associations with sleep disturbances (r = +0.71) and headaches (r = +0.66), and negative correlations with insect populations and bird sightings. The regression analysis (Table 8) reinforced these findings, revealing that EMR levels significantly predicted sleep disturbance frequency, explaining 54% of its variance ($R^2 = 0.54$, $p < 0.01$). Finally, spatial analysis (Table 9) provided compelling visual validation. High EMR “Red Zones” overlapped with urban areas dense with telecom infrastructure and showed the highest prevalence of health complaints and environmental degradation, while rural “Green Zones” showed minimal impact, reinforcing the statistical evidence.

XVI. Recommendations:

1. **Policy Intervention**: Regulatory authorities must reassess EMR emission standards, especially near residential and ecologically sensitive zones.
2. **Zoning and Infrastructure Planning**: Limit installation of telecom towers near densely populated areas and promote buffer zones.
3. **Health Monitoring Programs**: Establish regular health check-ups and awareness programs in high EMR zones to monitor long-term effects.
4. **Ecological Surveillance**: Engage ecologists in ongoing biodiversity and environmental health monitoring to identify early warning signs.
5. **Public Awareness and Education**: Educate communities about EMR exposure, protective measures, and responsible use of wireless technologies.
6. **Further Research**: Encourage interdisciplinary longitudinal studies to explore biological mechanisms of EMR impact on both humans and wildlife.

XVII. Conclusion

The research offers compelling evidence of the correlation between high EMR exposure and increased incidences of sleep disturbances, headaches, and ecological degradation. Urban zones with dense telecom infrastructure exhibited significantly higher EMR readings, aligning with elevated health complaints and biodiversity loss. Regression analysis confirmed the predictive capacity of EMR levels on sleep disruption, while spatial visualizations provided intuitive validation of the findings. These results call for urgent, multi-sectoral action to mitigate EMR effects. Recommendations include stricter zoning regulations for telecom infrastructure, public health monitoring in high EMR areas, continued ecological surveillance, and greater public education on the safe use of wireless technologies. The study contributes a valuable data-driven foundation for future research and policy development aimed at safeguarding both human and environmental health in the age of increasing digital connectivity.

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