Journal for Social Science Archives

Online ISSN: 3006-3310
Print ISSN: 3006-3302
Volume 3, Number 1, 2025, Pages 1349 – 1370
Journal Home Page
https://jssarchives.com/index.php/Journal/about

Geographical Information System Mapping of Existing Cellular Towers Infrastructure in Quetta City Centre, Pakistan

Shafi Ullah[1], Niamat Ullah[2], Anila Ali[3], Aziza Sarwar[4], Ali Asghar[5], Shahzaib Khan[6] & Syed Abdullah Sami[7]

[1]*Department of Computer Engineering, Balochistan University of Information Technology, Engineering & Management Sciences (BUITEMS), Quetta 87300, Pakistan, Email: shafi.ullah@buitms.edu.pk*
[2]*Spatial Decision Support System (SDSS) Lab, NCGSA, Balochistan University of Information Technology, Engineering & Management Sciences (BUITEMS), Quetta 87300, Pakistan, Email: niamatullahza@gmail.com*
[3]*Department of Environmental Sciences, Balochistan University of Information Technology, Engineering & Management Sciences (BUITEMS), Quetta 87300, Pakistan, Email: anila.zafar@buitms.edu.pk*
[4]*Department of Chemistry, Balochistan University of Information Technology, Engineering & Management Sciences (BUITEMS), Quetta 87300, Pakistan, Email: aziza.sarwar@buitms.edu.pk*
[5]*Department of Textile Engineering, Balochistan University of Information Technology, Engineering & Management Sciences (BUITEMS), Quetta 87300, Pakistan, Email: ali.asghar@buitms.edu.pk*
[6]*Spatial Decision Support System Lab, NCGSA, Balochistan University of Information Technology, Engineering & Management Sciences (BUITEMS), Quetta 87300, Pakistan, Email: shahzaibahmedkhan333@gmail.com*
[7]*Department of Environmental Sciences, (BUITEMS), Quetta 87300, Pakistan, Email: sabdullahsami85@gmail.com*

ARTICLE INFO

Article History:

Received:	*January*	*28, 2025*
Revised:	*March*	*15, 2025*
Accepted:	*March*	*19, 2025*
Available Online:	*March*	*21, 2025*

Keywords:

Existing Cellular Towers (EMF), GIS, remote sensing, Quetta, Balochistan

Corresponding Author:
Niamat Ullah
Email:
niamatullahza@gmail.com

ABSTRACT

Smart devices have become ubiquitous, forcing top communication providers to develop increasingly sophisticated transmission mechanisms to keep up with the demand. Mobile towers not only contain antennas and base transceiver stations but also repair communication links for users using Electro-Magnetic Field, Radiation (EMF-R). The telecom sector has advanced tremendously over the past decade. Such profligate growth in EMF-R requires to be investigated if they are operating under safe protocols i.e., distance between radiation range and population. Therefore, this study aimed to investigate the quantity of cell phone towers allocated in residential and commercial zones and if its operating under permissible levels (EMF-R) in the city center, Quetta district, Baluchistan. A Geographic Information System (GIS) was used for the demarcation of the base stations (n = 27). The total area under study was 5.75 km2 consisting of mixed activities (residential and commercial). EMF-RF was monitored through an Acoustimeter (Model: AM-10-RF) at 30m, 50m, and 300m. According to the previous studies, no residential activity should be present within 300m of the tower, whereas, the current study revealed that residential activities lie within a 30m radius of the tower. The peak E-Field Exposure readings in each radius. The readings in 30m and 50m are significantly beyond the FCC regulations, as the standard states that the reading should not be greater than 2 V/m in 300m. Many people are ignorant of the health concerns posed by cell phones and cell tower radiation because they do not use or have never used one. Cell phone firms maintain there are no health risks. However, other countries have adopted radiation regulations that are 1/100th to 1/1000th of these values based on their findings. The tower should be built at a distance of 300m from any residential or business activity. Use shielding materials to limit cell tower radiation. I suggest EMF-blocking paint and silver mesh drapes. The most cost-effective method is to simply shield your home's vital regions. Installing EMF-blocking canopies around your mattresses or filling your walls with conductive materials could help.

Introduction

As smart devices and technology have advanced, users have grown accustomed to using them in their daily lives. Since smart devices are becoming a necessary component of daily life, major communication providers have had to create increasingly complex transmission methods to keep up with the growing demand. Mobile towers serve as transmission carriers, enabling communication via radio frequency (RF) signals, in addition to housing antennas and base transceiver stations (Al-Sahly et al., 2018). Only a tiny portion of mobile phone users are aware of the possible health dangers connected with electromagnetic radiation (EMR) exposure, even though mobile phones are widely used for communication, employment, and other purposes (Pachuau & Pachuau, 2016). With the help of vast networks of cell towers that send out radio frequency signals, wireless communication has almost become ubiquitous. Concerns about the possible health effects of radiofrequency exposure, especially from base stations, have increased throughout the past ten years (Lalrinthara Pachuau et al., 2015). According to studies, RF radiation from mobile towers may have long-term negative health impacts. Although there are many benefits to telecommunications technology, concerns over safety regulations and the effects of extended exposure to radiofrequency emissions have been brought up by its quick development.

The mobile telecommunications sector in Pakistan is expanding quickly each year. More than half of Pakistanis own a cell phone, and 90% of them reside in locations with mobile phone service (Tahir Mehmood, 2015). With 184 million mobile users in 2012, the nation has the greatest mobile penetration rate in South Asia (Muhammad Akram Choudary et al., 2012). Cell tower electromagnetic field radiation (EMF-R) exposure has increased as a result of mobile network expansion, especially in densely populated areas. Cell towers are frequently erected close to residential structures in urban areas without proper regulatory monitoring, despite studies suggesting that residential buildings should keep a minimum of 300 meters away from cell towers to reduce extended EMF exposure. Research indicates that many mobile towers above advised RF exposure limits despite current safety rules, particularly in metropolitan settings with dense populations (Aldad et al., 2017). Increased radiofrequency radiation exposure has been associated with neurological problems, DNA damage, and oxidative stress, all of which may have long-term health effects (Yakymenko et al., 2016). Additionally, new research suggests that because of their physiological characteristics and longer exposure durations, children and the elderly are more vulnerable to the negative effects of radiofrequency radiation (Morris & Ziska, 2020).

To avoid thermal consequences, exposure limits are specified by international safety guidelines, such as those set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). However, other researchers contend that the present safety levels may not be adequate to safeguard public health due to growing concerns regarding non-thermal impacts, such as sleep difficulties, memory impairment, and hormone abnormalities (Bandara & Carpenter, 2018). To lessen possible health hazards, some nations have lowered acceptable limits for radiofrequency radiation and instituted stricter regulations (Sage & Burgio, 2018). This study aims to assess the spatial distribution and EMF exposure levels of cell towers in Quetta, Baluchistan, to evaluate compliance with safety regulations. A Geographic Information System (GIS) was used to map 27 cell towers within a 5.75 km² area consisting of mixed residential and commercial zones. EMF radiation levels were measured at distances of 30m, 50m, and 300m using an Acoustimeter (Model: AM-10-RF). The results indicate that several residential buildings are within 30m of cell towers, significantly below the recommended safe distance. Peak electric field (E-field) exposure

values recorded at 30m and 50m exceeded the Federal Communications Commission (FCC) standard of 2 V/m at 300m (Havas, 2017).

Similar studies in other regions have reported non-compliance with EMF safety regulations, highlighting the need for stricter monitoring (Hardell & Carlberg, 2019). High EMF-R exposure levels in residential areas raise serious concerns about potential health effects, including neurological disorders, sleep disturbances, and other long-term health impacts. Although telecommunication companies argue that their networks operate within permissible limits, studies indicate that some countries enforce stricter regulations, limiting exposure to as low as 1/100th of FCC standards due to health concerns (Pall, 2018). The lack of public awareness exacerbates the issue, as many residents are unaware of potential EMF hazards in their surroundings. Policymakers should impose more stringent zoning laws to guarantee a minimum of 300 meters between residential buildings and cell towers to reduce the risks of electromagnetic field exposure. To reduce interior exposure in high-risk settings, shielding options such as protective canopies, conductive walls, and EMF-blocking materials should be investigated. To assess long-term health effects and create region-specific safety regulations that strike a compromise between the expansion of telecommunications infrastructure and public health issues, more study is required.

Materials and methods

Study area

Quetta is the capital and most populated urban center of Balochistan with latitudes of 29°48' and 30°27' north and longitudes of 66°14' and 67°18' east are the coordinates of the district as shown in Figure 1. (Ullah et al., 2024). It covers an area of 3,447 kilometers square and with an elevation of 5,500. According to the 7th Population and Housing Census 2023, the population of Quetta district is 2,595,492 (2.59 million) with an urban proportion of 60.32% and a density of 752.97 people/km^2 (Pakistan Bureau of Statistics, 2024). Quetta is encircled by Pishin to the north, Sibi to the east, Mustung and Chaghi districts to the south, and Afghanistan to the west via the Durand Line (Ullah et al., 2025). The district is surrounded by notable mountain ranges that add to its natural beauty, including Sulaiman, Tobak Kakari, Murdar, Zarghoon, Takatu, and Chiltan. Quetta District comprises several administrative subdivisions that include City, Kuchlak, Saddar Tehsil, Sariab, and Sub-Tehsil Panjpai.

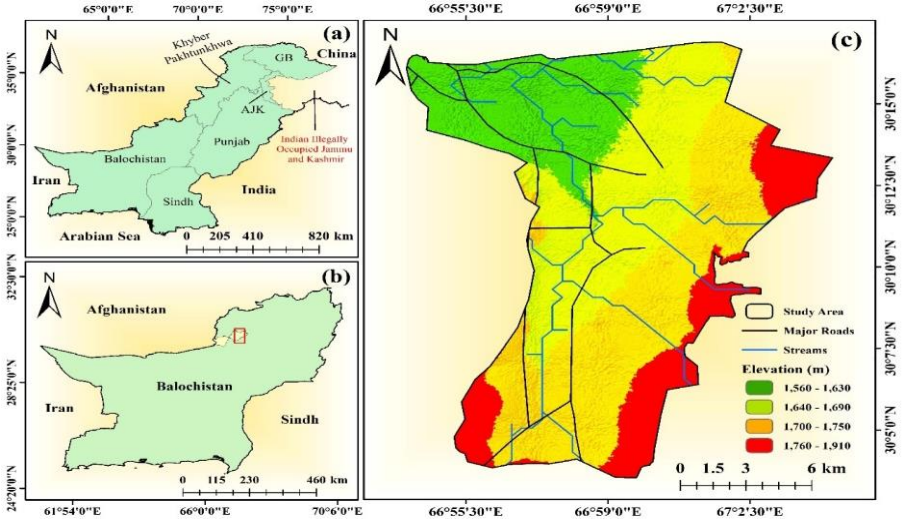


Figure 1. (a) Pakistan, (b) Balochistan province and (c) study are (Quetta City).

Methods

The methodology related to the exposure of radio frequency waves surrounded by the base stations will be measured and clearance of the site will also be checked through a Geographical Information System (GIS) are explained in detail.

Research Design

Framework for research design to highlight the structure of this study. It was carried out through the following steps:

Step 1: Preliminary study of the research focused on identifying the problem of RFR exposure effects on the surrounding environment. In this step, the reason for carrying out the study and its significance is justified.

Step 2: In order to create a background for the study, previous research conducted in reference to the identified topic was studied in detail. An understanding was developed of the electromagnetic field and its effects on human health in the perspective of psychological and physical. It was also identified that prolonged exposure to electromagnetic fields can affect health.

Step 3: Data collection and assessment at the study site helped to achieve a standard model for quantitative research and statistical analysis. This step included a detailed experimentation of RFR exposure near base stations. The identification of the base station in Quetta city was done through Geographical Information System (GIS). Characterizing the data of the base station obtained through GIS in low and high-density residential and commercial areas. Measurement of the radiation effects was completed through the Acoustimeter of the selected area.

Step 4: The data collected from the study site was compared with the safety standards.

Step 5: The last step focused on the conclusion and recommendation given after the completion of the study.

Study Flow Plan

The study area selected for the research is Quetta City which has a mixed-use activity i.e. both residential and commercial. Then using coordinates, the towers present in the study site were marked. Towers were named with the specific name i.e. T1-T27. ArcGIS10.8.2 software was used to map the tower on the site and the distance was marked surrounding each tower in 30m, 50m, and 300m respectively. The tower was marked with this radius to know which activity was occurring nearest to the tower location. RF exposure was monitored in each tower in each radius in all surroundings. RF exposure monitored from the tower will was compared with the safety standards. The figure below shows the flowchart for the present study.

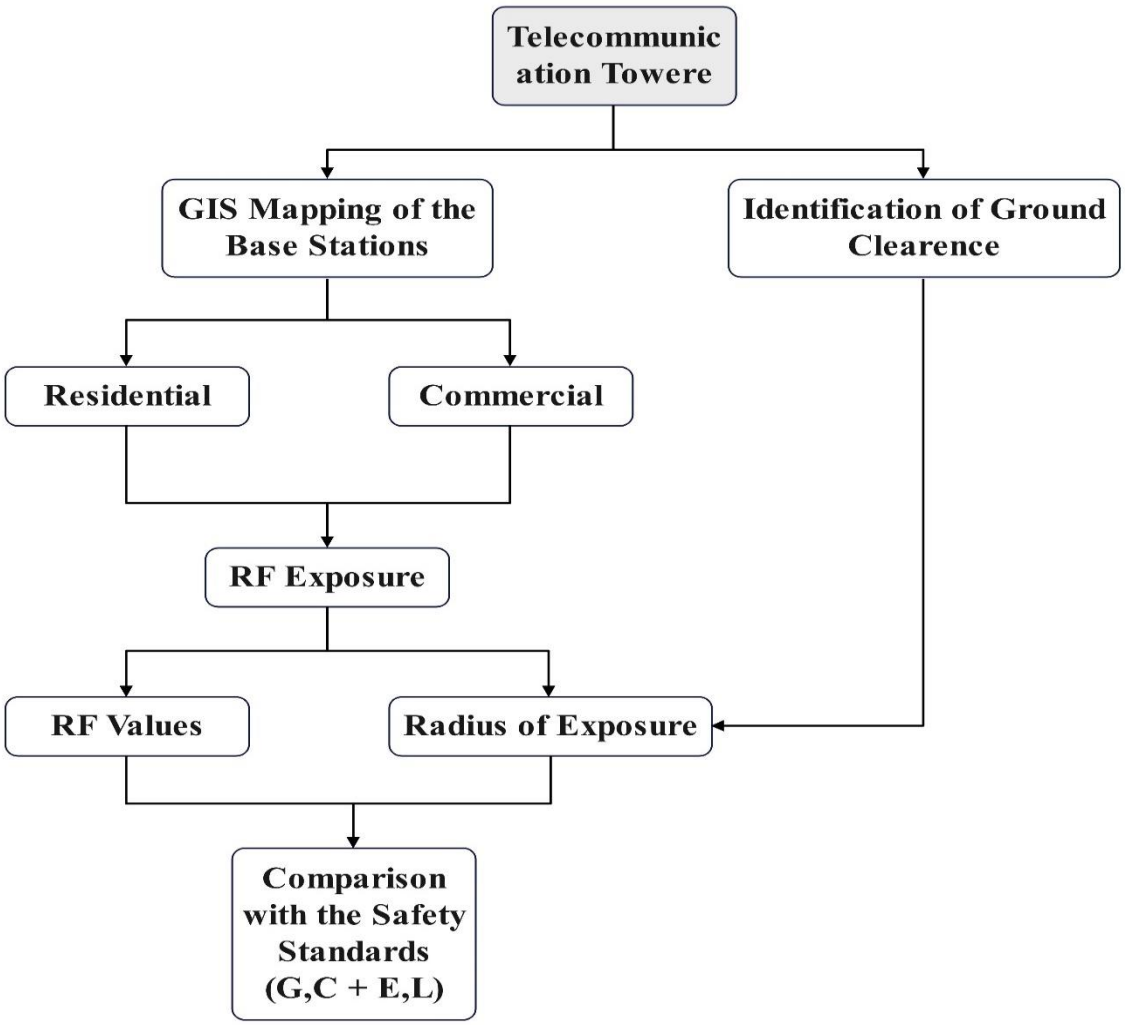


Figure 2. Study flow plan.

Site Selection Criteria

The area of the study identified for this research is the base stations located in Quetta city. The base station located in the city will be mapped through a Geographical Information System (GIS). Then the area will be characterized through usage as Residential and commercial areas. The population Density of residential areas in Downtown of the city is in large numbers as users prefer to live near the necessities in daily life usage. The tentative site for the research is the downtown area of the city with a mixed population Residential and commercial to study the effects of RF exposure from the base station. The study area for the research is from Jinnah Road to Quarry Road and the streets and roads in between these boundaries. A total of 27 base stations are present in the selected area that are working. The area of the study site is 5.75 km as shown in Figure 3a.

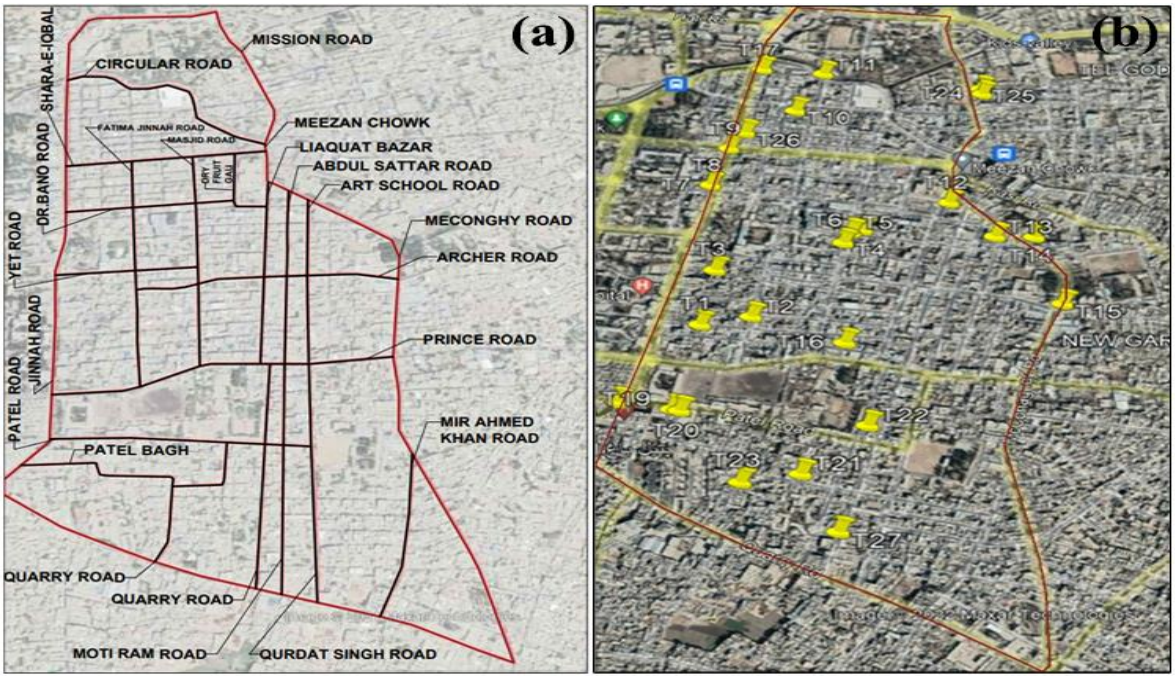


Figure 3. (a) Study site plan and (b) tower description in the study area.

Demarcation of Base Stations

The demarcation of the base station i.e. location of the towers in Quetta city will be mapped through GIS. Through the software, the exact location of the towers will be mapped in the master plan of Quetta City. The radius will be marked as 30m, 50m, and 300m surrounding each base station. Towers that will be monitored are 27 in numbers that are located in the study site that is discussed above. The figure shows the study site area is from Jinnah Road to Shara-e-Gulistan, Mission Road, Meezan Chowk, McConaughey Road to Quarry Road, and all the adjacent roads and streets in these surroundings. The area is 5.75 Km in which Residential and commercial activities are present. A total 27 numbers of towers are present in the study site and are shown as T_1-T_{27}. Figure 3b shows the tower description in the study area.

Study Area Population

The study population comprises the mixed population in the area selected for the study. Main Jinnah Road is commercial in which offices banks and shops are situated. The roads and streets adjacent to Jinnah Road like Patel Road, Patel Bagh, Fatima Jinnah Road, and adjacent streets have residential settlements with shops also.

Sample size of the Towers

The sample size of the towers is 27 in number and each tower is marked with a radius of 30m, 50m and 300m four readings will be observed in each radius of each tower, and from four sides i.e. total 12 number of readings will be monitored from each tower. The reading will be monitored for one minute around 12:00 pm. Figure 4 given below shows the sampling technique for individual towers.

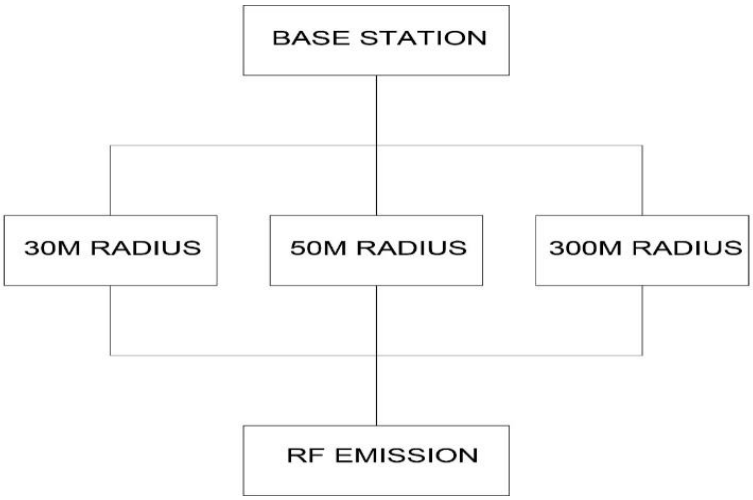


Figure 2. Sample size diagram.

RF EMF Exposure Monitoring

The identification of towers in the mixed areas i.e. Residential and Commercial will be identified through the GIS software. The ground clearance around the towers will also be identified through GIS software. The radius measurement of the exposure will be 30m, 50m, and 300m as studied in the literature review. The RF exposure will be monitored through the Acoustimeter in the following radius as mentioned and the reading will be monitored from all the sides of the towers as the boosters are attached to all four sides of the towers. The timing of the readings will be for one minute as the device which will be used i.e. the Acoustimeter gives the average reading for RF exposure. The total number of the readings will consist of the radius as mentioned above four readings will be monitored in each radius. Because persons living within a 50-300-meter radius of the towers are more susceptible to the harmful effects of electromagnetic radiation, the RF exposure of the settlement surrounding the towers will be monitored. Figure 5 below shows the exposure monitoring of the tower.

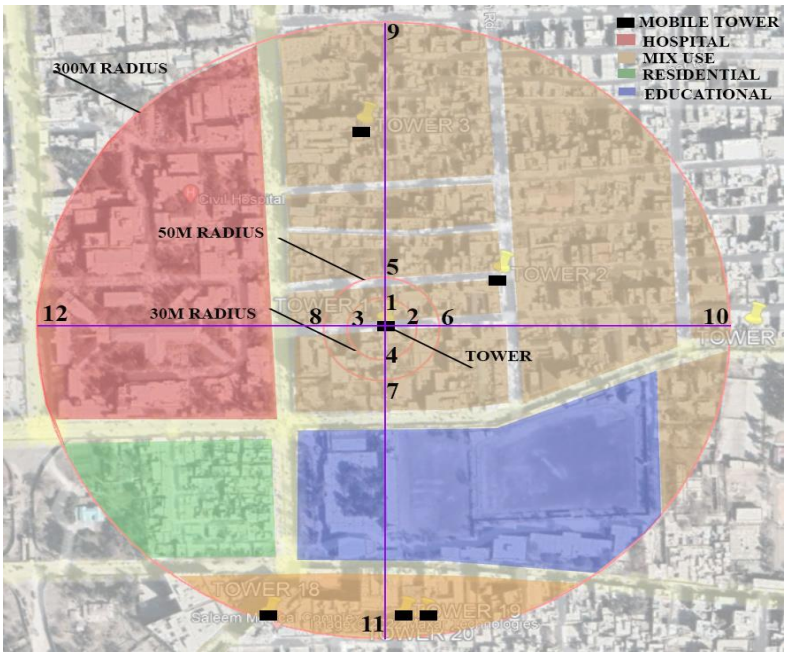


Figure 3. Exposure Monitoring of Towers (Google Earth)

Instrument used for the study

The data collection techniques include the monitoring of RFR exposure using a scientific instrument called Acoustimeter RF Meter Model AM-10. The technical details are presented below in Table 1. The sensor is capable of responding to levels as low as 0.02 V/m-audio from demodulation can be heard at these low levels. The LCD will display the maximum–hold frequency (since power was turned on), the max value, and the mean values.

Table 1. Specification of Acoustimeter RF Meter

Technical Specifications	Specified frequency response when the internal antenna is used: 200MHz-8000MHz +- 6DB+- 0.02 V/m
Measurement Range	Peak: 0.02 – 6.00 volts per meter, V/m Average: 1-100 000 microwatts/sq.m

Results and Discussion

In this section, the result related to the exposure of radio frequency waves from telecommunication towers was monitored through Acoustimeter in the selected study site. A total 27 numbers of towers were present in the study site the readings were monitored in three different radii as discussed 30m, 50m, and 300m respectively. Four readings were monitored in each radius surrounded by the tower. The readings were monitored around 12 pm-1 pm in the afternoon as the study site selected had mixed-use activities present i.e. commercial and residential.

Towers Located in the Study Site

As a result of technological advancement, the number of mobile towers is increasing day by day to meet the requirements. As the study site shows in 5.75 km of the area we have 27 numbers of towers which are way above. A cell tower range can be far reached about 19.2 miles (31 km). However, cell towers are more likely to work on a max range of about 10 miles (16 km), as after 10 miles the protocol used for cell phone calls becomes unreliable.3G/4G/5G (FR1) Mobile base station tower: it is technically possible to cover up to 50-150 km.

GIS Mapping

The towers located in the study site were pointed out on GIS and the radius was marked on each tower to monitor the RF exposure. The towers were marked by the coordinates point of the towers. The radius was marked on each tower in 30M, 50M, and 300M respectively. Figure 6 below shows the mapping and effective radius marked on each tower present on site.

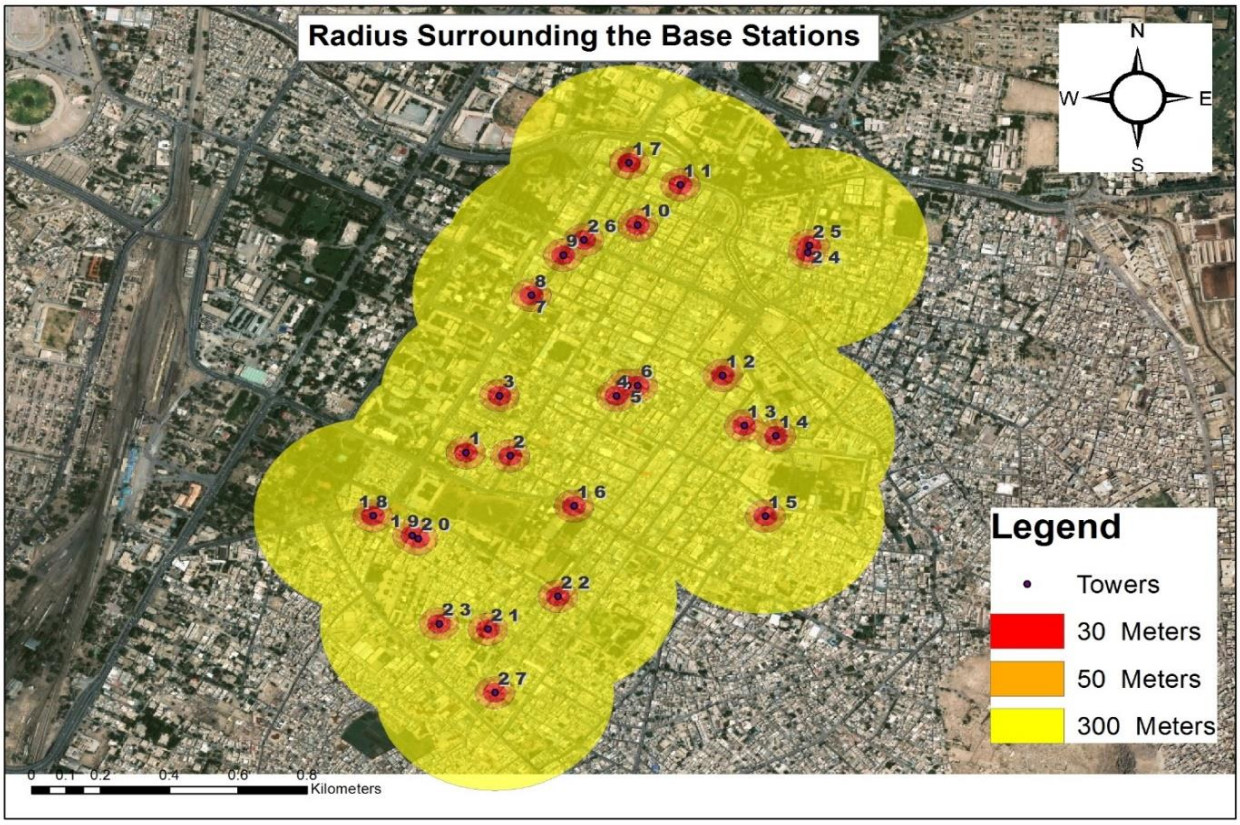


Figure 4. GIS mapping of towers and effective radius.

The towers were marked on GIS software and the radius were marked as discussed above. Then the activities under the radius were pointed out which activity is occurring in the area. As discussed above the residential activity should not be present in a 300m radius surrounding the tower. The table given below shows that in the present study site, we are having residential activities in a 30m radius that is at high exposure to the tower. Table 2 shows the tower details and the commercial and residential activities surrounding the towers.

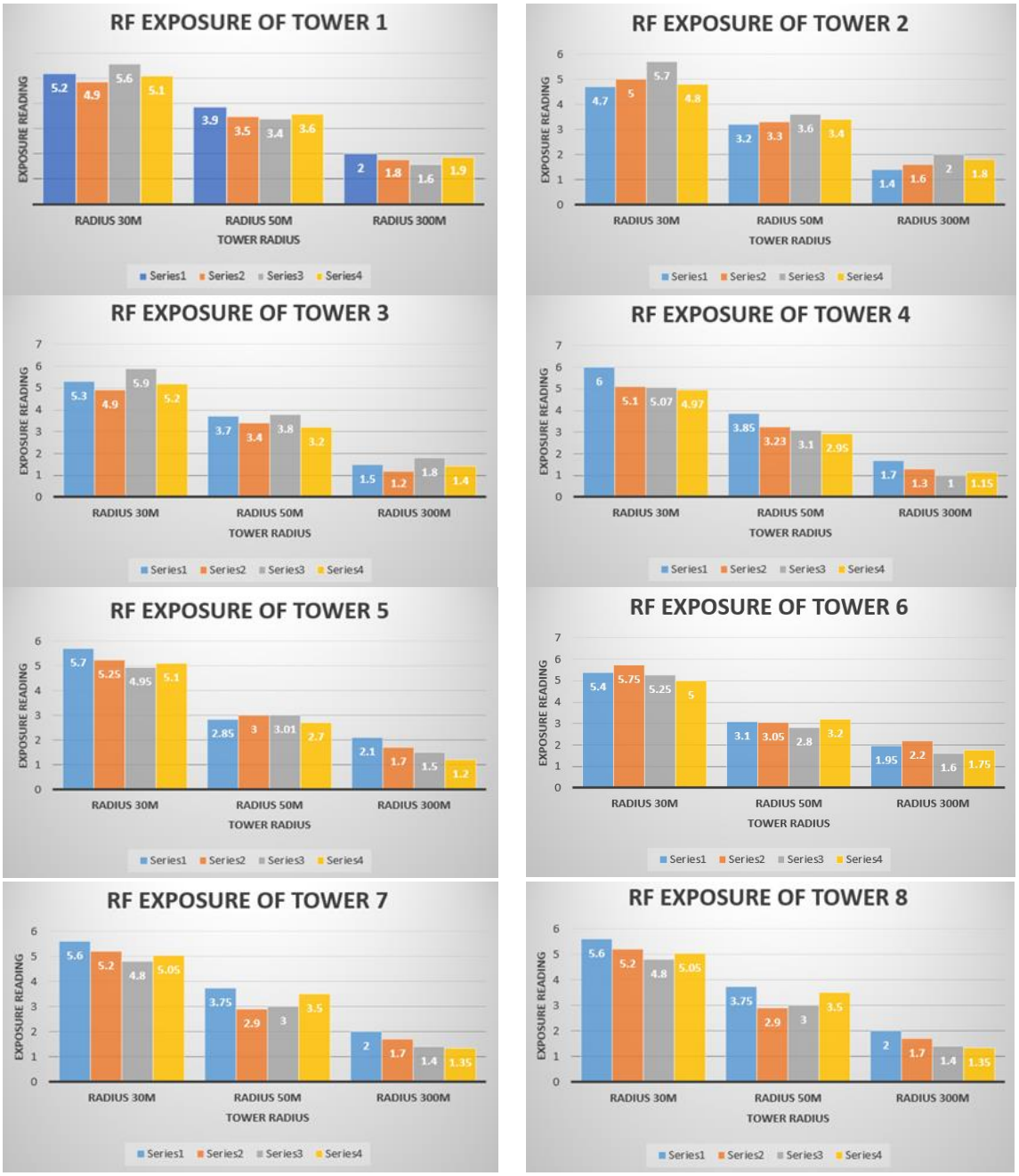
Table 2. Tower and Activity details.

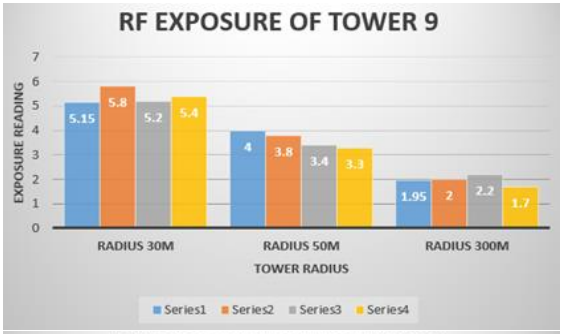
Location	Coordinates	Tower No.	Radius 30m		Radius 50m	
			Commercial	Residential	Commercial	Residential
Sher Muhammad Road	30°11’31.33’’N 67°0’34.85’’E	T1	4	2	11	9
Faiz Muhammad Road	30°11’31.00’’N 67°0’39.00’’E	T2	6	4	8	6
Krishna Street	30°11’37.00’’N 67°0’39.00’’E	T3	0	7	3	15
Masjid Road	30°11’37.00’’N 67°0’49.00’’E	T4	8	0	14	3
Masjid Road	30°11’38.00’’N 67°0’50.00’’E	T5	11	0	17	3
Masjid Road	30°11’38.00’’N 67°0’51.00’’E	T6	10	0	16	2

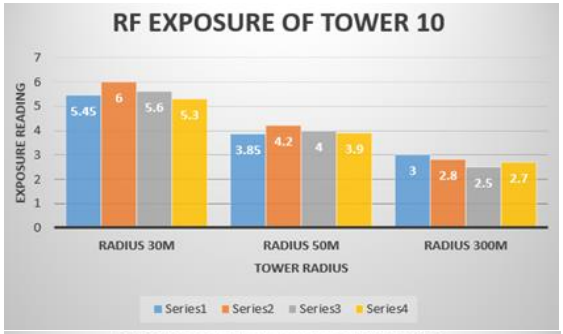
Jinnah Road	30°11’47.00’’N 67°0’41.00’’E	T7	7	0	27	0
Jinnah Road	30°11’47.00’’N 67°0’41.00’’E	T8	7	0	27	0
Jinnah Road	30°11’47.00’’N 67°0’44.00’’E	T9	9	0	25	0
Thana Road	30°11’54.00’’N 67°0’51.00’’E	T10	6	0	18	0
Jamal Uddin Afghani Road	30°11’58.00’’N 67°0’55.00’’E	T11	8	0	22	0
Liaquat Bazar	30°11’39.00’’N 67°0’59.00’’E	T12	5	0	20	0
Jamiat Rai Road	30°11’34.00’’N 67°1’1.00’’E	T13	7	0	15	3
McConaghey Road	30°11'33.00"N 67° 1'4.00"E	T14	11	0	18	4
McConaghey Road	30°11'25.00"N 67° 1'3.00"E	T15	6	0	17	4
Prince Road	30°11'26.00"N 67° 0'45.00"E	T16	7	0	15	0
Jinnah Road	30°12'0.19"N 67° 0'50.19"E	T17	6	0	17	0
Jinnah Road	30°11'25.19"N 67° 0'26.19"E	T18	2	0	6	3
Patel Bagh	30°11'23.09"N 67° 0'29.81"E	T19	2	6	6	10
Patel Bagh	30°11'23.09"N 67° 0'29.81"E	T20	2	6	6	10
Jalaluddin Street	30°11'13.73"N 67° 0'36.90"E	T21	4	8	8	25
Shawakshah Road	30°11'16.99"N 67° 0'43.48"E	T22	9	3	15	12
Mulltani Muhalla	30°11'14.27"N 67° 0'32.31"E	T23	0	15	3	27
Mission Road	30°11'51.26"N 67° 1'7.01"E	T24	8	0	18	0
Mission Road	30°11'51.94"N 67° 1'7.15"E	T25	9	1	20	2
Shahra-E-Iqbal	30°11'52.52"N 67° 0'45.96"E	T26	7	0	17	0
Moti Ram Road	30°11'7.40"N 67° 0'37.57"E	T27	3	7	5	15

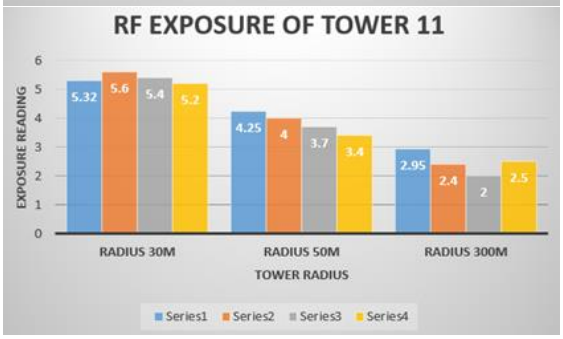
Monitoring of RF Exposure

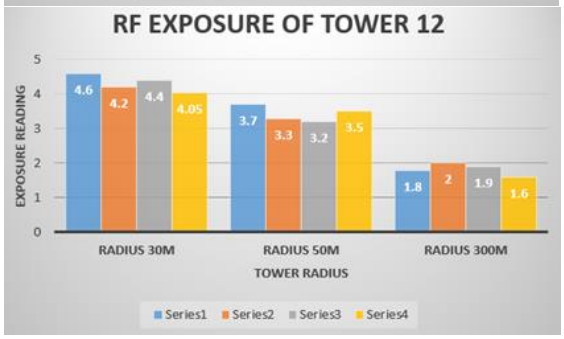
The RF Exposure was monitored from the RF Meter Model AM-10 Acoustimeter. The exposure was monitored in each radius in four quadrants. Four readings were monitored in a 30m radius and respectively in a 50m and 300m radius. The reading was monitored for 1 Min and the Peak E-Field (V/m) and Peak Power ($\mu W/m^2$) reading was noticed. The bar charts show the Peak E-Feld Exposure of the towers in each radius as shown in Figure 7.

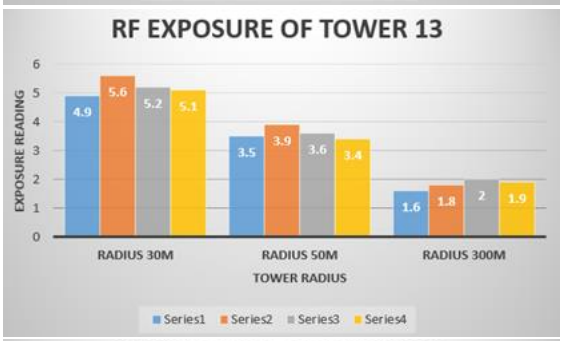


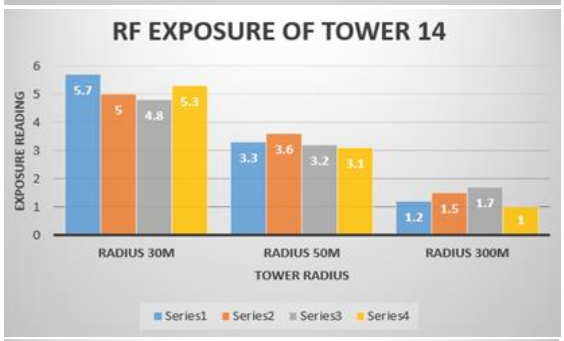

RF EXPOSURE OF TOWER 9
EXPOSURE READING
5.15
5.8
5.2
5.4
4
3.8
3.4
3.3
1.95
2
2.2
1.7
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4

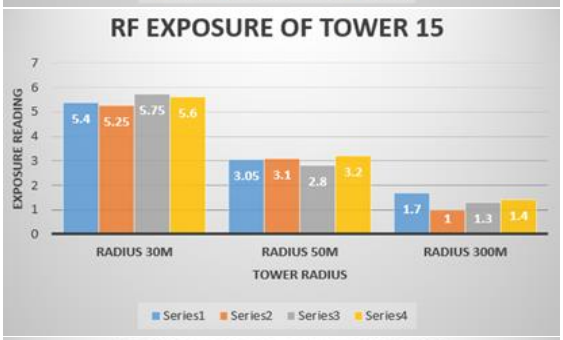

RF EXPOSURE OF TOWER 10
EXPOSURE READING
5.45
6
5.6
5.3
3.85
4.2
4
3.9
3
2.8
2.5
2.7
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4

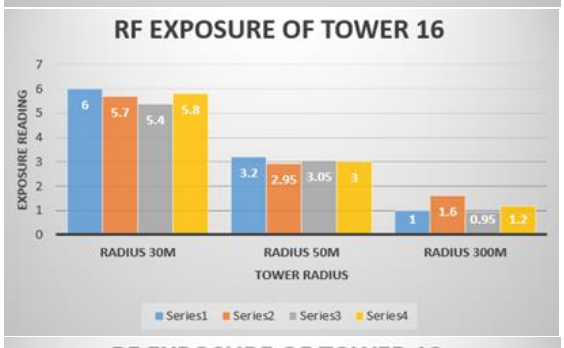

RF EXPOSURE OF TOWER 11
EXPOSURE READING
5.32
5.6
5.4
5.2
4.25
4
3.7
3.4
2.95
2.4
2
2.5
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4

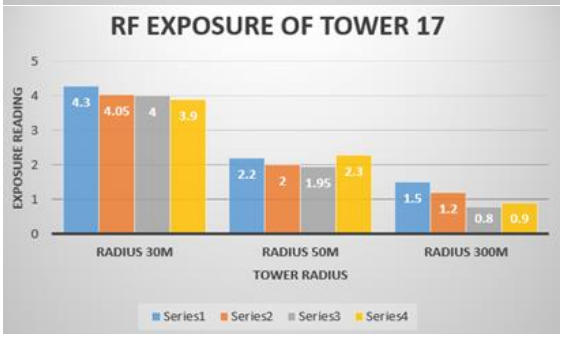

RF EXPOSURE OF TOWER 12
EXPOSURE READING
4.6
4.2
4.4
4.05
3.7
3.3
3.2
3.5
1.8
2
1.9
1.6
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4

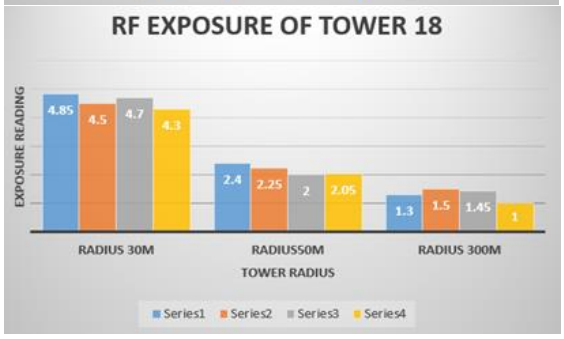

RF EXPOSURE OF TOWER 13
EXPOSURE READING
4.9
5.6
5.2
5.1
3.5
3.9
3.6
3.4
1.6
1.8
2
1.9
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4


RF EXPOSURE OF TOWER 14
EXPOSURE READING
5.7
5
4.8
5.3
3.3
3.6
3.2
3.1
1.2
1.5
1.7
1
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4


RF EXPOSURE OF TOWER 15
EXPOSURE READING
5.4
5.25
5.75
5.6
3.05
3.1
2.8
3.2
1.7
1
1.3
1.4
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4


RF EXPOSURE OF TOWER 16
EXPOSURE READING
6
5.7
5.4
5.8
3.2
2.95
3.05
3
1
1.6
0.95
1.2
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4


RF EXPOSURE OF TOWER 17
EXPOSURE READING
4.3
4.05
4
3.9
2.2
2
1.95
2.3
1.5
1.2
0.8
0.9
RADIUS 30M
RADIUS 50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4


RF EXPOSURE OF TOWER 18
EXPOSURE READING
4.85
4.5
4.7
4.3
2.4
2.25
2
2.05
1.3
1.5
1.45
1
RADIUS 30M
RADIUS50M
RADIUS 300M
TOWER RADIUS
Series1 Series2 Series3 Series4

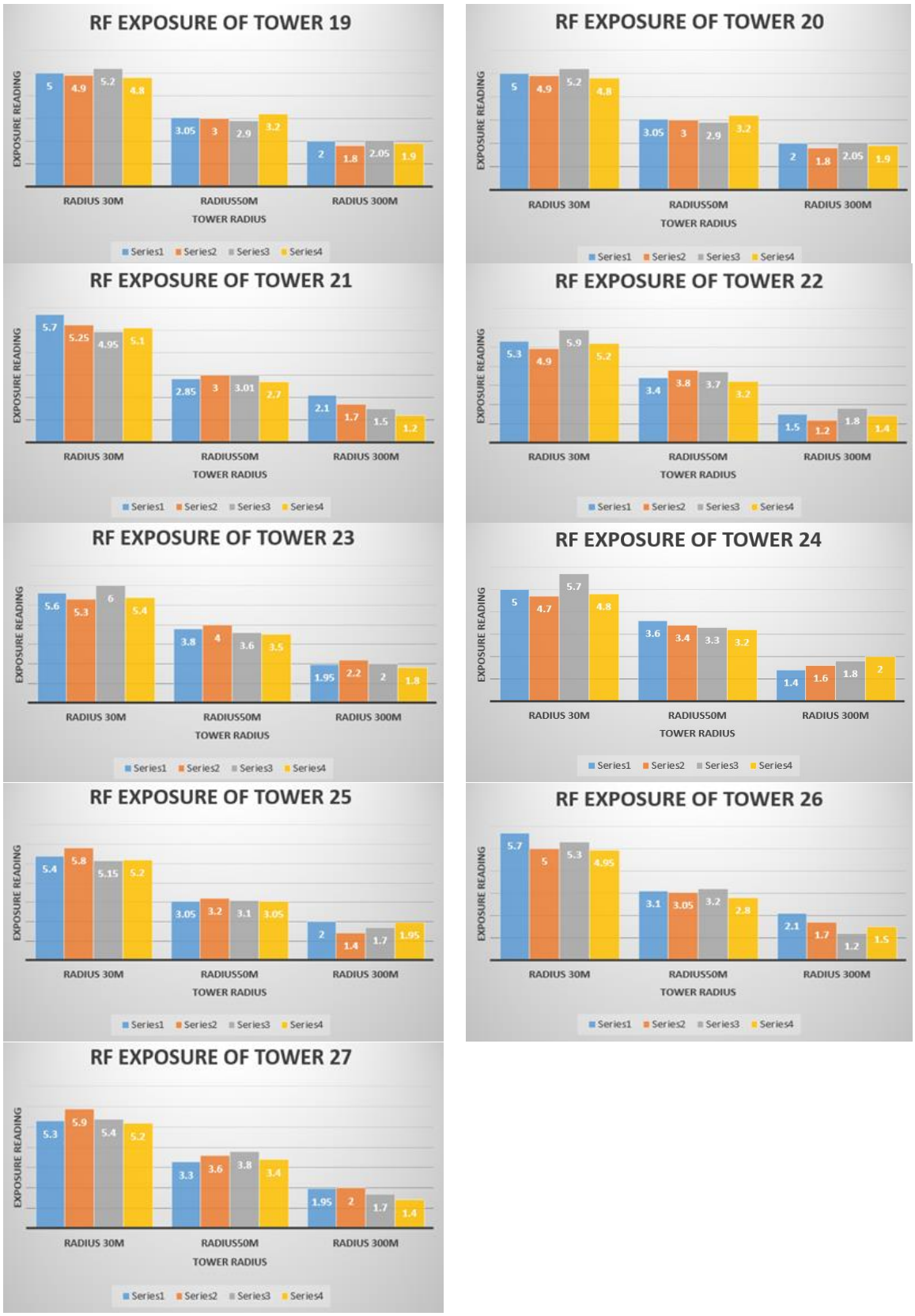


Figure 7. RF exposure of towers

Above are the bar charts that show the readings of the peak E-Field Exposure that were monitored in each radius. Four readings were monitored in each radius each reading is in the bar chart. As we

see in towers that were monitored the readings in 30m and 50m are above the FCC standards as the standard is that the reading should not be greater than 2 V/m in the distance of 300m. And as we can see in the above table we are having residential activities in 30m and 50m respectively. And as it is discussed in the literature review mobile towers should not be sited closer than 300m to the population. However, the towers that are sited in the study site have residential and commercial areas in a 30m radius which are under high exposure to radiation. The above bar charts show that even in a 300m radius in some towers we are having readings above the safety standard that is stated by FCC.

The bar chart (Figure 8) below shows the average peak reading of all the towers that are present in the study site. The safety standard line is also marked on the chart to be clearer what is the safety standard and what is the present situation of the exposure from the towers which we are dealing with.

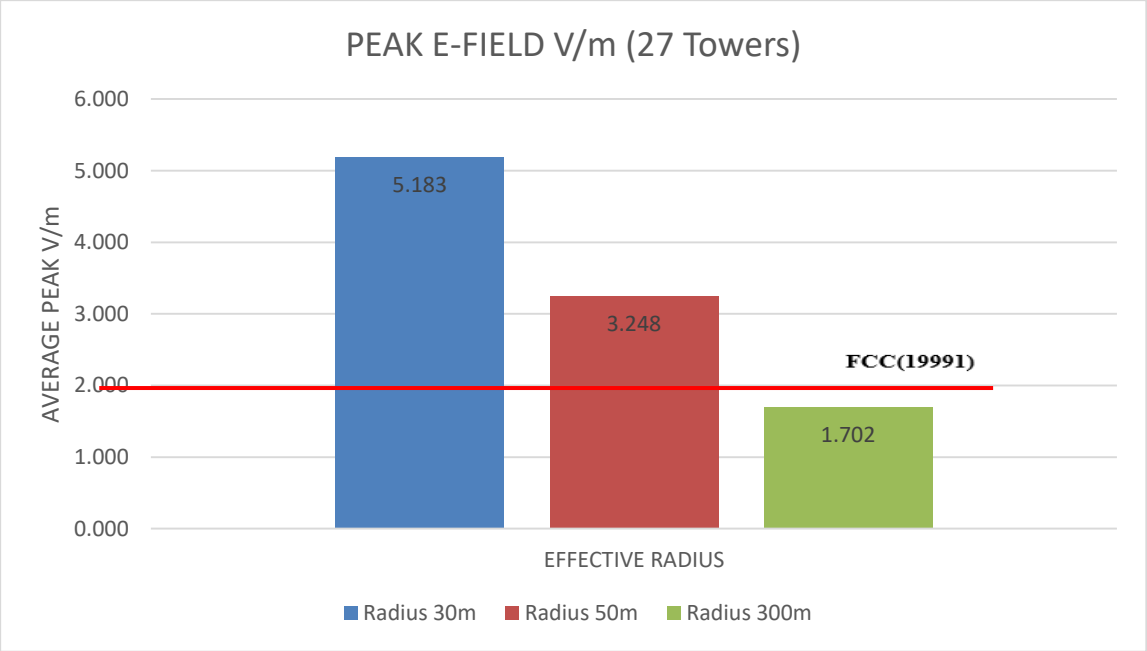


Figure 8. Average Peak E-Field Exposure

Monitoring of Peak Power

The average power monitored from the towers which are in the study site is shown in Figure 9. The average power monitored from each tower in a 30m radius is way above the safety standard which is notified by FCC that is 10,000 µW/m^2. The readings that were monitored in the study site had the highest reading beyond 80,000 µW/m^2. Similarly, the average power monitored in the radius of 50m is also beyond the safety line and the highest power monitored in the 50m radius is above 50,000 µW/m^2(Figure 10). Even in a 300m radius the average power monitored is crossing the safety line and is hitting up to 20,000 µW/m^2 which is not safe for the population residing under these towers (Figure 11).

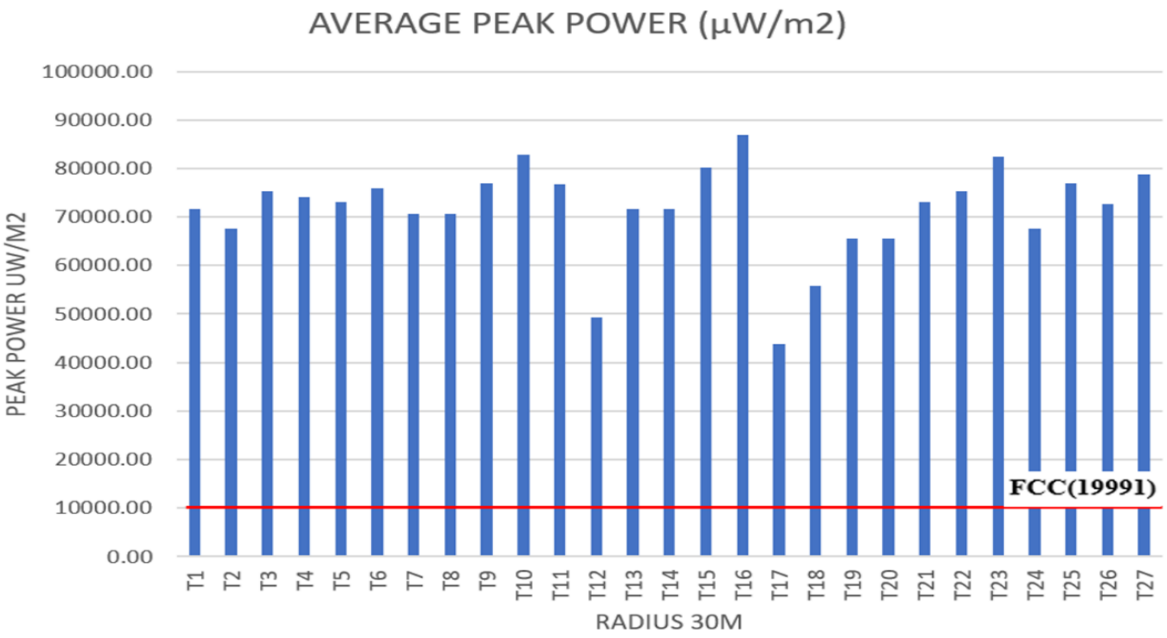


Figure 9. Average Peak Power at 30m

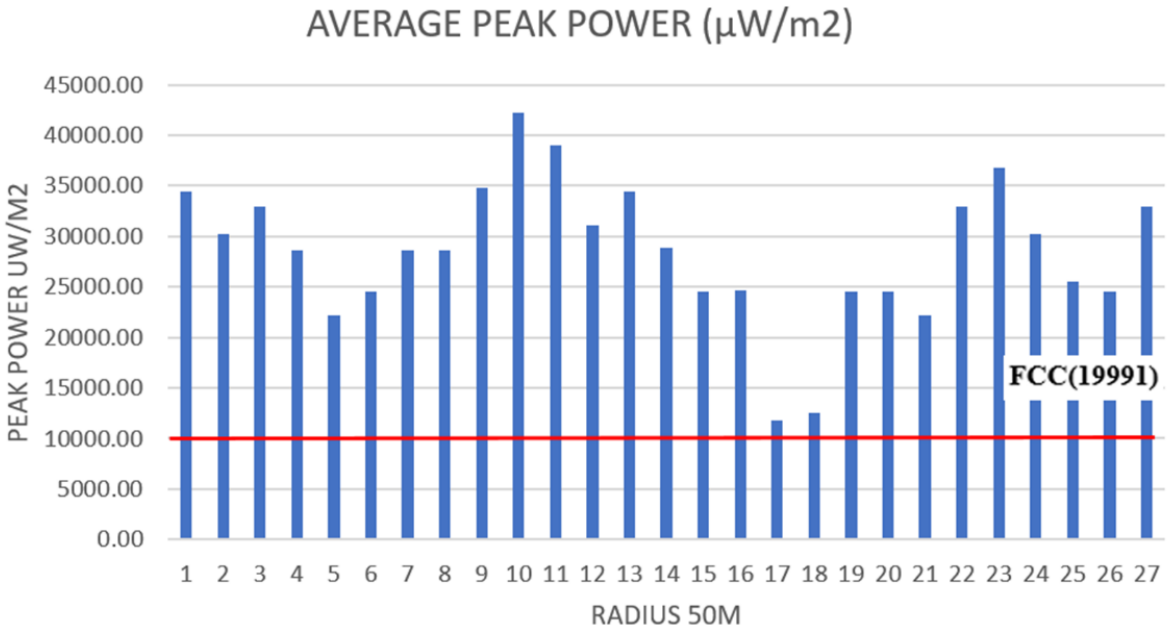


Figure 10. Average Peak Power at 50M

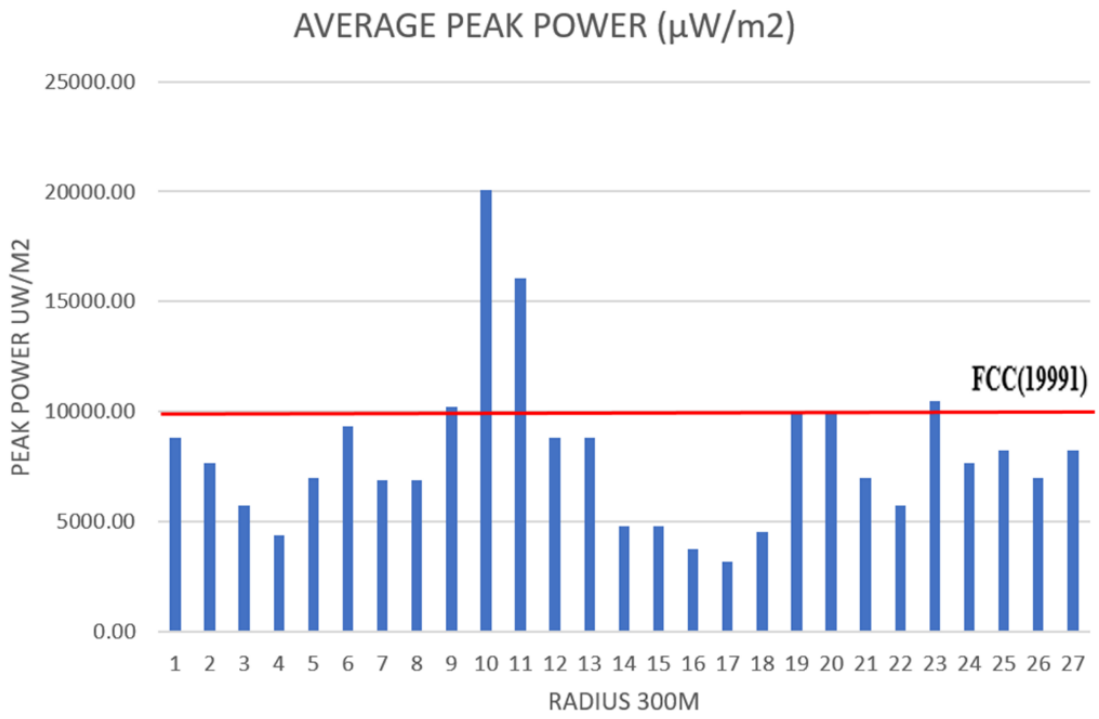


Figure 11. Average Peak Power at 300M

Exposure to Residential and Commercial Activity

As discussed above the residential and commercial activities should not be present in a 300m radius surrounding the tower as per the safety standard (Figure 12 & 13). The study site selected for the research has both of the activities present near the tower site even some of the towers are installed on the rooftop of the apartment building where people are living. The bar charts shown below show the RF exposure to the number of residential and commercial activities occurring in the surroundings of the tower. In the chart, the bars show the Peak power of towers which is monitored in the respective radius and the stacked lines on the chart show the residential and commercial activities.

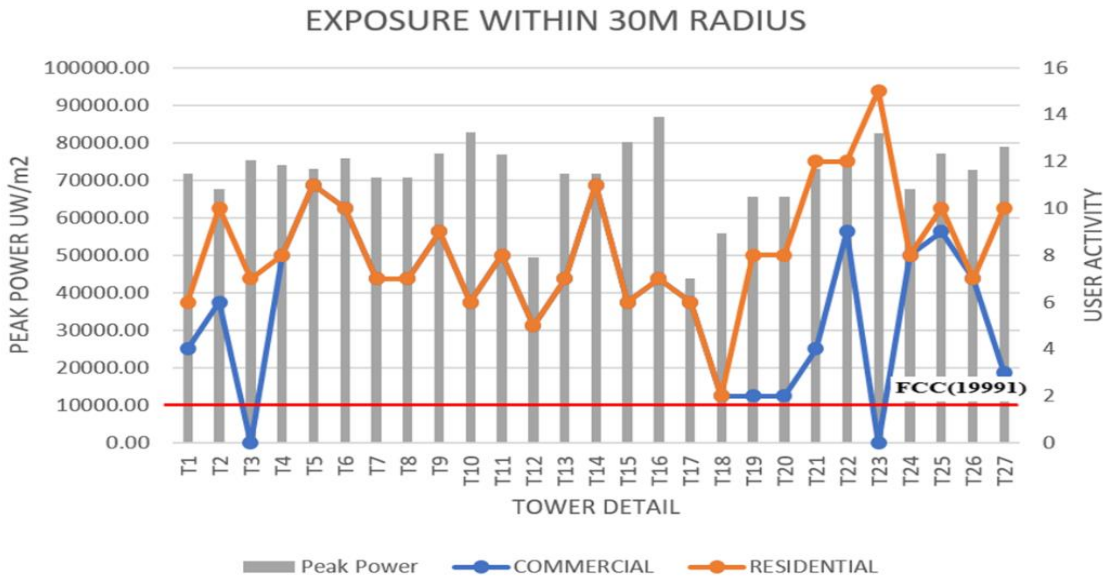


Figure 12. Exposure to User Activity

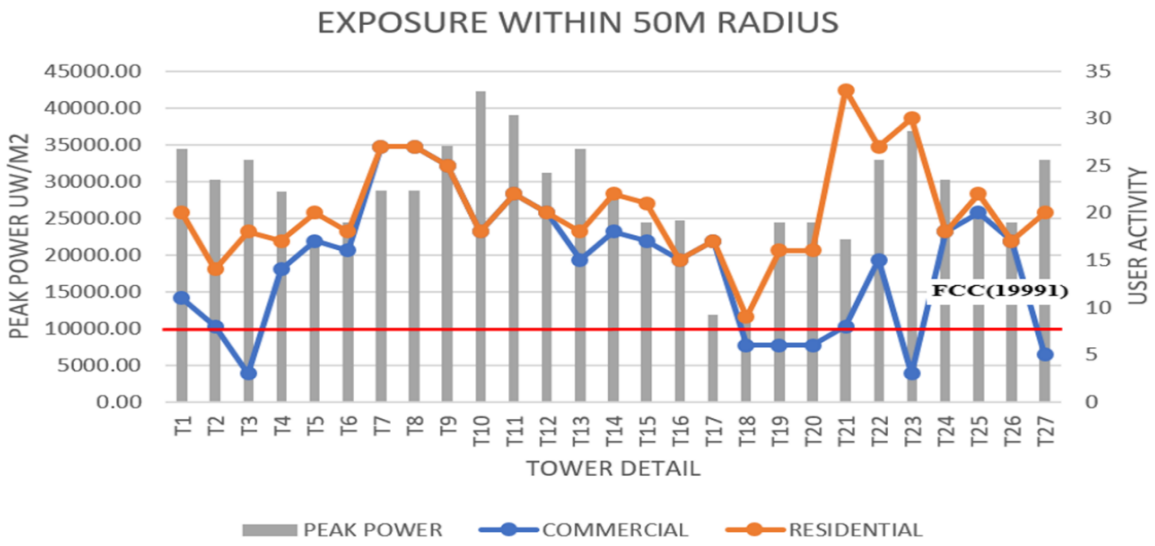


Figure 13. Exposure concerning User Activity

Comparison with Safety Standard

The safety standard from RF exposures is mainly from the thermal effects of RF emissions. This means that the main focus of the standards is to prevent the human body from being heated up. As we know the non-thermal effects are more dangerous as compared to thermal effects as they are slow poison for the human body. Table 3 shows the comparison of the safety standards with the average power monitored from the towers in each radius in the research site area.

Table 3. Comparison of the Average Peak Power with Safety Standards

INTERNATIONAL SAFETY STANDARDS	GENERAL PUBLIC EXPOSURE LIMIT µw/m^2	AVERAGE PEAK POWER 30 M RADIUS µw/m^2	DIFFERENCE (TIMES)	AVERAGE PEAK POWER 50 M RADIUS µw/m^2	DIFFERENCE (TIMES)	AVERAGE PEAK POWER 300 M RADIUS µw/m^2	DIFFERENCE (TIMES)	CITATION
FCC 1999	10,000.00	71,610.25	7.16	28,448.15	2.84	8,012.08	0.801	https://www.fcc.gov/engineering-technology/electromagnetic-compatibility-division/radio-frequency-safety/faq/rf-safety#Q9
SALZBURG-1998 & 2000	1,000.00	71,610.25	71.61	28,448.15	28.45	8,012.08	8.012	Proceedings.PDF (salzburg.gv.at)
BELGIUM-WALLONIA	1,200,000.00	71,610.25	0.06	28,448.15	0.02	8,012.08	0.007	https://www.robindestoits.org/attachment/337945/
Exposure limit in Italy in sensitive areas	25,000.00	71,610.25	2.86	28,448.15	1.14	8,012.08	0.320	https://www.robindestoits.org/attachment/337945/
Exposure limit in CSSR, Belgium, Luxembourg	240,000.00	71,610.25	0.30	28,448.15	0.12	8,012.08	0.033	https://www.robindestoits.org/attachment/337945/
Exposure limit in Australia	2,000,000.00	71,610.25	0.04	28,448.15	0.01	8,012.08	0.004	https://www.robindestoits.org/attachment/337945/

Exposure Limit in Auckland, New Zealand	500,000.00	71,610.25	0.14	28,448.15	0.06	8,012.08	0.016	https://www.robindestoits.org/attachment/337945/
ECOLOG 1998 (Germany) Precaution recommendation only	90,000.00	71,610.25	0.80	28,448.15	0.32	8,012.08	0.089	https://www.robindestoits.org/attachment/337945/
Mobile phones will work at levels	0.00003	71,610.25	--	28,448.15	--	8,012.08	--	https://www.robindestoits.org/attachment/337945/

Discussion

The findings show that the research site's towers' radio frequency (RF) exposure is greatly above the safety thresholds established by regulatory bodies. A worrying degree of exposure was indicated by the research area's highest recorded RF power, which surpassed 80,000 µW/m². The peak output was over 50,000 µW/m², much beyond the safety limit, even at a 50m radius. Additionally, the 300-meter radius showed dangerously high exposure levels, up to 20,000 µW/m². These results are consistent with other research indicating that cell tower RF exposure often exceeds permissible limits in cities (Kumar et al., 2021).

There are serious health risks associated with excessive radiofrequency emissions in residential and business locations. Long-term exposure to radiofrequency radiation has been associated with a higher risk of neurological problems, sleep disruptions, and possible carcinogenic effects, particularly in residential areas (Belpomme et al., 2018). To increase direct exposure to inhabitants, some towers were erected on apartment rooftops at the study location. More stringent zoning laws are required to prevent excessive exposure, as seen by the relationship between peak power levels and surrounding human activity.

According to mounting data, non-thermal impacts like oxidative stress, DNA damage, and cognitive decline can be even more harmful to one's health (Belpomme et al., 2018; Yakymenko et al., 2015). All measured radii (30, 50, and 300 meters) exceed safety restrictions, according to the study's findings, supporting the notion that the public's health may not be sufficiently protected by the present RF safety regulations. Stricter regulation restrictions that consider both thermal and non-thermal effects have also been advocated by earlier research. The possible connection between RF exposure and cancer, especially brain tumors and leukemia, is one of the main worries. Based on epidemiological research, the International Agency for Research on Cancer (IARC) has categorized radiofrequency electromagnetic fields as potentially carcinogenic to humans (Group 2B) (IARC, 2011). Additionally, according to a 2019 study by Hardell and Carlberg, prolonged exposure to radiofrequency radiation from cell phone towers may raise the risk of glioma and auditory neuroma. Comprehensive public health assessments and legislative changes are desperately needed, especially in light of the growing number of cell towers in metropolitan areas.

The effects of RF radiation on the environment must also be taken into account. Numerous studies show that RF radiation has an impact on biodiversity, especially on pollinators like birds and bees (Cucurachi et al., 2013). High RF emissions have been found to cause disturbances in their reproductive and navigational habits, which may have a domino impact on ecosystems. To guarantee sustainable urban development, urban planning authorities must include RF exposure estimates in environmental impact studies. Regulatory agencies should think about reviewing the current safety standards and enforcing more stringent regulations for tower installations close to residential and commercial areas in light of the high levels of radiofrequency exposure found in the research region. Long-term epidemiological studies should be the main focus of future research to

evaluate the effects of chronic radiofrequency radiation on public health. Furthermore, RF exposure concerns in urban environments may be reduced by combining shielding technology with alternate tower placement techniques (Bandara & Carpenter, 2018). To solve the issues raised by RF radiation exposure and create regulations that put the health of people and the environment first, researchers, policymakers, and medical professionals must work together.

Future Work

This study has provided significant insights into the spatial distribution and EMF exposure levels of mobile towers in Quetta, Balochistan. However, there are several areas for future research. First, a larger dataset incorporating more cities and regions across Pakistan would provide a more comprehensive analysis of EMF exposure trends. Second, longitudinal studies should be conducted to evaluate the long-term health effects of RF radiation on local populations, particularly among vulnerable groups such as children and the elderly. Third, more advanced EMF measurement techniques, such as spectrum analysis and continuous monitoring, should be utilized to improve data accuracy. Additionally, future research should explore mitigation strategies, including architectural shielding methods and smart city planning approaches to minimize EMF exposure in urban environments. Finally, integrating public awareness campaigns and policy advocacy into future studies will help address the regulatory gaps and promote safer mobile network expansion strategies.

Conclusion

Many people are unaware of the significance of the health risks posed by radiation from cell phones and cell towers because they do not use them or have never used one. Cell phone companies continue to assert that there are no health consequences. Even organizations such as the World Health Organization, the International Commission on Nuclear Radiation Protection and Research, the Federal Communications Commission, and others have not recommended stricter safe radiation guidelines, whereas several countries have adopted radiation norms that are 1/100th to 1/1000th of these values based on their studies. The cell phone industry is becoming a carbon copy of the tobacco industry, which for years insisted that smoking was not hazardous, despite the fact that millions of people all over the world have suffered as a result of smoking. Since mobile phone/tower radiation cannot be seen or smelled, and its effects on health are only noticed after a lengthy period of time, it may be even more harmful than tobacco smoking. As a result, the vast majority of people tend to be careless when it comes to personal protection. Unfortunately, ignorance and non-awareness contribute to this pain, and we are all unwittingly ingesting this slow poison without even realizing it. However, even if people are aware of the radiation concern, they may not have the option to relocate if the tower is erected near their place of employment or residence. Along with constant radiation from cell towers, there is also radiation from mobile phones, wireless phones, computers, laptops, TV towers, FM towers, AM towers, microwave ovens, and other electronic devices like printers. All of these radiations, which are cumulative in nature, are being sent into our environment. As a result, it is critical that policymakers enact and enforce tougher radiation standards. This does not imply that we should cease to live in close proximity to these towers. We are all aware that automobiles pollute the environment; nevertheless, have we ceased using them? Instead, solutions such as unleaded gasoline, catalytic converters to minimize emissions, CNG-powered automobiles, hybrid vehicles, and other technologies were discovered. If people working for mobile phone companies believe there is no danger to their health, then ask them to stand in front of their own transmitting tower at 1-meter distance in the main beam for 6 hours and see if they are willing to take the chance. In approximately 600 hours, a similar impact will be observed at a distance of 10 meters (25 days). Do you think people will stop using cell phones if mobile phone companies acknowledge that

radiation causes major health problems? Not really, because the cell technology has several advantages over other technologies. Researchers, technocrats, and entrepreneurs will come up with possible solutions, which may be expensive but cannot be greater than the health risks that humans, birds, and animals, as well as the environment, are exposed to at the time of the disaster.

Recommendations

The following recommendations are given based on the findings of this study:

- The tower should be installed in an area where no residential and commercial activity should not be closer than 300m.
- Use shielding materials that can help reduce the radiation received from cell towers.
- I recommend things like metallic mesh curtains, window films, and EMF-blocking paint.
- The most cost-effective solution is simply focused on shielding the key areas in your home. For example, this could mean installing EMF-blocking canopies around your beds or lining your walls with conductive materials.

Acknowledgment: This article was made possible with the Spatial Decision Support System (SDSS) Lab, NCGSA, BUITEMS, Quetta, Pakistan.

Author contributions: Shafi Ullah, Niamat Ullah led the idea, design, and data analysis, writing review, and editing. Anila Ali, Aziza Sarwar, Ali Asghar and Shazaib Khan methodology, writing review and editing, data collection, and draft writing.

Funding: The current research has not received any funding.

Conflict of interest: The authors declare no conflict of interest.

References

1. Al-Sahly, A., et al. (2018). Mobile communication and its impact on RF exposure.
2. Aldad, T. S., Gan, G., Gao, X. B., & Taylor, H. S. (2017). Fetal radiofrequency radiation exposure from 800-1900 Mhz-rated cellular telephones affects neurodevelopment and behavior in mice. *Scientific Reports, 7*(1), 411-423.
3. Ali, Kalbe (25 August 2021). "Pakistan to remain behind in smartphone usage, 5G coverage: GSMA" Akman, Effects of Electricity in Buildings on Human Health, YEM Printing, Yapı magazine, V. 183, P. 100-102, Istanbul, 1997.
4. Bandara, P., & Carpenter, D. O. (2018). Planetary electromagnetic pollution: It is time to assess its impact. *The Lancet Planetary Health, 2*(12), e512-e514.
5. Belpomme, D., Hardell, L., Belyaev, I., Burgio, E., & Carpenter, D. O. (2018). Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective. *Environmental Pollution, 242*, 643-658.
6. Country report, vol. 2015, no. February, pp. 1–15, 2015.
7. Cucurachi, S., Tamis, W. L. M., Vijver, M. G., Peijnenburg, W. J. G. M., Bolte, J. F. B., & de Snoo, G. R. (2013). A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF). *Environment International, 51*, 116-140.
8. Havas, M. (2017). *Electromagnetic exposure and regulatory standards*.
9. Hardell, L., & Carlberg, M. (2019). *Compliance issues in EMF safety regulations*.
10. Hardell, L., & Carlberg, M. (2019). Environmental radiofrequency electromagnetic fields and brain tumor incidence in the Nordic countries. *Environmental Research, 176*, 108-114.

11. Havas, M. (2017). Radiation from wireless technology affects the blood, the heart, and the autonomic nervous system. *Reviews on Environmental Health, 32*(2), 193-204.
12. Frei, Patrizia, Evelyn Mohler, Alfred Bürgi, Jürg Fröhlich, Georg Neubauer, Charlotte Braun-Fahrländer, and Martin Röösli. "A prediction model for personal radio frequency electromagnetic field exposure." *Science of the total environment* 408, no. 1 (2009): 102-108.
13. Griffiths, David J. "Introduction to electrodynamics." (2005): 574-574.
14. Hardell, L., & Carlberg, M. (2019). Health risks from radiofrequency radiation, including 5G, should be assessed by experts with no conflicts of interest. *Oncology Letters, 17*(4), 3606-3608.
15. International Agency for Research on Cancer (IARC). (2011). IARC classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B). *World Health Organization Press Release, 208*.
16. Kumar, N., Sharma, N., & Shukla, A. (2021). A review of health risks associated with mobile phone base stations and wireless networks radiation. *International Journal of Environmental Research and Public Health, 18*(7), 3856.
17. Kumar, Girish. "Cell tower radiation." *Mumbai, December* (2010).
18. Lalrinthara Pachuau, et al. (2015). *The impact of RF exposure from mobile towers*.
19. Muhammad Akram Choudary, et al. (2012). *Mobile penetration in South Asia: The case of Pakistan*.
20. Muhammad, Akram Ch, Muhammad Asim Faheem, Muhammad Khyzer Bin Dost, and Iqra Abdullah. "Globalization's impacts on Pakistan's economy and telecom sector of Pakistan." *International Journal of Business and Social Science* 3, no. 1 (2012).
21. Morris, G., & Ziska, L. H. (2020). Wireless radiation exposure and children's health. *Current Environmental Health Reports, 7*(1), 1-10.
22. Mohler, Evelyn, Patrizia Frei, Jürg Fröhlich, Charlotte Braun-Fahrländer, Martin Röösli, and QUALIFEX-team. "Exposure to radiofrequency electromagnetic fields and sleep quality: a prospective cohort study." *PloS one* 7, no. 5 (2012): e37455.
23. Sage, C., & Burgio, E. (2018). Electromagnetic fields and radiofrequency radiation: Effects on human health. *Environmental Research, 176*, 109-117.
24. Saim, Korur, Korkmaz Serra Zerrin, and Sayın Selçuk. "Electromagnetic Pollution in Buildings and Its Effects on Human Health." In *The International Conference on Electrical Engineering*, vol. 7, no. 7th International Conference on Electrical Engineering ICEENG 2010, pp. 1-9. Military Technical College, 2010.
25. Siegrist, Michael, Heinz Gutscher, and Timothy C. Earle. "Perception of risk: the influence of general trust, and general confidence." *Journal of risk research* 8, no. 2 (2005): 145-156.
26. Singh, Tanvir, Amit Kumar, and Dr Sawtantar Singh Khurmi. "Scarce Frequency Spectrum and Multiple Access Techniques in Mobile Communication Networks." (2011).
27. Pakistan Bureau of Statistics. (2024). 7th Population and Housing Census 2023: Detailed Results. Retrieved from https://www.pbs.gov.pk/digital-census/detailed-results
28. Pachuau, L., & Pachuau, P. (2016). *Electromagnetic radiation and public health concerns*.
29. Pall, M. (2018). *Health risks associated with RF exposure from mobile communication networks*.
30. Pall, M. L. (2018). Wi-Fi is an important threat to human health. *Environmental Research, 164*, 405-416.
31. Presman, A. *Electromagnetic fields and life*. Springer Science & Business Media, 2013.
32. Tahir Mehmood. (2015). *Mobile telecommunications in Pakistan: Growth and health implications*.

33. Redlarski, Grzegorz, Bogdan Lewczuk, Arkadiusz Żak, Andrzej Koncicki, Marek Krawczuk, Janusz Piechocki, Kazimierz Jakubiuk et al. "The influence of electromagnetic pollution on living organisms: historical trends and forecasting changes." *BioMed research international* 2015 (2015).
34. Ullah, N., Rehman, T., Mengal, S., Amanullah, Shafi Ullah, Khan, M. M., & Kakar, A. U. (2025). Impacts of social media on the academic performance of university students in Pakistan. The Critical Review of Social Sciences Studies, 3(1), 3426–3437. https://doi.org/10.59075/22essj49
35. Yakymenko, I., Sidorik, E., Kyrylenko, S., & Chekhun, V. (2015). Long-term exposure to microwave radiation provokes cancer growth: Evidences from radars and mobile communication systems. *Experimental Oncology, 37*(3), 219-225.