Jurnal
Teknologi

Full Paper

A PRELIMINARY STUDY OF AMBIENT ELECTROMAGNETIC RADIATION AT BASE TOWER STATIONS IN RESIDENTIAL AREAS IN KUALA NERUS

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Article history
Received
3 May 2023
Received in revised form
14 August 2023
Accepted
6 September 2023
Published Online
20 December 2023

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Graphical abstract

Abstract

Introduction: Mobile communications have developed into an integral component of our daily life. The growing demand for mobile communication services in Kuala Nerus has seen an increase in the installation of base station towers (BST) in residential areas, as well as near schools, and hospitals. Kuala Nerus was selected as a study location because it is a newly developed district in Terengganu, hence, it is crucial to perform electromagnetic radiation (EMR) measurements in the early stages. Mobile service providers typically expand the number of base stations to improve signal reception in anticipation of increasing demand. Objective/aim: This study aimed to measure the RF EMR exposure level in residential areas in Kuala Nerus by measuring the strength of its electric field (EF) strength and power density (PD) value while comparing it with the International Commission on Non-Ionizing Radiation Protection (ICNIRP)'s standard guidelines which is 61 (V/m) or 1000 (μW/cm²). This study also developed a GIS map showing EMR exposure levels in residential areas at selected BSTs in Kuala Nerus. Materials and methods: Measurements were made using NARDA NBM 550, connected to a probe that could detect frequencies from 100kHz to 6GHz since Kuala Nerus only comply with 2G, 3G and 4G network. The data collection period for each point was approximately 6 minutes during daytime. Results: Average radiation levels in terms of EF strength at all locations were found to vary between 0.26 (V/m) to 3.35 (V/m) equivalent to (PD value about 0.02 μW/cm² to 2.97 μW/cm²). The highest level was measured at Surau Kg Pok Tuyu, which was 5.48%. This ambient is 18 times lower than the Malaysian Communications and Multimedia Commission (MCMC) exposure limit for public areas and all the peak recorded levels were within the limits mentioned in the standard guidelines. The EMR saturation value was used to develop the GIS mapping by applying the Inverse Distance Weighted (IDW) Interpolation technique and a colour-code map of Kuala Nerus was produced. Conclusion: The RF value obtained does not exceed the standard limit, which in turn contributes indirectly to health monitoring initiatives for public NIR exposure. This study found that exposure levels in selected BSTs in residential areas in Kuala Nerus were within the standard guideline limits.

Keywords: Base Station Tower, Radiofrequency, Electromagnetic Radiation, Public Exposure, Nonionizing Radiation, Residential Area

Abstrak

Pengenalan: Komunikasi mudah alih telah berkembang menjadi komponen penting dalam kehidupan seharian kita. Permintaan yang semakin meningkat untuk perkhidmatan komunikasi mudah alih di Kuala Nerus menyaksikan peningkatan dalam pemasangan menara stesen pangkalan (BST) di kawasan perumahan, serta berhampiran sekolah, dan hospital. Kuala Nerus dipilih sebagai lokasi kajian kerana ia merupakan daerah yang baru dibangunkan di Terengganu, justeru, adalah penting untuk melakukan pengukuran sinaran elektromagnet (EMR) pada peringkat awal. Pembekal perkhidmatan mudah alih biasanya mengembangkan bilangan stesen pangkalan untuk meningkatkan penerimaan isyarat dengan menjangkakan peningkatan permintaan. Objektif/matlamat: Kajian ini bertujuan untuk mengukur tahap pendedahan RF EMR di kawasan kediaman di Kuala Nerus dengan mengukur kekuatan kekuatan medan elektrik (EF) dan nilai ketumpatan kuasa (PD) sambil membandingkannya dengan garis panduan standard ICNIRP iaitu sebanyak 61 (V/m) or 1000 (μW/cm²). Kajian ini juga membangunkan peta GIS yang menunjukkan tahap pendedahan EMR di kawasan perumahan di BST terpilih di Kuala Nerus. Bahan dan kaedah: Pengukuran dibuat menggunakan NARDA NBM 550, disambungkan kepada probe yang boleh mengesan frekuensi dari 100kHz hingga 6GHz dan bersesuaian dengan Kuaa Nerus yang hanya menyediakan jaringan rangkaian 2G,3G dan 4G. Tempoh pengumpulan data untuk setiap titik adalah lebih kurang 6 minit pada waktu siang. Keputusan: Tahap sinaran purata dari segi kekuatan EF di semua lokasi didapati berbeza antara 0.26 (V/m) hingga 3.35 (V/m) (nilai PD kira-kira 0.02 μW/cm² hingga 2.97 μW/cm²). Paras tertinggi diukur di Surau Kg Pok Tuyu, iaitu 5.48% atau 18 kali lebih rendah daripada had pendedahan SKMM untuk kawasan awam dan semua paras tertinggi yang direkodkan adalah dalam had yang dinyatakan dalam garis panduan standard. Nilai tepu EMR digunakan untuk membangunkan pemetaan GIS dengan menggunakan teknik Interpolasi Inverse Distance Weighted (IDW) dan peta kod warna Kuala Nerus telah dihasilkan. Kesimpulan: Nilai RF yang diperolehi tidak melebihi had standard, yang seterusnya menyumbang secara tidak langsung kepada inisiatif pemantauan kesihatan untuk pendedahan NIR awam. Kajian ini mendapati tahap pendedahan dalam BST terpilih di kawasan perumahan di Kuala Nerus berada dalam had garis panduan standard.

Kata kunci: Menara Stesen Pangkalan, Radiofrekuensi, Sinaran Elektromagnet, Pendedahan Awam, Sinaran Tanpa Pengionan, Kawasan Kediaman

1.0 INTRODUCTION

Non-Ionizing Radiation (NIR) has been a source of concern for the public in today's advanced technological environment. Humans are exposed to high levels of ambient NIR due to the expanding telecommunications sector, whether inside or outside. NIR sources are generated by all electrical and electronic equipment, including moving vehicles, power grid lines, television transmitters, satellite communication, and mobile phones as well as their supporting Base Station Towers (BSTs), which have increased exponentially in lockstep with the increase in user population. Therefore, rapid expansion of communications systems occurs throughout the world in tandem with global advancement, particularly in developing countries[1]. As for Kuala Nerus, EMR measurements must be performed early to monitor the RF value emitted from BSTs since Kuala Nerus is a newly developed district in Terengganu. Thus, there are numerous future government development projects that can cause public concern regarding EMR pollution. EMR measurement in this new district also benefits the public, government and MCMC. In Nigeria, for example, there is widespread apprehension regarding this issue because thousands of BSTs have been placed near or in residential areas [2] There are numerous studies that specifically focus on environmental pollution from cell-phone tower radiation, particularly affecting people living in densely populated residential areas near the base station towers [3], [4]. Mapping and monitoring EMF radiation levels are still required in the early stages. More research is needed in this area, by employing a highly sensitive measuring and mapping system to better understand and reduce risk factors associated with human health and the environment [3].

NIR is a form of electromagnetic radiation (EMR) that carries and emits less energy than ionizing radiation (IR). While EMR provides numerous benefits for humans, it also has certain drawbacks in cases of excessive exposure. For example, if an IR source, such as an X-ray, produces an extreme dose or is used repeatedly on a person, it may trigger gene mutations in the short term [5]. Although the energy emitted by NIR sources is less than that emitted by IR sources, it nevertheless has the potential to harm the human body if exposed for an extended period or repeatedly. Although NIR is low-vitality radiation it can still affect the cell structure or the Deoxyribonucleic Acid (DNA), and over-exposure to this radiation can cause skin injury [6]. Hence, the public has been made aware of all these concerns, especially those who are more exposed to NIR sources than IR sources. Among the frequently discussed topics are the detrimental effects of cell phone use and the reaction of BSTs surrounding people's homes. The wireless telecommunication revolution began in the 1990s and has continued to prosper until today. This demonstrates that the telecommunications sector plays a crucial role in human life for a variety of reasons. Telecommunications is the science of long-distance communication that uses electric signals or electromagnetic waves. Electrical signals and electromagnetic waves are abbreviations for radio frequency (RF), which carry communications data [7]. Modern culture is constantly exposed to a high-tech lifestyle. Cell phone use, for example, is a significant part of daily life and a vital communication tool for individuals of all ages in today's world of globalisation although NIR has significant effects on humans, plants, and animals, including microorganisms like bacteria [8].

With the increasing demand for strong network coverage, most telecommunication companies inaugurated BSTs in residential areas. Previous studies have identified specific criteria for installing BSTs [9]. For example, sites with high traffic or large areas have a propensity to radiate more strongly. Inhabited or residential areas are also prone to complaints by residents. Places near buildings, colleges, and hospitals are investigated thoroughly to ensure enforcement. Selections were made based on various site characteristics, such as the developer, greenfield, town hall, indoor, outdoor, etc. This study agreed with previous studies that many of the base stations in Craiova have antennas installed next to residential and business buildings to guarantee that consumers have sufficient network coverage [10]. A simple station and its transmission power are built to enable cell phone transmission and signal reception up to a few kilometres for proper communication. However, the number of installed base stations that are required to serve a region effectively depends on the number of subscribers and the density of the traffic they generate [11].

According to ICNIRP, the power of a base station is generally between 10 and 50 watts, depending on the area it serves, and the number of calls received [12]. This is not very powerful relative to other transmitters, such as radio and TV transmitters, that typically operate at a power range of between a few kilowatts to a few megawatts. Naturally, the field intensity declines very quickly based on the distance from the source and can be measured (as the opposite side). The specific sensitivity of the base station to HF fields is exceptional. Mobile phone (high frequency) HF penetration is mostly intermittent and is highest in the head or bodily regions or where the handset is placed. Base stations, though, are a cause of health issue due to long term effect exposure to the EMR. For example, people that living near to the base station are likely to get sleep disturbances and concentration problems [13]. However, the health issue is less visible compared to that of a cell phone usage, regardless of whether a mobile phone is used. There a study conducts to evaluate the sperm quality due to the EMR from the mobile phone usage. The finding shows that there are relatively decreased progressive motility of the sperm after being exposed to the EMR from the mobile phone[14]

2.0 METHODOLOGY

2.1 Materials and Method

In this study, electromagnetic radiation values were measured using a NARDA NBM 550, which was connected to an Isotropic Probe EF0691 that can measure frequencies from 100kHz to 6GHz. This equipment only used to measure the 2G,3G and 4G network since Kuala Nerus will be installed with 5G at the end of year 2023 [15]. The set-up of the measuring equipment is shown in Figure 1. Another device was also used to determine the approximate height of BSTs and measure the distance between every point of measurement in correspondence to the identified BST in the vicinity, which is called the Mileseey Golf Laser Rangefinder, as shown in Figure 2. All the devices used in this study were calibrated before the data collection was performed. Measurement of these exposure levels was taken at 50 m to 1000 m in the proximity of the BSTs based on data retrieved between 8 a.m. to 5 p.m. on the same day [16]. The measurement was recorded at a six-minute duration for each point for all BSTs. The recommendation by ICNIRP is to measure EMR at a duration of between six to fifteen minutes because this is the time taken for the body to fully absorb the EMR and have a significant effect on the human body [17]. During the data collection process, the distance of the point from a BST and the number of antennas was recorded. Figure 3 shows the EMR study location for all ten BSTs in Kuala Nerus. All the locations were within the BST vicinity and located in residential areas. All buildings, landscapes or obstacles nearby the measurement location were also identified and recorded.

Figure 1 The apparatus setup diagram (NARDA NBM 550)

Figure 2 The Mileseey Golf Laser RangeFinder PF210 (laser distance meter)

Figure 3 EMR study location in Kuala Nerus

The flowchart for methods used in this study are summarised in Figure 4 and divided into four phases. It begins with the identification of the selected BSTs in Kuala Nerus until the development of GIS mapping of EMR saturation exposure values.

2.2 Location of Measurement

The identification of Base Station Towers (BSTs) in this study was carried out using Open Signal and Cell Tower Map Malaysia applications. These two apps provide information regarding BSTs around Malaysia, including Kuala Nerus, Terengganu. Based on Table 1, there are about 33 BSTs installed around Kuala Nerus. However only ten BSTs with high surrounding population in residential areas were selected since they can provide significant values about the population and sites that have been earmarked for development purposes.

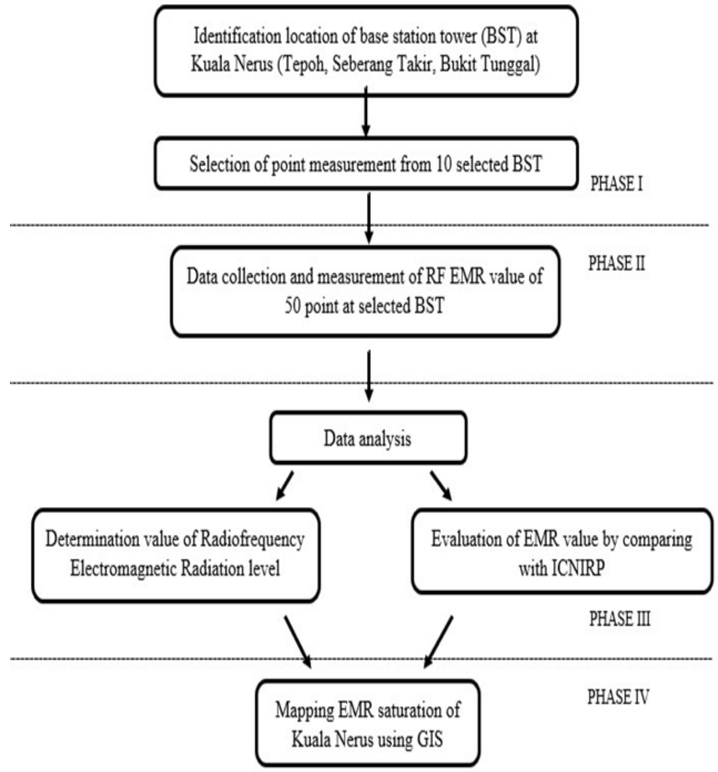

Figure 4 The Methodology Flowchart

Table 1 List of BSTs around Kuala Nerus

BST	Location	Category of Area
1	Taman Baiduri	
2	Perindustrian Gong Badak	
3	Gong Kuin	
4	Wakaf Tembesu	
5	Taman Desa Bakti	
6	Kg Jati	
7	Kg Kubang Badak	
8	Kg PokTuyu	Urban
9	Kg Banggol Paya Terong	
10	Kg Tok Meng/Bukit Tunggal	
11	Kg Baru Seberang Takir	
12	Lapangan Terbang Sultan Mahmud	
13	Stadium Sultan Zainal Abidin	
14	Kg Banggol Tiang Kulat/Mydin Gong Badak	
15	Taman Desa Perwira/Tok Jembal	
16	Kg Teluk Ketapang	
17	UMT/Tok Jembal	
18	Kg Pdg Nenas	
19	Kg Duyung	
20	Kg Padang	Sub Urban
21	Kg Batin	

BST	Location	Category of Area
22	Kg Seberang Bukit Tumbuh	
23	Kg Bukit Datu	
24	Kg Padang Air	
25	Tok Jiring	
26	Bukit Cempaka	
27	Kg Gemuroh	
28	Kg Jeram Hilir	
29	Kg Banggol Donas	Rural
30	KK Manir	
31	Kg Baloh	
32	Kg Banggol Tuan Muda	
33	Tepoh	

Ten BSTs were selected in this study, as shown in Figure 5. The BSTs were divided into three subdistricts, namely Tepoh (consisting of Taman Baiduri, Taman Perindustrian Gong Badak, Kg PokTuyu, Kg Jati and Wakaf Tembesu), Seberang Takir (consisting of Gong Kuin, Tok Jembal, Kg Kubang Badak and Teluk Ketapang) and Bukit Tunggal (consisting of Kg Banggol Paya Terong). Five points were identified for each BST and labelled from P1 to P5. All ten BST selected points are shown in Figure 5. The data collection locations along with the distance and coordinates are shown in Table 2, while Figure 6 shows the overview of all ten BST locations in Kuala Nerus.

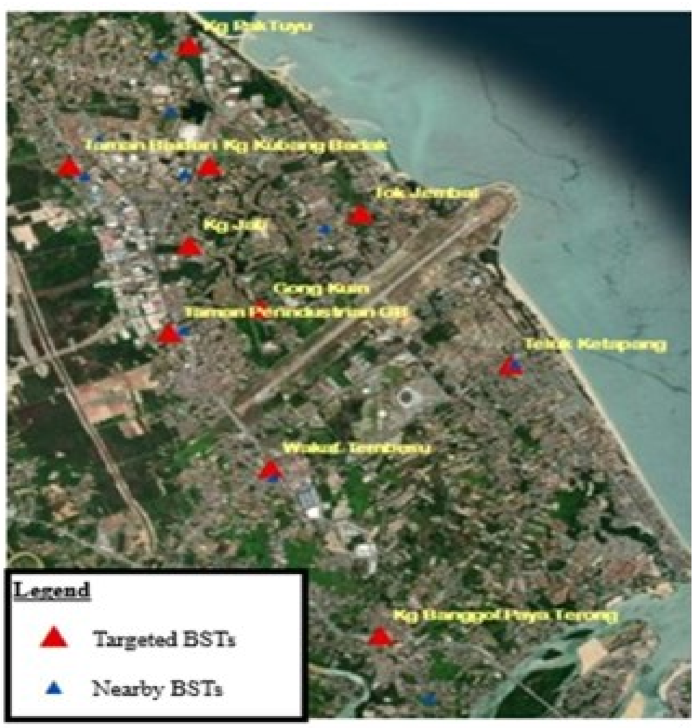

Figure 5 Location of all ten BSTs in Kuala Nerus District. The location is divided into three subdistricts (Tepoh, Seberang Takir and Bukit Tunggal)

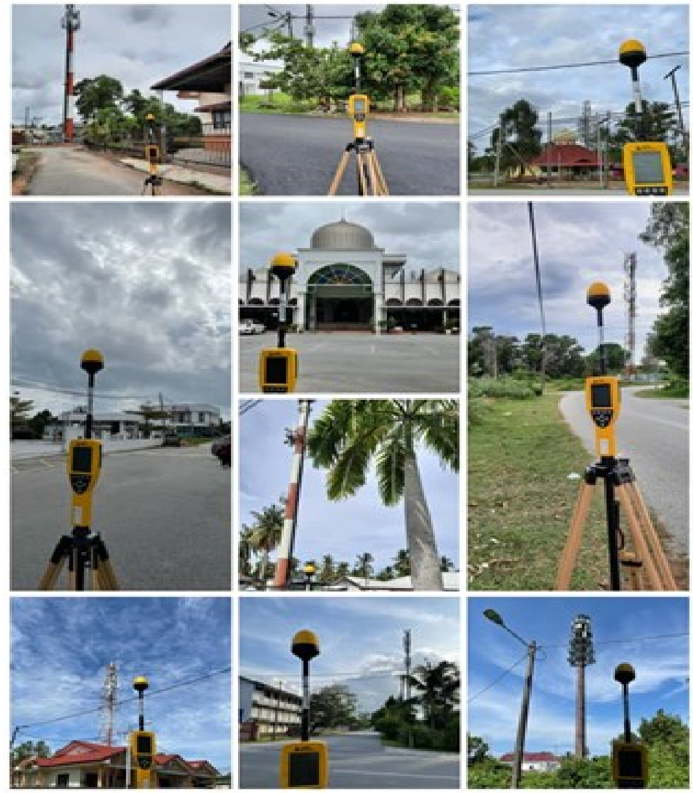

Figure 6 Overview of all ten BSTs in Kuala Nerus District

Table 2 List of BSTs around Kuala Nerus

BST	Location	Distance (m)	Coordinates	Category of Area
Taman Baiduri 5°23'58.1"N 103°04'18.5"E	P1	53.8	5°23'58.8"N 103°04'17.6"E	Sub Urban
	P2	114.7	5°23'52.3"N 103°04'25.7"E	Sub Urban
	P3	209.8	5°24'07.7"N 103°04'15.2"E	Sub Urban
	P4	311.2	5°24'03.7"N 103°04'21.7"E	Sub Urban
	P5	332.6	5°24'01.5"N 103°04'27.7"E	Urban
Taman Perindustrian GB 5°22'41.2"N 103°04'56.1"E	P1	54.5	5°22'40.3"N 103°04'55.8"E	Urban
	P2	96.5	5°22'44.6"N 103°05'00.4"E	Urban
	P3	137	5°22'52.9"N 103°04'52.9"E	Urban
	P4	220.2	5°22'35.6"N 103°05'01.5"E	Urban
	P5	248.6	5°22'37.2"N 103°05'03.2"E	Sub Urban
Kg PokTuyu 5°24'51.2"N 103°05'00.9"E	P1	79.7	5°24'50.0"N 103°04'58.2"E	Urban
	P2	122.4	5°24'47.0"N 103°04'51.0"E	Urban
	P3	160.5	5°24'52.4"N 103°05'04.1"E	Sub Urban
	P4	194.8	5°24'47.0"N 103°04'57.1"E	Urban
	P5	261.2	5°24'46.1"N 103°04'56.2"E	Sub Urban
Kg Jati 5°23'19.9"N 103°05'01.6"E	P1	56.7	5°23'20.1"N 103°05'02.7"E	Urban
	P2	180.5	5°23'16.2"N 103°04'58.2"E	Urban
	P3	210.7	5°23'23.0"N 103°04'54.9"E	Urban
	P4	262.2	5°23'14.0"N 103°05'06.7"E	Sub Urban
	P5	374.1	5°23'13.7"N 103°04'52.5"E	Urban
Wakaf Tembesu 5°21'39.1"N 103°05'29.8"E	P1	197.2	5°21'22.1"N 103°05'42.5"E	Urban
	P2	198.9	5°21'37.9"N 103°05'32.4"E	Urban
	P3	325.4	5°21'52.1"N 103°05'19.9"E	Urban
	P4	473.4	5°21'54.3"N 103°05'22.6"E	Urban
	P5	632.5	5°21'21.7"N 103°05'44.8"E	Urban
BST6 Gong Kuin 5°22'51.7"N 103°05'28.8"E	P1	50.3	5°22'51.2"N 103°05'29.4"E	Sub Urban
	P2	505.7	5°22'50.2"N 103°05'45.9"E	Sub Urban
	P3	639.4	5°22'54.5"N 103°05'49.4"E	Rural
	P4	986.3	5°22'59.5"N 103°06'01.3"E	Rural
	P5	998.8	5°23'03.2"N 103°05'58.7"E	Sub Urban
Tok Jembal 5°23'35.5"N 103°06'03.7"E	P1	83.6	5°23'23.4"N 103°05'50.2"E	Sub Urban
	P2	113.4	5°23'37.5"N 103°06'07.8"E	Sub Urban
	P3	416.9	5°23'34.3"N 103°05'50.2"E	Rural
	P4	425.1	5°23'29.9"N 103°05'51.1"E	Rural
	P5	543.4	5°23'41.5"N 103°06'16.6"E	Rural
Kubang Badak 5°23'55.4"N 103°05'10.2"E	P1	70	5°23'54.5"N 103°05'09.5"E	Urban
	P2	127	5°23'56.6"N 103°05'07.8"E	Urban
	P3	180	5°23'53.4"N 103°05'05.6"E	Urban
	P4	259.5	5°23'50.1"N 103°05'04.2"E	Urban
	P5	289.7	5°23'52.9"N 103°05'01.8"E	Urban
Teluk Ketapang 5°22'26.9"N 103°06'59.0"E	P1	32.5	5°22'28.4"N 103°07'01.6"E	Sub Urban
	P2	126	5°22'30.6"N 103°06'59.5"E	Sub Urban
	P3	135.2	5°22'30.5"N 103°06'58.4"E	Sub Urban
	P4	204.2	5°22'25.3"N 103°07'08.1"E	Rural
	P5	224.1	5°22'26.4"N 103°06'57.2"E	Sub Urban
Kg Banggol Paya Terong 5°20'23.1"N 103°06'10.2"E	P1	59.1	5°20'23.2"N 103°06'10.6"E	Sub Urban
	P2	344.1	5°20'22.1"N 103°06'21.9"E	Urban
	P3	358	5°20'08.0"N 103°06'20.0"E	Rural
	P4	442.5	5°20'00.7"N 103°06'17.6"E	Sub Urban
	P5	782.1	5°20'32.9"N 103°06'28.7"E	Sub Urban

2.3 Data Analysis

After the data collection process, raw data were extracted from the NARDA NBM 550 and transferred to a laptop using a local area network or LAN cable and NARDA Transfer Software. While using the software, the EF strength (V/m) and PD (μW/cm²) were selected, and large data values were stored in a .cvs file. A graph showing frequency against electric field strength and power density was plotted to identify the peak points. Another similar graph was plotted but with the ICNIRP limit inserted as a comparison with the acquired data.

3.0 RESULTS AND DISCUSSION

3.1 Electric Field Strength (V/m) and Power Density (μW/cm²)

Based on the graph for Tepoh subdistrict, the highest average value for electric field (EF) strength in Figure 7 is 3.35 (V/m) and the highest average value for power density (PD) in Figure 8 is 2.97 (μW/cm²), which was identified at the BST in Surau Kg Pok Tuyu. The lowest EF average value is 0.26 (V/m) with a PD value of 0.02 (μW/cm²), which was identified in Wakaf Tembesu, specifically in Tadika Lapangan Ilmu.

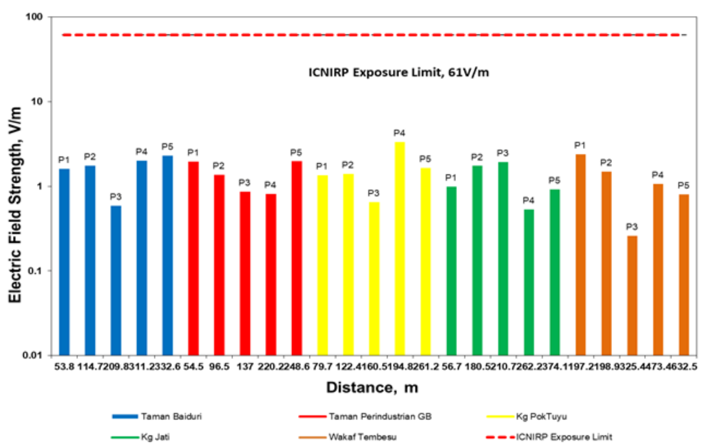

Figure 7 Exposure value of Electric Field Strength for each point at all five BSTs located in the Tepoh subdistrict

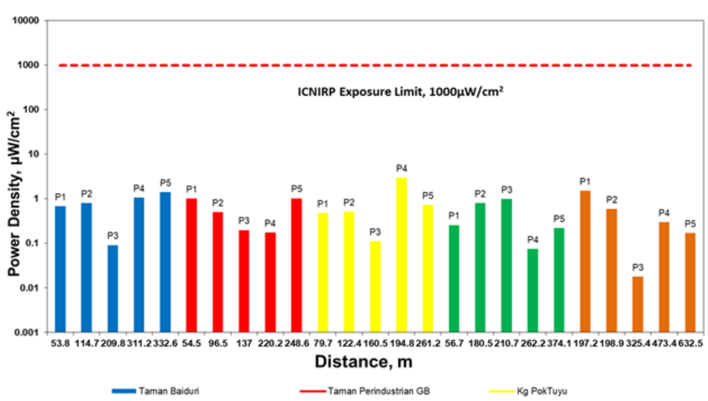

Figure 8 Exposure value of Power Density for each point at all five BSTs located in the Tepoh subdistrict

As for the graph for the location in Seberang Takir subdistrict in Figures 9 and 10, the highest EF average value is 2.47 (V/m) and PD value is 1.62 (μW/cm²) for the Klinik Kesihatan Seberang Takir location. The lowest average EF value of 0.30 (V/m) with a PD average value of0.02 (μW/cm²) was identified in Kg Pak Tijah.

As for the Seberang Takir subdistrict, Klinik Kesihatan Seberang Takir located at Teluk Ketapang had the highest EF average value of 2.47 (V/m) and a PD value of 1.62 (μW/cm²). The higher RF value at this point was due to fluctuations from another BST in the vicinity, which was about 200m in the opposite direction from the initial BST and located at SK Teluk Ketapang. Furthermore, the Klinik Kesihatan was located beside the main road near to restaurants, schools and beside the Regimen Askar Melayu DiRaja camp. At that time, the Klinik Kesihatan was in operation and people had gathered inside the point of location. Moreover, construction and repair works were being carried out at that time causing more RF saturation in the area. Besides, fluctuations in EF strength level measured along the distance for each site was probably due to other NIR sources present at that particular point. This view was consistent with another research, which found that the vast majority of people nowadays use cell phones that tends to contribute to an increase in EMF levels [20]. The existence of construction work in this area could also have an impact on neighbouring exposure levels since most construction machinery is electrical in nature. Thus, all electrical equipment utilized in daily life is a source of EM radiation, and hence, contributes to a rise in EMR exposure levels [21].

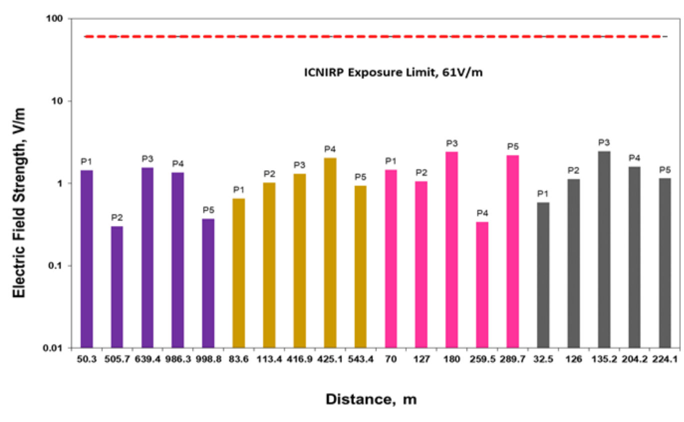

Figure 9 Exposure value of Electric Field Strength for each point at all four BSTs located in Seberang Takir

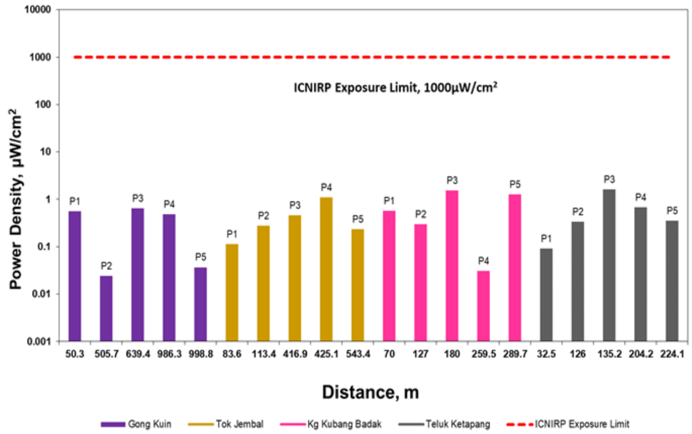

Figure 10 Exposure value of Power Density for each point at all four BSTs located in Seberang Takir

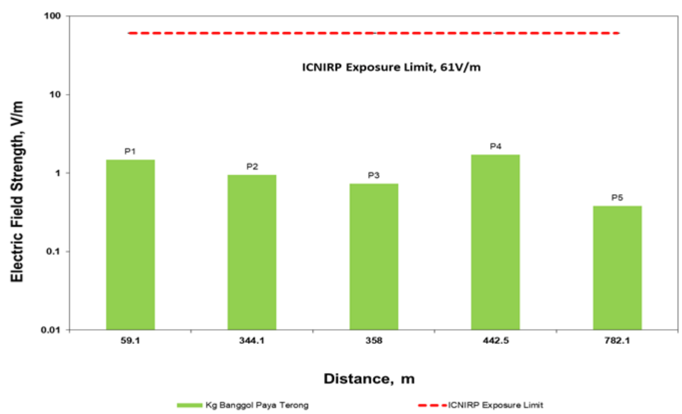

Figure 11 Exposure value of Electric Field Strength for each point located in Bukit Tunggal

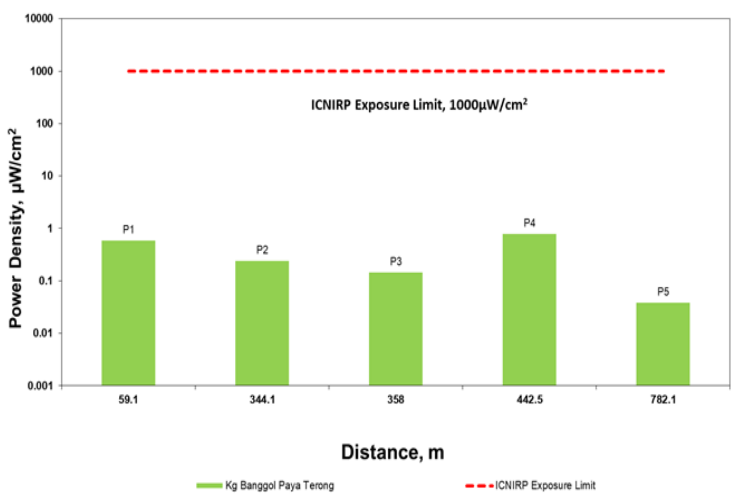

Figure 12 Exposure value of Power Density for each point located in Bukit Tunggal

Lastly, in reference to the graph in Figures 11 and 12 regarding the Bukit Tunggal location, it shows that the highest EF and PD average value is about 1.72 (V/m) and 0.79 (µW/cm²), which was identified at Klinik Kesihatan Bukit Tunggal. However, for the SMK Bukit Tunggal location at Kg Banggol Paya Terong the lowest average EF value is 0.38 (V/m) and PD value is 0.04 (µW/cm²). All the EF strength and PD values are summarized and shown in Table 3 below.

As for Bukit Tunggal subdistrict, the point located was in Klinik Kesihatan Bukit Tunggal, Kg Banggol Paya Terong, where the highest EF average reading was 1.72 (V/m) with a PD value of 0.79 (µW/cm²). Klinik Kesihatan Bukit Tunggal is surrounded by a residential area, school and is near the Kelantan-Kuala Terengganu main road, which is among the busiest roadway routes in Terengganu. This opinion is consistent with previous research, which found that signal sources from moving automobiles do contribute to ambient NIR exposure levels [22]. One factor that could cause higher RF values is a new BST installation to support 4G coverage located within 300m of the vicinity. In comparison to the more prevalent 3G technology, such frequencies have a limited range. This necessitates the placement of transmitters closer together in ever denser arrays [23]. All the facilities and residential homes were scattered around the BSTs located in residential areas and schools. However, most facilities require the utilization of a strong network to increase services and production efficiency [24]. Thus, many BSTs were built in close proximity to these structures in order to increase the network's strength. Since each measuring area has unique characteristics in terms of population density, micro-environment, and concrete buildings, hence, exposure values may vary based on the measurement location. Furthermore, fluctuating EF strength levels reported along the distance for each site are most likely due to various NIR sources accessible at that location. When comparing the findings to a previous study, it was found that the influence of RF fluctuations can be caused by the number of calls made from the BST during the time of measurement [22].

The average radiation levels were found to vary between 0.26 (V/m) to 3.35 (V/m) (0.02 µW/cm² to 2.97 µW/cm²) at all the measurement locations, with the highest level being 5.48% or over 18 times lower than the MCMC exposure limit for the public measured at Surau Pok Tuyu, whereby all the peaks recorded were within the standard guidelines stipulated by ICNIRP. The standard limit for RF EMR public exposure is shown in Table 3 while the summarized EMR value at Kuala Nerus is shown in Table 4 and Table 5 below. In contrast with EMR readings in Sweden in 2022, it demonstrates an imbalanced RF field distribution with numerous hotspots and Skeppsbron street was saturated with high levels of radiofrequency radiation [25].

Table 3 Standard limit of RF EMR public exposure

Organization	Frequency	Electric field (V/m)	Magnetic field (A/m)	Power density (mW/cm²)
ICNIRP	10 MHz - 400 MHz	28	0.073	200
	400 MHz – 2 GHz	$1.375f^{0.5}$	$0.0037f^{0.5}$	f/2
	2 GHz – 300 GHz	61	0.16	1000
MALAYSIA (MCMC)	10 MHz – 400 MHz	28	0.073	200
	400 MHz – 2 GHz	$1.375f^{0.5}$	$0.0037f^{0.5}$	f/2
	2 GHz – 300 GHz	61	0.16	1000

Table 4 Summary of exposure values for Electric Field

BST	Location	Distance (m)	Electric field (V/m)			
			Min	Max	Ave	Stdev
BST1	P1	53.8	1.43	1.81	1.60	±0.06
	P2	114.7	1.49	1.92	1.74	±0.08
	P3	209.8	0.47	0.76	0.59	±0.05
	P4	311.2	1.61	2.52	2.00	±0.17
	P5	332.6	1.93	2.62	2.31	±0.13
BST2	P1	54.5	1.70	2.32	1.95	±0.11
	P2	96.5	1.10	1.75	1.37	±0.11
	P3	137	0.60	1.10	0.87	±0.08
	P4	220.2	0.58	1.18	0.81	±0.10
	P5	248.6	0.70	2.80	1.97	±0.25
BST3	P1	79.7	1.09	1.58	1.34	±0.09
	P2	122.4	1.14	1.77	1.39	±0.08
	P3	160.5	0.47	0.86	0.65	±0.07
	P4	194.8	1.75	5.03	3.35	±0.62
	P5	261.2	1.09	2.30	1.65	±0.24
BST4	P1	56.7	0.75	1.32	0.98	±0.11
	P2	180.5	1.32	2.29	1.74	±0.20
	P3	210.7	1.46	2.65	1.93	±0.23
	P4	262.2	0.35	0.92	0.53	±0.10
	P5	374.1	0.53	1.28	0.92	±0.12
BST5	P1	197.2	1.65	2.99	2.40	±0.27
	P2	198.9	1.15	1.75	1.49	±0.11
	P3	325.4	0.05	0.42	0.26	±0.07
	P4	473.4	0.49	1.56	1.07	±0.18
	P5	632.5	0.53	1.03	0.80	±0.09
BST6	P1	50.3	1.39	1.54	1.45	±0.04
	P2	505.7	0.13	0.69	0.30	±0.09
	P3	639.4	1.27	1.86	1.56	±0.10
	P4	986.3	1.12	1.56	1.36	±0.08
	P5	998.8	0.20	0.68	0.37	±0.07
BST7	P1	83.6	0.50	1.08	0.65	±0.09
	P2	113.4	0.86	1.36	1.02	±0.09
	P3	416.9	1.03	1.65	1.31	±0.11
	P4	425.1	1.40	2.53	2.03	±0.25
	P5	543.4	0.66	1.22	0.94	±0.12
BST8	P1	70	1.18	1.85	1.47	±0.11
	P2	127	0.84	1.55	1.06	±0.13
	P3	180	1.70	3.21	2.41	±0.29
	P4	259.5	0.18	0.48	0.34	±0.06
	P5	289.7	1.77	2.68	2.19	±0.17
BST9	P1	32.5	0.38	0.83	0.59	±0.09
	P2	126	0.85	1.55	1.13	±0.13
	P3	135.2	1.92	3.69	2.47	±0.31
	P4	204.2	1.29	1.89	1.60	±0.12
	P5	224.1	0.93	1.46	1.15	±0.10
BST10	P1	59.1	1.27	1.87	1.49	±0.12
	P2	344.1	0.80	1.15	0.95	±0.06
	P3	358	0.53	0.92	0.74	±0.06
	P4	442.5	1.35	2.14	1.72	±0.14
	P5	782.1	0.17	0.55	0.38	±0.07

Table 5 Summary of exposure values for Power Density

BST	Location	Distance (m)	Power Density (μW/cm²)			
			Min	Max	Ave	Stdev
BST1	P1	53.8	0.54	0.87	0.68	±0.00
	P2	114.7	0.59	0.98	0.81	±0.00
	P3	209.8	0.06	0.15	0.09	±0.00
	P4	311.2	0.69	1.69	1.06	±0.01
	P5	332.6	0.99	1.82	1.41	±0.00
BST2	P1	54.5	0.77	1.43	1.01	±0.00
	P2	96.5	0.32	0.81	0.50	±0.00
	P3	137	0.10	0.32	0.20	±0.00
	P4	220.2	0.09	0.37	0.17	±0.00
	P5	248.6	0.13	2.08	1.03	±0.02
BST3	P1	79.7	0.31	0.66	0.48	±0.00
	P2	122.4	0.34	0.84	0.51	±0.00
	P3	160.5	0.06	0.19	0.11	±0.00
	P4	194.8	0.81	6.71	2.97	±0.10
	P5	261.2	0.32	1.40	0.72	±0.02
BST4	P1	56.7	0.15	0.47	0.26	±0.00
	P2	180.5	0.47	1.39	0.80	±0.01
	P3	210.7	0.57	1.86	0.98	±0.01
	P4	262.2	0.03	0.23	0.07	±0.00
	P5	374.1	0.07	0.43	0.22	±0.00
BST5	P1	197.2	0.72	2.36	1.52	±0.02
	P2	198.9	0.35	0.81	0.59	±0.00
	P3	325.4	0.00	0.05	0.02	±0.00
	P4	473.4	0.06	0.64	0.30	±0.01
	P5	632.5	0.08	0.28	0.17	±0.00
BST6	P1	50.3	0.51	0.63	0.56	±0.00
	P2	505.7	0.00	0.13	0.02	±0.00
	P3	639.4	0.43	0.91	0.64	±0.00
	P4	986.3	0.33	0.65	0.49	±0.00
	P5	998.8	0.01	0.12	0.04	±0.00
BST7	P1	83.6	0.07	0.31	0.11	±0.00
	P2	113.4	0.19	0.49	0.28	±0.00
	P3	416.9	0.28	0.72	0.46	±0.00
	P4	425.1	0.52	1.70	1.10	±0.02
	P5	543.4	0.11	0.39	0.24	±0.00
BST8	P1	70	0.37	0.91	0.57	±0.00
	P2	127	0.19	0.63	0.30	±0.00
	P3	180	0.77	2.73	1.54	±0.02
	P4	259.5	0.01	0.06	0.03	±0.00
	P5	289.7	0.83	1.90	1.28	±0.01
BST9	P1	32.5	0.04	0.18	0.09	±0.00
	P2	126	0.19	0.64	0.34	±0.00
	P3	135.2	0.98	3.60	1.62	±0.03
	P4	204.2	0.44	0.95	0.67	±0.00
	P5	224.1	0.23	0.56	0.35	±0.00
BST10	P1	59.1	0.43	0.93	0.59	±0.00
	P2	344.1	0.17	0.35	0.24	±0.00
	P3	358	0.07	0.23	0.14	±0.00
	P4	442.5	0.49	1.22	0.79	±0.01
	P5	782.1	0.01	0.08	0.04	±0.00

3.2 Inverse Distance Weighted (IDW) Interpolation GIS mapping of EMR at Selected BSTs around Kuala Nerus

The GIS mapping of Kuala Nerus also shows that the BST at Kg Pok Tuyu is in a red coloured region, as shown in Figure 12. This region represents the highest average value of EF strength compared to another region that is yellow and green coloured.

The GIS mapping of IDW Interpolation shows that the exposure level in the affected area can be determined using the exposure value key provided on each map displayed, where the darkest red colour represents the highest level of radiation exposure, while a red colour that fades into yellow indicates a high-medium level of radiation exposure, and a yellow-greenish colour indicates a low level of radiation exposure, and finally, the darkest green indicates the lowest level of radiation exposure. Based on Figure 12 below, the darkest red colour is located at P4, which refers to Surau Pok Tuyu, in comparison to all the locations in Kuala Nerus. Surau Pok Tuyu is also located at the centre of two BSTs in the vicinity, which spikes the value of the EF strength, especially during the daytime. This is due to the collision of signals transmitted by all neighbouring BSTs, which could interact in one of two ways, either constructive interference or destructive interference. However, in this location, constructive interference was built [26]

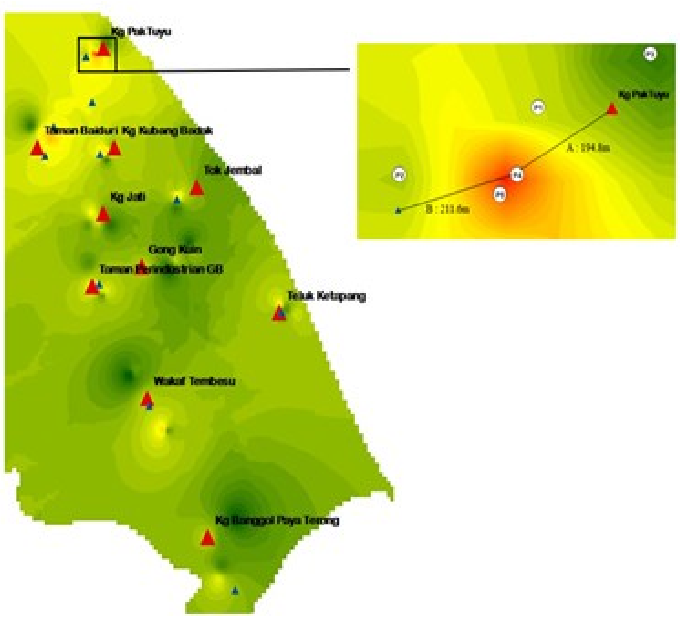

Figure 12 Mapping of EMR saturation at ten selected BSTs in Kuala Nerus

4.0 CONCLUSION

It can be concluded that the non-ionizing radiation exposure issue is worrying due to the harmful effects it could have, thus, it is important to have a current reading to ensure that the current reading does not exceed the standard limits, which in turn could indirectly lead to health screening initiatives for the public to determine NIR exposure. This study shows that exposure levels are within the standard limit and most of the sources that contribute to RF EMR in residential areas in Kuala Nerus comes from mobile cellular phone services. Adding additional antennas to the structure or raising the transmitting power of existing antennas is likely to increase radiation levels, and if this happens, a new evaluation of the site may be required.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Acknowledgement

The authors would like to thank employees of the Malaysia Nuclear Agency's Non-Ionizing Group for their tremendous assistance and hospitality during the research. The Fundamental Research Grant Scheme provided financing for this study (RACER/1/2019/SKK06/UNISZA//1).

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