World Journal of Environmental Biosciences
Available Online at: **www.environmentaljournals.org**

Volume 13, Issue 2: 1-5

https://doi.org/10.51847/YYlqFBgHxk

ISSN 2277- 8047

Effects of Electromagnetic Radiation and Radio Frequency on Freshwater Calanoid and Cyclopoid Copepods

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ABSTRACT

Copepods belonging to planktonic species are small crustaceans found in water bodies. Plankton are the primary producers that are important for food webs and ecosystems. This study analyzes the effects of planktonic species in current telecommunication devices that emit radio frequency and produce EM fields. In recent years, there has been massive growth in the number of mobile tower stations. Case studies have been conducted on the effects of radiation from these towers on various organisms. In the present study, plankton species were exposed to two EMFs of 190 V and 230 V and an RF of 9 GHz for different time durations. The highest mortality rates for the calanoid copepod Neodiaptomus species were 21.81 ± 3.14, 34.55 ± 1.81, and for the cyclopoid copepod Mesocyclops species were 18.18 ± 3.15, 21.21 ± 2.78, 190 v and 230 v power supplies exposed at 300 min, respectively. Variation in the amount of protein in Neodiaptomus sp. and Mesocyclops sp. was indicated by the effect of radiation. The data on mortality, sublethal duration, motility, protein concentration, and amino acid content are discussed in the present study.

Keywords: *Copepods, EMR, Biochemical profile, Motility*

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Received: 08 January 2024
Accepted: 27 March 2024

INTRODUCTION

Electromagnetic radiation and radio frequency are forms of energy that are present in our everyday environment. Electromagnetic radiation is a type of energy that is emitted from sources such as the sun, light bulbs, and electronic devices. It is characterized by its wavelengths and frequencies, which can range from extremely low frequencies to very high frequencies. Radiofrequency, on the other hand, is a specific range of electromagnetic radiation that is commonly used in technologies such as wireless communication, television broadcasting, and medical imaging. Understanding the properties and effects of these forms of energy is crucial in assessing their impact on living organisms, particularly freshwater copepods. These tiny crustaceans play a vital role in freshwater ecosystems and are sensitive to changes in their environment, including exposure to electromagnetic radiation and radio frequency. By studying the effects of these energy sources on copepods, we can gain a better understanding of their potential implications on aquatic ecosystems and biodiversity as a whole (Ndacyayisenga *et al*., 2023).

Aquatic ecosystems are affected by various types of radiation, such as UV-B and radio waves. The effects of UV radiation on coastal photosynthetic plankton morphology are carried out by a mixing process (i.e., based on the irradiation level) (Helbling *et al*., 2003; Llabrés & Agusti, 2010), and solar radiation affects the DNA damage of bacterioplankton (Jeffrey *et al*., 1996; Visser *et al*., 1999). Cooke *et al*. (2008) reported positive effects of UV radiation on plankton in a transparent lake where species such as *Leptodiaptomus minutes*, *Daphnia catawba*, and *Cyclops scutifer*. However, it was indirectly affected by ultraviolet radiation, which had a significant effect on all *L. minuttus* life stages. Electromagnetic radiation (EMR) is the energy transferred by waves of combined electrical and magnetic charge, capable of traveling through a vacuum and at the universal speed of light in whatever media it is passing through. They are ionizing and non-ionizing radiations based on the ionizing and non-ionizing atoms in ordinary chemical matter. Radio-frequency radiation covers a large segment of the electromagnetic spectrum and falls within the non-ionizing bands. Its frequency ranges from 10 GHz to 300 GHz. Levitt and Lai (2011) reviewed radiation exposure from different types of antenna arrays, cell phone base stations, and microwaves, as well as non-ionizing electromagnetic fields, biological effects, and environmental pollution. The influence of electromagnetic field on dinoflagellates bioluminescence has been investigated by McCown *et al*. (2005). According to their study, bioluminescence may be inhibited by the strength and frequency of electromagnetic fields. The biological effects of exposure at all levels and guidelines were also explored. For many marine organisms, the ability to detect E- and B-fields begins in the embryonic and juvenile phases of life. For instance, it has been demonstrated through controlled tests that B-fields cause fish and sea urchins to delay their embryonic growth (Zimmerman *et al*., 1990; Cameron *et al*., 1993; Levin & Ernst 1995). EM fields have been shown in numerous studies to modify cell formation, as well as circulation, gas exchange, embryonic development, and orientation. The effects of radiation on different trophic-level organisms have been thoroughly reviewed by several investigators (Siebeck *et al*., 1994; Zagarese *et al*., 1994; Browman *et al*., 2000; Perin & Lean, 2004; Häder *et al*., 2011). The impact of radiation on zooplankton should be investigated, as saving a sustainable ecosystem is important. This study analyzes the effects of planktonic species in current telecommunication devices that emit radio frequency and produce EM fields.

MATERIALS AND METHODS

Collection of sample

The plankton samples were collected from the Padalam freshwater bodies, Kanchipuram, Tamil Nadu, using a plankton net made up of a Bolten-silk net (50 µm mesh size) and immediately transferred to the laboratory. *Neodiaptomus* species and *Mesocyclops* species have been identified based on standard key characters (Reddy, 1994). They were acclimatized to laboratory conditions and fed baker's yeast (500 ppm) (Altaff & Sivakumar, 2003) for further study.

The setup for the Reflex klystron tube was adjusted during the working process. The samples were then exposed to radiation. It contained 50 *Neodiaptomus* sp. and *Mesocyclops* sp., which were exposed in triplicate to various EMF ranges of 190V and 230 V with a constant RF of 9GHz. They were exposed for various time intervals (30–300 min). After incubation, samples were taken to determine the mortality and motility of the species. The sub-lethal time of radiation to *Neodiaptomus* sp. and *Mesocyclops* sp. was calculated using probit analysis.

Based on the sub-lethal time, the animals were exposed and subjected to protein and amino acid analyses. The samples were homogenized in RIPA buffer, and the total protein content was estimated. For amino acid analysis, the samples were hydrolyzed with 6 ml of 6N HCl and incubated in a water bath for 24 h with every one-hour interval cyclo-mixed samples. They were centrifuged at 3500rpm for 15 min, and the supernatant was neutralized using 1N NaOH and subjected to sample analysis using HPLC (Agilent HPLC 1100) (Boulter & Barber, 1963).

Statistical analysis

Mortality and motility data were subjected to statistical analysis. Values are presented as mean ± SD, and one-way ANOVA followed by posthoc (DMRT's multiple range test) tests were performed to calculate the significant difference ($P < 0.05$) between the duration in the electromagnetic frequency.

RESULTS AND DISCUSSION

The present research findings shed light on the substantial influence of electromagnetic radiation on the mortality rate of two species *Neodiaptomus* sp. and *Mesocyclops* sp. The study focused on the exposure to electromagnetic radiation of 190v and 230v with a radio frequency of 9GHz at different times (30, 60, 90, 120, 180, 240, and 300 min) durations. The prolonged exposure led to a remarkable increase in the mortality rate for both species. The mortality rates were recorded as 21.81 ± 3.14 and 34.55 ± 1.81 for *Neodiaptomus* sp. Exposed to 190 v and 230v, respectively. Similarly, for *Mesocyclops* sp., the rates were 18.18 ± 3.15 and 21.21 ± 2.78, respectively. This was in stark contrast to the control group, no mortality was noted **(Table 1)**. One-way ANOVA for mortality of *Neodiaptomus* sp. and *Mesocyclops* sp. showed significant differences ($P < 0.05$) at different durations of both frequencies (df = 6, 14; P = 0.000). DMRT's test showed no significant difference ($P > 0.05$) between the two species about the control and 30 min. exposure. However, the animals exposed for 300 min were compared for other durations, and the control group was significantly different ($P < 0.05$) **(Table 1)**.

Table 1. Mortality percentage of *Neodiaptomus* species and *Mesocyclops* species on Electromagnetic Radiation Exposure in different durations at 190 v and 230 v.

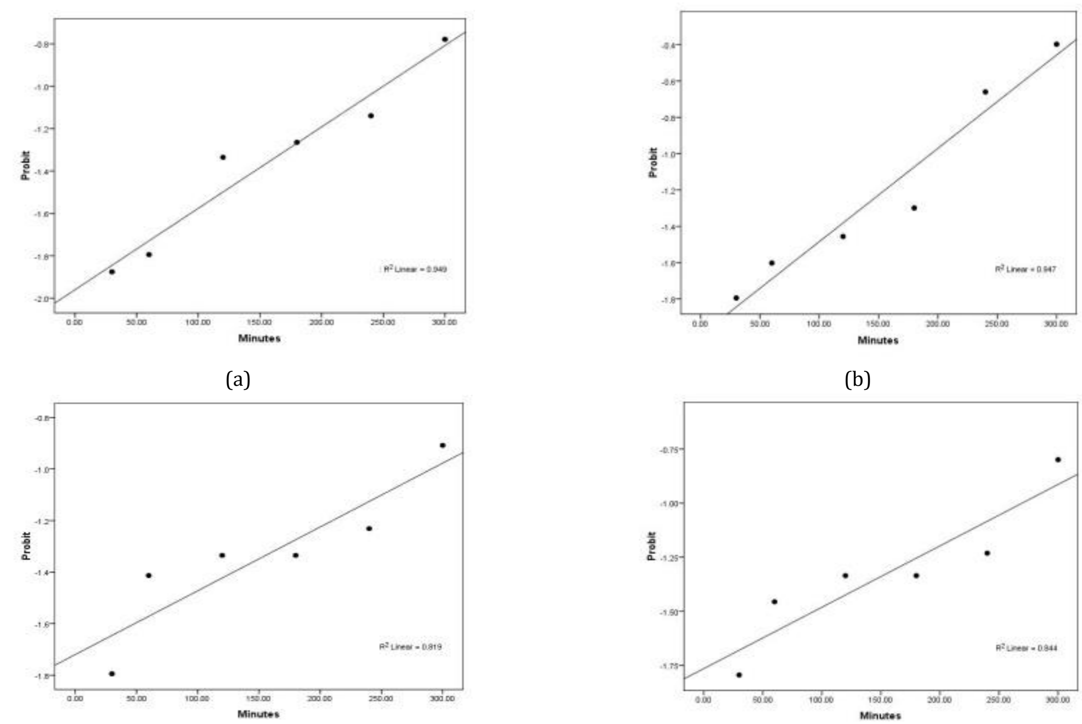
TIME (min)	***Neodiaptomus* species**		***Mesocyclops* species**	
	190 v	**230 v**	**190 v**	**230 v**
Control	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
30	3.03 ± 1.05^{a}	3.63 ± 1.81^{ab}	3.64 ± 1.85^{a}	3.64 ± 1.82^{ab}
60	3.63 ± 1.81^{a}	5.46 ± 1.05^{bc}	7.88 ± 1.05^{b}	7.27 ± 1.82^{bc}
120	7.27 ± 1.82^{b}	9.09 ± 1.82^{bc}	9.10 ± 1.82^{b}	9.09 ± 3.15^{c}
180	9.70 ± 1.05^{b}	10.30 ± 2.78^{c}	9.09 ± 3.15^{b}	9.09 ± 1.82^{c}
240	12.73 ± 1.82^{b}	25.46 ± 3.15^{d}	10.91 ± 1.82^{b}	10.91 ± 1.22^{c}
300	21.81 ± 3.14^{c}	34.55 ± 1.81^{e}	18.18 ± 3.15^{c}	21.21 ± 2.78^{d}
	Probit Analysis (in minutes)			
LF_t50	517	378	704	614

Different superscripts in the same column showed significant differences at P< 0.05 level; Anova followed by DMRTs performed.

Several investigators have reported that solar ultraviolet radiation is harmful to aquatic organisms and may reduce the productivity of marine ecosystems (Siebeck *et al*., 1994; Perin & Lean, 2004; Häder *et al*., 2011). The impact of mobile tower radiation on planktonic community reports is very limited. Most studies have focused on the effects of UV radiation on zooplankton. Owing to mobile tower radiation (3G, 4G, Wi-Fi) within 96 h, plankton leads to the death or deformation of the morphological structure.

Probit analysis of both species at the two frequencies showed a positive correlation with mortality and time duration **(Figure 1)**. The lethal frequency time (LFt 50) for *Neodiaptomus* sp. was 517 min. and 378 min. and *Mesocyclops* sp., respectively, at 704 min. and 614 min. in 190 v and 230 v, respectively **(Table 1)**.

The motility of *Neodiaptomus* sp. and *Mesocyclops* sp traveled in the range of 19.46 ± 1.23 cm to 58.30 ± 0.65 cm, 17.66 ± 0.51 cm to 38.03 ± 1.56 cm in 190 v while in 230 v 38.83 ± 1.95 cm to 48.57 ± 1.16 cm, 12.30 ± 1.30 cm to 43.53 ± 0.72 cm after exposure of radiation in 30 min and 300 min, respectively **(Table 2)**. One-way ANOVA and DMRT's test for motility of both species in the two radiation exposures were significantly different (P < 0.05) when compared to the different durations (df = 6,14; P = 0.000). However, in the 190 v exposed *Mesocyclops* species, there was no significant difference **(Table 2)** between 180 min and 300 min.



(a) (b) (c) (d)

Figure 1. Probit Analysis of *Neodiaptomus* species and *Mesocyclops* species on Electromagnetic Radiation Exposure in different durations at 190 v and 230 v.
a) *Neodiaptomus* species at 190 v, b) *Neodiaptomus* species at 230 v, c) *Mesocyclops* species at 190 v, d) *Mesocyclops* species at 230 v.

Table 2. Motility of *Neodiaptomus* species and *Mesocyclops* species on Electromagnetic Radiation Exposure in different durations at 190 v and 230 v.

TIME (min)	*Neodiaptomus* species		*Mesocyclops* species	
	190 v (cm)	230 v (cm)	190 v (cm)	230 v (cm)
Control	70.53 ± 2.21^{a}	70.53 ± 2.21^{a}	96.00 ± 1.00^{e}	96.00 ± 1.00^{g}
30	58.30 ± 0.65^{b}	38.03 ± 1.56^{b}	48.57 ± 1.16^{d}	43.53 ± 0.72^{f}
60	47.63 ± 0.73^{c}	31.83 ± 1.30^{c}	44.40 ± 1.20^{c}	38.77 ± 1.20^{e}
120	37.56 ± 0.83^{d}	25.31 ± 0.72^{d}	43.03 ± 1.00^{bc}	31.57 ± 1.00^{d}
180	31.46 ± 1.90^{e}	22.70 ± 0.91^{e}	40.90 ± 1.93^{ab}	27.33 ± 1.07^{c}
240	27.70 ± 0.90^{f}	20.03 ± 0.51^{f}	39.97 ± 2.06^{a}	21.40 ± 1.10^{b}
300	19.46 ± 1.23^{g}	17.66 ± 0.51^{g}	38.83 ± 1.95^{a}	12.30 ± 1.30^{a}

Different superscripts in the same column showed significant differences at P < 0.05 level; Anova followed by DMRTs performed.

The protein content was high (21 µg/mg and 52 µg/mg of *Neodiaptomus* sp. and *Mesocyclops* sp., respectively) in the 230 v exposed organisms compared to the control **(Figure 2)**. This may be the result of overexpression of the gene due to radiation. Kwee *et al.* (2001) have reported that after radiation exposure some stress protein levels had increased. The same results were reported for the amino acid profiles **(Tables 3 and 4)**.

The impact of electromagnetic radiation on freshwater copepods is a crucial area of study due to the potential consequences on these organisms' health and ecosystem dynamics. The present study has shown that exposure to radiofrequency electromagnetic fields can lead to changes in the behavior, biochemical profile, and survival of copepods. These effects may disrupt the trophic interactions and population dynamics of copepods, which play a vital role in freshwater food webs. Additionally, the increased prevalence of electromagnetic radiation in freshwater environments, such as from electronic devices and communication infrastructures, raises concerns about the long-term effects on copepod populations and overall ecosystem stability. Further investigation into the specific mechanisms underlying the impact of electromagnetic radiation on Calanoid copepods is necessary to develop effective conservation strategies and mitigate potential negative outcomes (Mauchline, 1998). Studies have shown that radio frequency exposure can have a significant impact on freshwater cyclopoid copepods, affecting their behavior, reproduction, and overall health. The electromagnetic radiation emitted by radio waves can disrupt the natural habitat and behavior of these small crustaceans, leading to changes in their feeding patterns and reproductive cycles. Additionally, prolonged exposure to radiofrequency has been linked to decreased survival rates and overall population decline in freshwater cyclopoid copepods. These findings highlight the need for further research into the long-term effects of radio frequency on aquatic ecosystems and the potential consequences for biodiversity (Heberger & Reynolds, 1977).

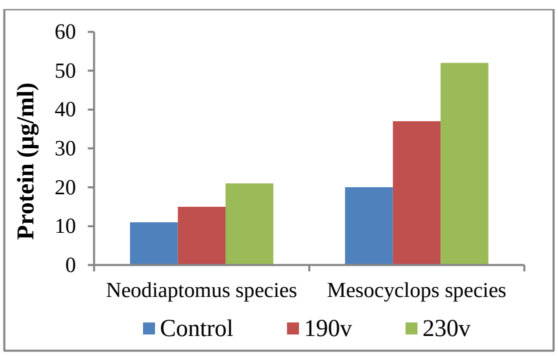


Figure 2. Probit Analysis of *Neodiaptomus* species and *Mesocyclops* species on Electromagnetic Radiation Exposure in different durations at 190v and 230v.

Table 3. Amino acid profile (nmol) of *Neodiaptomus* species on Electromagnetic Radiation Exposure in different durations at 190 v and 230 v.

Amino acids	Control	190 v	230 v
Aspartic acid	18	18	59
Glutamic acid	26	34	89
Serine	19	44	68
Histidine	3	8	42
Glycine	36	67	97
Threonine	6	13	31
Arginine	15	28	95
Alanine	16	20	66
Tyrosine	68	64	87
Methionine	2	4	14
Valine	3	3	6
Phenylalanine	7	10	24
Isoleucine	8	9	22
Leucine	11	18	59
Lysine	19	18	52

Table 4. Amino acid profile (nmol) of *Mesocyclops* species on Electromagnetic Radiation Exposure in different durations at 190 v and 230 v.

Amino acids	Control	190 v	230 v
Glutamic acid	12	27	95
Serine	27	68	97
Histidine	9	12	43
Glycine	42	119	130
Threonine	8	33	76
Arginine	20	96	120
Alanine	14	57	136
Tyrosine	104	95	72
Methionine	2	9	25
Valine	3	8	9
Phenylalanine	7	17	36
Isoleucine	5	12	29
Leucine	9	48	89
Lysine	18	48	82

For zooplankton species, the life stages were distributed throughout the mixed layer. It seems likely that radiation represents only a minor source of direct mortality in the population. However, for those species whose early life stages are the surface layer of water bodies, there may be circumstances in which the contribution of radiation to the population's mortality could be much more significant. The impacts of direct or indirect effects, which may be of much greater importance to plankton populations and ecosystems, are yet to be evaluated.

CONCLUSION

In conclusion, the findings of this study suggest that electromagnetic radiation and radio frequency signals have significant effects on freshwater calanoid and cyclopoid copepods. These effects include changes in behavior, reproductive success, and overall population dynamics. The implications of these results are significant, as copepods play a crucial role in freshwater ecosystems as a key food source for many aquatic organisms. Further research is needed to fully understand the long-term effects of electromagnetic radiation on copepod populations and to develop strategies for mitigating these potential impacts on aquatic ecosystems. Overall, this study highlights the need for more research on the potential impacts of human activities on freshwater biodiversity and the importance of considering the unintended consequences of technological advancements on vulnerable aquatic species.

ACKNOWLEDGMENTS: The authors are thankful to the Management and the Principal of Karpaga Vinayaga College of Engineering and Technology for permitting us to carry out this work and to Mr. Sathishkumar, Technician, Department of Electronics and Communication Engineering for his assistance and help in the entire work.

CONFLICT OF INTEREST: None.

FINANCIAL SUPPORT: None.

ETHICS STATEMENT: None.

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