

Thermal Impact of Chronic Exposure to High-Frequency Non-ionizing EM Radiation on Avian Skin: A Theoretical Approach

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The manuscript reveals that the high-frequency electromagnetic radiations emitted from transmission towers affect birds' health. As the number of mobile phones is increasing rapidly, this radiation is present almost everywhere in the environment. This study uses a theoretical model based on Maxwell's equations to evaluate the thermal effects of electromagnetic radiation (EMR) of 3.5 GHz to 5.5 GHz frequency on avian skin. When birds fly from 1 to 10 m around a mobile phone tower, the electric field intensity is decreased by 90%. The results of the Specific Absorption Rate (SAR) inside the skin of avian show that its value is directly proportional to the frequency of the incident electromagnetic wave. The change in temperature in the skin tissue is calculated for the electromagnetic wave exposure duration of 1 to 15 min. At a frequency of 5.5 GHz and 1 m from a transmission source, the SAR reached 27.65 W/kg, and the skin temperature increased by up to 7.11°C after 15 min of exposure, indicating significant bioeffects. This study aids in the protection of birds by evaluating the thermal effects of electromagnetic radiation exposure and contributes to establishing safer exposure limits.

Keywords: Electric Field, Epidermis of Bird's skin, Electromagnetic waves, Frequency, Specific Absorption Rate (SAR), Thermal effect

1 Introduction

In the current era, mobile phones have become an indispensable part of daily life. We cannot imagine our lives without cell phones. According to our requirements, the number of mobile phone towers has increased in the last two decades. Many studies show that as the number of mobile towers increased, the population of birds decreased gradually¹⁻³. The electromagnetic (EM) field generated from the high-frequency electromagnetic radiations (EMR) directly affects the brain of birds, due to which birds lose their ability to navigate⁴. The high-frequency EM radiations refer to radio waves ranging from 3 Hz to 300 GHz. In this manuscript, we studied the effects of high-frequency non-ionizing electromagnetic waves on the epidermis layer of birds. In this study, high-frequency EM radiations are defined as radiation in the 3.5 GHz to 5.5 GHz range, particularly used in 5G communication. The epidermis is the outer surface of a bird's skin. Due to the lightweight and thinner skin layers as compared to humans, birds are also susceptible to EM radiation. As the electromagnetic waves radiated from the mobile phone towers affect human beings, the radiations also affect the birds⁵.

When radiation strikes the bird's body, an electric field is induced within the body. Consequently, the body absorbs the radiation. The energy absorption of radiation varies across different body parts, depending on the frequency of the incident radiation. If the energy absorption becomes excessively high, it poses a health hazard to birds. In this manuscript, the Specific Absorption Rate (SAR) is calculated to find out the absorption of energy per unit mass inside the bird's body. The growth in the source of EM radiation, such as mobile phone towers, has raised concerns about its environmental impact on avian species. The electromagnetic radiations emitted by mobile towers also disrupt biological processes such as reproduction and feeding behaviors of birds, interfering with the navigational abilities of birds⁷. A survey was conducted on the avifaunal diversity from January 2022 to December 2022 in the urban area of the Aligarh region. This survey exposed that the avifaunal species experience various harmful health effects, such as changes in behavior, distorted breeding, feeding, and migration rates⁸. The long-term exposure to high-frequency EM waves can be the cause of oxidative stress within cells, leading to potential tissue damage and continuous health issues. The impacts of EM waves are not the same on all the organs of the birds,

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but they vary with the electrical properties, such as conductivity and permittivity, of the tissues. These effects are magnified for birds nesting or perching close to mobile towers. This frequency band was selected based on typical operating conditions of communication systems and regulatory standards, ensuring relevance to real-world scenarios. The effects of electromagnetic rays on a bird's skin at different distances from the tower are calculated. Calculating temperature rise in the birds' skin through SAR analysis is a novel approach rarely addressed in existing research. This research highlights the need for regulatory bodies to mitigate the environmental impact of mobile telecommunications infrastructure.

2 Review of Literature

The radio frequency (RF) radiation may harm living organisms like avian just like human beings. When these waves penetrate inside the bird's skin, they affect internal organs and tissues. When the bird flies in the area where mobile towers are present, they are highly affected by these radiations⁹. Radio frequency waves affect the bird's skull, which distracts them from finding their path to fly. The magnetic field produced by electromagnetic waves affects the brain of the birds, which can cause the death of birds^{10,11}. Birds are very sensitive to electric and magnetic field radiation. When birds come across the region of the electric field generated from the electromagnetic waves, some part of the field penetrates inside the outer layer of the avian's body, due to which a voltage drop across the tissues and cells occurs. As a result, some stress is developed inside the bird's skin. This stress may cause many diseases in the birds. The EMR damages the eggs and embryos of birds. It has also been observed that due to the effects of EM waves, the plumage of birds gets discolored. The discoloration of the plumage is the main symptom of illness and stress in birds¹². As a result, the electromagnetic radiation is very harmful to the birds, so we have to take this matter very seriously. As per some researchers, mobile phones should be used for the lowest possible time. Also, make sure that the EM frequency range that we are using is within the permissible limit. The prolonged exposure to high-frequency EM fields can damage the immune system of birds, which can make them more susceptible to diseases¹³. This weakened immune response may accelerate the decline in bird populations in densely populated areas of mobile phone towers. The thermal effects of EM radiation

can cause stress in birds, specifically smaller species with lower body mass. The thermal change in the body of birds due to the EM radiation for various periods of exposure time has also been calculated. Some studies have indicated that electromagnetic exposure can induce oxidative stress in birds. Which can result in the generation of free radicals. These free radicals can cause cellular damage and impair vital functions¹⁴. The navigational ability of birds depends on the Earth's magnetic field, which is strongly disrupted by the artificial magnetic field produced by the EM sources¹⁵. This disorientation affects the migration patterns, breeding cycles and survival rates of birds. It is discussed in a previous study that further research is required to identify the specific frequencies and durations of exposure of non-ionizing electromagnetic fields on the environment and wildlife, including birds¹⁶. This suggestion is addressed in this manuscript. The thermal effect in the skin tissue for the chronic exposure of up to 15 minutes is calculated in this study. The chronic exposure is defined as long-term exposure of EM radiation, typically in the context of environmental exposure scenarios. In this manuscript, the effects of EM fields are analyzed using specific theoretical approaches.

3 Materials and Methods

To assess the biological effects of electromagnetic radiation on birds, theoretical calculations were conducted based on exposure levels near mobile phone transmission towers. We are considering the tower as a point source, and spherical radiations are emitted from it. Figure 1 shows the distribution of the electric field from a point source. The spherical radiation becomes plane after a particular distance is covered.

When a bird sits near the transmission tower of the mobile phone, it will come under the influence of the field surrounding the transmission tower due to EMR. The field (E_0) around the tower is determined by

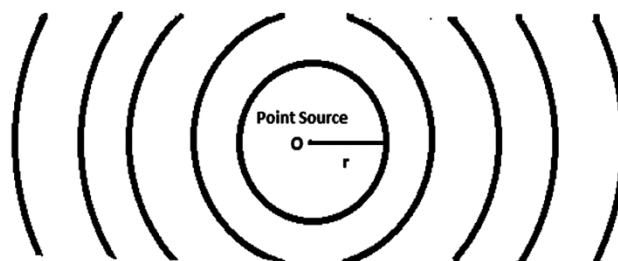


Fig. 1 — Emission of electromagnetic waves from the point source

$$E_0 = 7.74 \frac{\sqrt{P}}{x} \quad \dots (1)$$

The power of the transmission tower is denoted by P and x represent the distance of the bird from the tower. The power P used for the mobile tower is taken as 200 W, which is based on the current 5G network. The field around the tower becomes

$$E_0 = \frac{109.545}{x} \quad \dots (2)$$

The above-given electric field is incident on the skin of the bird. The field penetrates inside the skin of the bird. The field inside the epidermis layer of the skin of birds is given by

$$E_z = E_0 e^{(-z/\delta)} \quad \dots (3)$$

where E_z and E_0 represent the penetrated and incident electric field, respectively. δ represents the skin depth, which depends on the frequency of the incident wave. The calculations have been made for the EM waves spectrum radiated from the mobile

phone and towers. The energy absorbed per unit mass by the skin tissue is given by

$$SAR = \frac{\sigma E_z^2}{\rho} \quad \dots (4)$$

Where σ & ρ are the conductivity and mass density of the bird's skin tissue. The heating effect in the skin tissue due to the exposure to EM radiation is given by

$$\Delta T = \Delta t SAR/C \quad \dots (5)$$

ΔT represents the change in temperature in the epidermis layer of skin, C is the specific heat of the tissue, which is taken as 3500 J/kg⁰C and Δt is the exposure period of the EM radiation. This study examines the heat produced in the skin tissue for the chronic EM exposure for the period of 1-15 minutes.

4 Observations

The calculated values of the parameters, including the electric field, SAR, and change in temperature variation following EM radiation exposure, were calculated using Eqs 1-5. The resulting values are presented in Tables 1-5.

Table 1 — Change in temperature inside the epidermis layer of a bird's skin due to the exposure of EM radiation of frequency 3.5 GHz

External Electric field(E_0) V/m	Distance from the tower (m)	Penetrated electric field (V/m) inside bird's skin at the depth of 1 μ m	Specific Absorption rate (W/Kg) inside bird's skin at the depth of 1 μ m	Change in temperature ΔT (0 C) for various exposure durations			
				1 min	5 min	10 min	15 min
109.545	1	109.538	16.11	0.28	1.38	2.76	4.14
54.772	2	54.769	4.03	0.07	0.35	0.69	1.04
36.515	3	36.513	1.79	0.03	0.15	0.31	0.46
27.386	4	27.385	1.01	0.02	0.09	0.17	0.26
21.909	5	21.908	0.64	0.01	0.06	0.11	0.17
18.257	6	18.256	0.45	0.01	0.04	0.08	0.12
15.649	7	15.648	0.33	0.01	0.03	0.06	0.08
13.693	8	13.692	0.25	0.00	0.02	0.04	0.06
12.172	9	12.171	0.20	0.00	0.02	0.03	0.05
10.954	10	10.954	0.16	0.00	0.01	0.03	0.04

Table 2 — Change in temperature inside the epidermis layer of a bird's skin due to the exposure of EM radiation of frequency 4.0 GHz

External Electric field(E_0) V/m	Distance from the tower (m)	Penetrated electric field (V/m) inside the bird's skin at a depth of 1 μ m	Specific Absorption rate (W/Kg) inside the bird's skin at a depth of 1 μ m	Change in temperature ΔT (0 C) for various exposure durations			
				1 min	5 min	10 min	15 min
109.545	1	109.538	18.63	0.32	1.60	3.19	4.79
54.772	2	54.769	4.66	0.08	0.40	0.80	1.20
36.515	3	36.513	2.07	0.04	0.18	0.35	0.53
27.386	4	27.385	1.16	0.02	0.10	0.20	0.30
21.909	5	21.908	0.75	0.01	0.06	0.13	0.19
18.257	6	18.256	0.52	0.01	0.04	0.09	0.13
15.649	7	15.648	0.38	0.01	0.03	0.07	0.10
13.693	8	13.692	0.29	0.00	0.02	0.05	0.07
12.172	9	12.171	0.23	0.00	0.02	0.04	0.06
10.954	10	10.954	0.19	0.00	0.02	0.03	0.05

Table 3 — Change in temperature inside the epidermis layer of a bird’s skin due to the exposure of EM radiation of frequency 4.5 GHz

External Electric field(E_0) V/m	Distance from the tower (m)	Penetrated electric field (V/m) inside the bird’s skin at a depth of 1 μ m	Specific Absorption rate (W/Kg) inside the bird’s skin at a depth of 1 μ m	Change in temperature ΔT ($^{\circ}$ C) for various exposure durations			
				1 min	5 min	10 min	15 min
109.545	1	109.536	21.48	0.37	1.84	3.68	5.52
54.772	2	54.768	5.37	0.09	0.46	0.92	1.38
36.515	3	36.512	2.39	0.04	0.20	0.41	0.61
27.386	4	27.384	1.34	0.02	0.12	0.23	0.35
21.909	5	21.907	0.86	0.01	0.07	0.15	0.22
18.257	6	18.256	0.60	0.01	0.05	0.10	0.15
15.649	7	15.648	0.44	0.01	0.04	0.08	0.11
13.693	8	13.692	0.34	0.01	0.03	0.06	0.09
12.172	9	12.171	0.27	0.00	0.02	0.05	0.07
10.954	10	10.954	0.21	0.00	0.02	0.04	0.06

Table 4 — Change in temperature inside the epidermis layer of a bird’s skin due to the exposure of EM radiation of frequency 5.0 GHz

External Electric field(E_0) V/m	Distance from the tower (m)	Penetrated electric field (V/m) inside the bird’s skin at a depth of 1 μ m	Specific Absorption rate (W/Kg) inside the bird’s skin at a depth of 1 μ m	Change in temperature ΔT ($^{\circ}$ C) for various exposure durations			
				1 min	5 min	10 min	15 min
109.545	1	109.535	24.45	0.42	2.10	4.19	6.29
54.772	2	54.767	6.11	0.10	0.52	1.05	1.57
36.515	3	36.512	2.72	0.05	0.23	0.47	0.70
27.386	4	27.384	1.53	0.03	0.13	0.26	0.39
21.909	5	21.907	0.98	0.02	0.08	0.17	0.25
18.257	6	18.256	0.68	0.01	0.06	0.12	0.17
15.649	7	15.648	0.50	0.01	0.04	0.09	0.13
13.693	8	13.692	0.38	0.01	0.03	0.07	0.10
12.172	9	12.171	0.30	0.01	0.03	0.05	0.08
10.954	10	10.953	0.24	0.00	0.02	0.04	0.06

Table 5 — Change in temperature inside the epidermis layer of a bird’s skin due to the exposure of EM radiation of frequency 5.5 GHz

External Electric field(E_0) V/m	Distance from the tower (m)	Penetrated electric field (V/m) inside the bird’s skin at a depth of 1 μ m	Specific Absorption rate (W/Kg) inside the bird’s skin at a depth of 1 μ m	Change in temperature ΔT ($^{\circ}$ C) for various exposure durations			
				1 min	5 min	10 min	15 min
109.545	1	109.533	27.65	0.47	2.37	4.74	7.11
54.772	2	54.767	6.91	0.12	0.59	1.19	1.78
36.515	3	36.511	3.07	0.05	0.26	0.53	0.79
27.386	4	27.383	1.73	0.03	0.15	0.30	0.44
21.909	5	21.907	1.11	0.02	0.09	0.19	0.28
18.257	6	18.256	0.77	0.01	0.07	0.13	0.20
15.649	7	15.648	0.56	0.01	0.05	0.10	0.15
13.693	8	13.692	0.43	0.01	0.04	0.07	0.11
12.172	9	12.170	0.34	0.01	0.03	0.06	0.09
10.954	10	10.953	0.28	0.00	0.02	0.05	0.07

5 Results and Discussion

When the bird is sitting at various distances from the source of EM waves, like mobile phone transmission towers, the effects of EM waves on the bird’s health are different. The wave will incident on the body and penetrate inside the epidermis layer of the bird’s skin. The electric fields about the

transmission towers and the field entered inside the bird’s body are determined in this study. The variation of the electric field at various distances from the mobile phone towers is computed and represented in Fig. 2. This figure also represents the produced electric field around the tower and shows that it continuously decreases with distance from the tower.

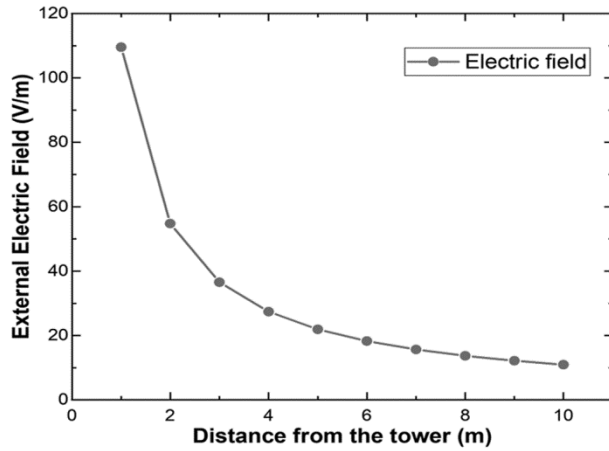


Fig. 2 — Variation of Electric Field around the high-frequency mobile phone tower

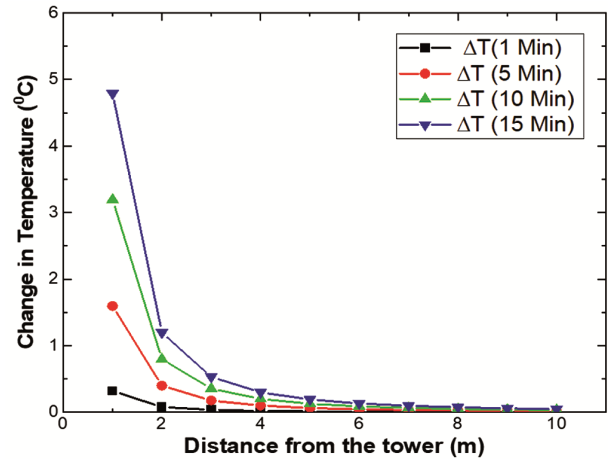


Fig. 4 — The change in temperature inside the epidermis layer of a bird's skin due to the EM exposure of 4.0 GHz, concerning the distance from the tower

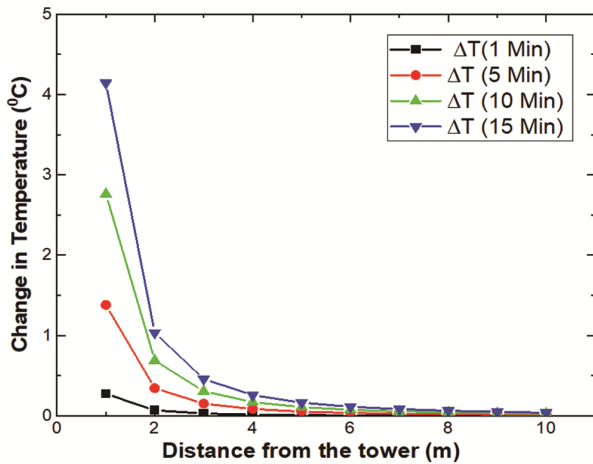


Fig. 3 — The change in temperature inside the epidermis layer of a bird's skin due to the EM exposure of 3.5 GHz, concerning the distance from the tower

If we observe the result concerning the flying birds, it is observed that the electric field is decreased by 90% if birds are flying from 1 to 10 m around the tower. This study evaluates the interaction of EM waves of various frequencies with the epidermis layer of the bird's skin. The interaction is analyzed by calculating the parameters, including the penetrated electric field, SAR, and change in temperature (ΔT) inside the epidermis layer of the bird's skin.

The calculations of the electric field have been made when the EMR of 3.5 GHz is penetrated inside the skin at a depth of 1 μm and are represented in Table 1. It is observed that the incident electric fields are reduced by 0.0062% inside the epidermis layer.

This reduction trend is steady across all distances (1 m to 10 m) studied. The energy absorption by the bird's body is decreased with increasing distance from

the cell tower. The SAR value is calculated inside the skin to find out the energy absorption by the skin. SAR is proportional to the square of the penetrated electric field. A reduction in the SAR value is obtained with increasing distance from the tower. The SAR is decreased from 16.11 W/kg to 0.16 W/kg as the bird moves from 1 m to 10 m away from the tower, respectively. These observed values determine that the energy absorption is highest near the tower and decreases with increasing distance. The change in temperature (ΔT) in the skin tissue is also calculated for exposure periods of 1-15 minutes. A direct correlation is obtained between the exposure period and the increase in temperature, which is shown in Fig. 3. The observations at 1 m away from the tower represent that the temperature rise is 0.28 $^{\circ}\text{C}$ for the EM radiation exposure of 1 minute, 1.38 $^{\circ}\text{C}$ for 5 min, 2.76 $^{\circ}\text{C}$ for 10 min, and 4.14 $^{\circ}\text{C}$ for 15 min. The temperature rise is less due to the reduced electric field and SAR values. The temperature rise is highest near the tower and decreases with distance from the tower.

It is observed from Table 2 that the value of the electric field increases when the EM waves of 4.0 GHz incident on the epidermis skin layer of birds. At a distance of 1 m, the SAR for bird skin reaches 18.63 W/kg, while the value at 10 m stands at 0.19 W/kg. The electromagnetic absorption levels for birds are tremendously higher when they are near the tower. The exposed skin of birds experiences its most significant temperature elevation to 4.79 $^{\circ}\text{C}$ at 1 m proximity while showing a minimal temperature rise of 0.05 $^{\circ}\text{C}$ at 10 m. It is observed from Fig. 4 that the study shows that birds near electromagnetic towers can develop thermal stress as well as tissue damage

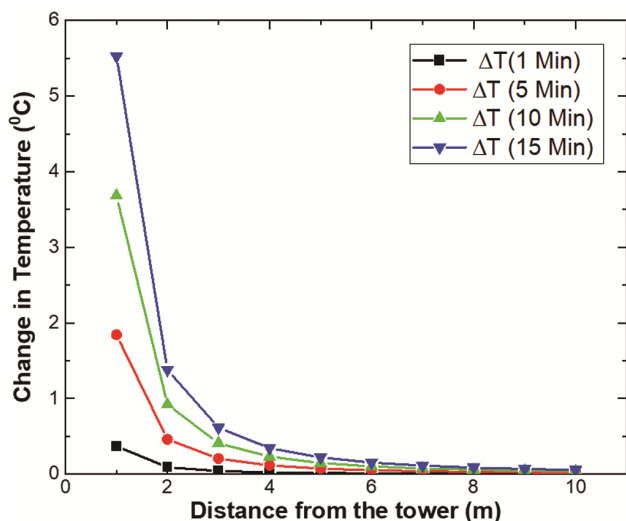


Fig. 5 — The change in temperature inside the epidermis layer of a bird’s skin due to the EM exposure of 4.5 GHz, concerning the distance from the tower

through a long-duration exposure. The SAR, together with temperature elevation, becomes much lower when subject to distances exceeding 5 m, which leads to reduced biological damage potential. Birds must stay away from high electromagnetic field areas to reduce risks, and they need to limit their time under such radiation.

When EM waves of frequency 4.5 GHz are incident on the body of birds, the calculated parameters are represented in Table 3. When a bird is flying 1 to 10 m around the mobile phone tower, the electric field is reduced by 0.0083% compared to the incident field inside the epidermis at a depth of 1 μm . The decay in the electric field is nearly the same around the tower from 1 m to 10 m. The calculations of SAR and temperature change have also been made when the EMR of 3.5 GHz is penetrated inside the skin at a depth of 1 μm and are represented in Table 1. The energy absorption per unit mass by the bird’s skin is 21.48 W/kg at 1 m and reduced to 0.21 W/kg at 10 m. It is obtained that the energy absorption increases as the frequency of the incident wave is increased. The temperature change increases with the duration of exposure to EM radiation, as represented in Fig. 5. At a distance of 1 m from the tower, the temperature change is 0.37°C for 1 minute and rises to 5.52°C for 15 min of exposure duration at 1 μm depth inside the skin of birds. It is also observed that the temperature rise is also increases with the exposure duration and frequency.

The electric field produced by the interaction of 5.0 GHz electromagnetic radiation with birds has

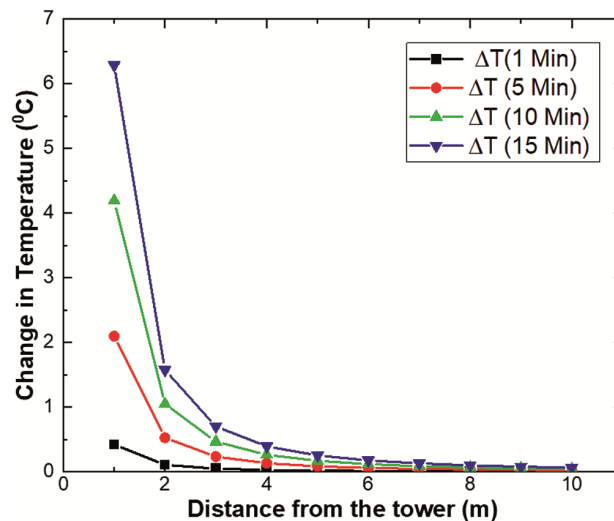


Fig. 6 — The change in temperature inside the epidermis layer of a bird’s skin due to the EM exposure of 5.0 GHz, concerning the distance from the tower

been calculated. The statistical investigation shown in Table 4 indicates that the tower proximity affects both the external electric field (E_0) and the penetrated electric field inside the bird’s skin. The SAR value demonstrates its value of 24.45 W/kg at a 1-meter distance, which reduces to 0.24 W/kg at a 10-meter distance. The SAR analysis indicates that the birds located near electromagnetic sources such as towers absorb more energy. The maximum temperature change (ΔT) reaches 6.29 °C after 15 min of exposure at a 1m distance, while the temperature rise at 10 meters is limited to 0.06 °C. The variation of temperature change with EM exposure duration is given in Fig. 6. The research establishes that birds that encounter powerful electromagnetic fields near them are likely to experience severe thermal damage to their biology, which could result in cellular breakdown and disrupted metabolism. The change in SAR along with the temperature rise results in a significant drop, followed in lower safety risks. The research demonstrates that individuals must stay at a sufficient distance from strong electromagnetic field areas to reduce possible harmful biological consequences.

Table 5 represents the penetrated electric field, SAR and change in temperature in the bird’s skin tissue when exposed to EM radiations of 5.5 GHz. These parameters are computed inside the skin at 1 μm depth. The incident electric field is decreased by 0.0109 % inside the epidermis when a bird is 1 to 10 m away from the cell tower. SAR value is directly proportional to the incident electric field. Therefore,

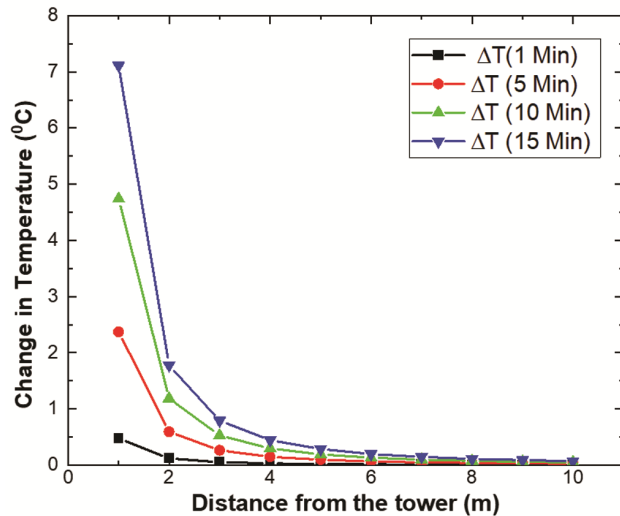


Fig. 7 — The change in temperature inside the epidermis layer of a bird's skin due to the EM exposure of 5.5 GHz, concerning the distance from the tower source

the SAR value is higher near the tower and decreases with distance. The SAR value is 27.65 W/kg and reduces to 0.28 W/kg from 1 m to 10 m away from the mobile phone transmission tower. It is also observed that the amount of absorbed energy has a direct correlation with incident frequency. The rise in temperature in the skin tissue (ΔT) is directly proportional to the SAR value. The higher SAR values inside the skin, the more heating in the tissue is observed. The rise in temperature of 0.47 °C in the skin tissue is observed for an exposure duration of 1 min, and it increases to 7.11°C with the prolonged exposure of 15 min, which is shown in Fig. 7. A limitation of this study is that it does not consider a specific bird species; rather, the rise in temperature in the skin was calculated using generalized values applicable to birds in general.

6 Conclusion

The variation of the electric field around the mobile phone transmission tower is calculated. It is concluded from the above analysis that the external electric field is decreased by 90 % from 1 to 10 m around the tower. It is also obtained that as the frequency of the incident wave is raised, the external electric field, SAR value, and tissue heating are also increased. The electric field generated from the high-frequency transmission tower is 109.545 V/m at 1 m about the cell tower, which is very high as per the ICNIRP (International Commission on Non-ionizing Radiation Protection) guidelines for electric field^{17,18}. When electromagnetic waves are incident on a bird's

skin, the energy is absorbed by the epidermis layer. The SAR value indicates that the amount of absorbed energy is much less than the amount of energy. The impact of the electric field decreases with the increase in the distance of the bird from the tower. As the incident electromagnetic waves enter inside the body, an electric field is induced into the organs of the birds. The reduction in the external electric field inside the skin tissue shows its absorptive property. This diminution is vital to understanding the interaction of EM waves with biological tissues. The measured SAR values indicate that the energy absorption is highest near the source of EM radiation and diminishes with distance. The calculated temperature rise provides the thermal effects of EM wave exposure on bird skin. While the temperature increases at short distances and for a prolonged exposure duration. This temperature rise diminishes with distance from the source. It is crucial to understand the interaction of EM radiation with biological tissues for evaluating the potential risks to the health of birds.

It is also concluded that the electric fields induced around the transmission tower are harmful to the bird's skin. The penetration of high-frequency electromagnetic waves inside the skin cells and other body organs of birds represents the cause of many diseases in birds. The close proximity to electromagnetic sources results in more energy absorption and heating in the bird's skin tissue. The tissue heating may potentially affect the biological functioning of the body. These outcomes highlight the importance of maintaining a suitable distance from electromagnetic sources to mitigate potential thermal effects on biological tissues. It is recommended that transmission towers be situated away from areas with high avian populations to minimize potential biological impacts. The public awareness campaigns should be organized to minimize unnecessary mobile phone usage.

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