

High ambient radiofrequency radiation in Stockholm city, Sweden

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Abstract. We measured the radiofrequency (RF) radiation at central parts in Stockholm, Sweden in March and April 2017. The same measurement round tour was used each time. We used EME Spy 200 for the measurements as in our previous studies in Stockholm. The results were based on 11,482 entries, corresponding to more than 12 h measurements. The total mean level was 5,494 $\mu\text{W}/\text{m}^2$ (median 3,346; range 36.6-205,155). The major contributions were down links from LTE 800 (4G), GSM + UMTS 900 (3G), GSM 1800 (2G), UMTS 2100 (3G) and LTE 2600 (4G). Regarding different places, the highest RF radiation was measured at the Hay Market with a mean level of 10,728 $\mu\text{W}/\text{m}^2$ (median 8,578; range 335-68,815). This is a square used for shopping, and both retailers and visitors may spend considerable time at this place. Also, the Sergel Plaza had high radiation with a mean of 7,768 $\mu\text{W}/\text{m}^2$. All measurements exceeded the target level of 30-60 $\mu\text{W}/\text{m}^2$ based on non-thermal (no heating) effects, according to the BioInitiative Report. Based on short-term thermal effects, The International Commission on Non-Ionizing Radiation Protection established guideline 2 of 10 W/m^2 (2,000,000-10,000,000 $\mu\text{W}/\text{m}^2$) depending on frequency in 1998, and has not changed it despite solid evidence of non-thermal biological effects at substantially lower exposure levels. These environmental RF radiation levels are expected to increase with the introduction of 5G for wireless communication.

Introduction

Our research team has during the recent years made measurements of radiofrequency (RF) radiation at the Central Station (1), in the Old Town (2), and in a private apartment (3) in Stockholm, Sweden. We found high levels in certain places such as a square (Järntorget) in the Old Town with nearby base stations. Also, in the apartment high levels were measured due

to the proximity to base stations. In contrast we measured low levels in parts of the WHO office in Geneva, Switzerland (4). We now report the results of measurements in Stockholm city performed in March and April 2017.

These results give an estimate of RF radiation levels before the introduction of the fifth generation, 5G, for wireless communication. During the time for all these measurements no 5G was implemented. Despite an EU appeal by more than 200 scientists and medical doctors asking for a moratorium on the introduction of 5G until further independent research on consequences on health and environment are performed, there seems to be no plans to halt the building of that network (5). In addition, the animal studies by the National Toxicology Program (NTP) in USA (6-8) and the Ramazzini Institute in Italy (9) have recently provided additional evidence on the carcinogenicity of RF radiation.

Apart from the cancer risk from exposure to RF radiation, several studies show other possible adverse health effects in inhabitants living near mobile base station. Symptoms like headache, fatigue, dizziness, sleep disturbances, cardiovascular symptoms, depression and difficulties with concentration and memory have been reported (10-15). A study in Rimbach, Germany, showed adverse effects on the neurotransmitters adrenalin, noradrenalin, dopamin and phenyletylamine after a GSM mobile base station was activated 2004 (16). Hormone profiles were measured in volunteers living near a mobile base station. Serum cortisol, plasma ACTH and thyroid hormones decreased statistically significantly. Prolactin in young women and testosterone in men also decreased during the study time of up to six years (17). Two different studies from India showed that persons who lived near mobile phone base stations had higher frequency of micronuclei, lowered antioxidant levels and induced DNA damage in their blood lymphocytes (18,19). Also lowered levels of stimulated salivary secretion and more health complaints have been seen (15) and an increase of salivary cortisol after exposure to RF radiation from mobile phone base stations has been reported (20).

A biological mechanism for exposure to RF radiation and possible harmful effects can be the stimulation of oxidative stress. A study showed lower values of antioxidant levels and a higher mean level of lipid peroxidation assay as a sign for increased free radicals in a study population living near mobile phone base stations (21). Free radicals may play an important role in many diseases such as cancer and cardiovascular, immunological and endocrine diseases (21). A spatial

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correlation between mortality in cancer and distance to a mobile phone base station was found in a study in Brazil (22). Also in a review, 2 of 3 studies showed augmented cancer incidence for people living near mobile base stations (23).

This study forms part of our on-going measurements of RF radiation in public places. Of special interest is places with many visitors but also including areas with persons working for several hours per day. This was a measurement study with no involvement of test persons. Thus, no ethical permission was needed.

Materials and methods

EME Spy 200 Exposimeter. In this study an EME Spy 200 exposimeter with a valid calibration was used to collect the exposure data. Axial isotropy is from ± 1 to ± 2.8 dB depending on the frequency band. The measurement accuracy is very good relative to this type of measurements and the measurement errors are not biologically significant. The exposimeter measures 20 predefined frequency bands as presented in Table I. They cover the frequencies of most public RF radiation emitting devices currently used in Sweden. The exposimeter covers frequencies from 88 to 5,850 MHz. For FM, TV3, TETRA, TV4&5, Wi-Fi 2G and Wi-Fi 5G the lower detection limit is 0.01 V/m ($0.27 \mu\text{W}/\text{m}^2$); for all other bands the lower detection limit is 0.005 V/m ($0.066 \mu\text{W}/\text{m}^2$). For all bands the upper detection limit is 6 V/m ($95,544 \mu\text{W}/\text{m}^2$; $9.5544 \mu\text{W}/\text{cm}^2$). The sampling time used in this study was every fourth second which is the fastest for the given exposimeter.

The exposimeter measures different telecommunications protocols: FM (frequency modulation) radio broadcasting; TV (television) broadcasting; TETRA emergency services (police, rescue, etc.); GSM (global system for mobile communications) second generation mobile communications; UMTS (universal mobile telecommunications systems) third generation mobile communications, 3G; LTE (long term evolution) fourth generation mobile communications standard, 4G; DECT (digital European cordless telecommunications) cordless telephone systems standard; Wi-Fi wireless local area network protocol; WIMAX (worldwide interoperability for microwave access) wireless communication standard for high speed voice, data and Internet.

EME SPY 200 utilizes 3-axis antennas to capture RF radiation from all possible directions and polarizations. The exposimeter was held at some distance (approximately 0.4 meters) from the body. The unit reports the exposure in a conservative manner since each reported value is the sampling outcome, where many samples are taken and statistically processed including minimum, mean, median and maximum values.

Study design. All measurements were performed during March and April 2017. Each measurement tour started at Stureplan, Stockholm that is a common place for visitors, see Fig. 1. It always followed the same route via Norrmalmstorg plaza to Sergel Plaza. From there streets passing the Central Railway station and Rosenbad, the administrative center for the Government, and further via the main street Drottninggatan ending at the Hay Market, a place for outdoor shopping, were used. Finally, Kungsgatan was measured ending at Stureplan

again. The measurement rounds were conducted on a steady pace, keeping a constant speed. In order to spatially represent the mean RF exposure levels, the squares were covered by spiral movement pattern, covering the space by evenly distributed layout. The measurement rounds covered the major public hotspots, hence we consider the route to be representative of a public exposure in this city. In total measurements were made during five different days.

Statistical methods. Means in $\mu\text{W}/\text{m}^2$ were calculated for all measured frequency bands and a box plot was constructed to illustrate the distribution of total exposure for all measurement locations. Values at lower detection limit were treated as no (0) exposure. Total exposure was calculated as the sum of all measured frequency bands. Stata/SE 12.1 (Stata/SE 12.1 for Windows; StataCorp., College Station, TX, USA) was used for all calculations.

Results

Total round. The results were based on 11,482 entries in total corresponding to more than 12 h of measurements, see Table II. The total mean level was $5,494 \mu\text{W}/\text{m}^2$ (median 3,346, range 36.6-205,155). The major contributions were from down links (DL) from LTE 800 (4G), GSM + UMTS 900 (3G), GSM 1800 (2G), UMTS 2100 (3G), and LTE 2600 (4G), see Table II. If all down links were excluded from the measurements the mean level dropped to $118 \mu\text{W}/\text{m}^2$ (median 36.0, range 0-9,157).

The Hay Market. As shown in Table III and Fig. 2 the highest RF-radiation was measured at the Hay Market with mean level $10,728 \mu\text{W}/\text{m}^2$ and median $8,578 \mu\text{W}/\text{m}^2$. These results were based on 1,202 entries, see Table IV. LTE 2600 DL showed the highest mean level, $3,697 \mu\text{W}/\text{m}^2$. There was a large variability in signal strength during the measurements ranging from 335 to $68,815 \mu\text{W}/\text{m}^2$ with high mean and average values, see Fig. 3.

The Sergel Plaza. Also the Sergel Plaza had a high mean level, $7,768 \mu\text{W}/\text{m}^2$ (median 6,466, range 66.6-50,897), Table III and Fig. 2. Table V shows the contribution of different frequencies. Also here LTE 2600 DL (4G) gave the highest level.

Discussion

As shown in Fig. 1 the same pathway was used each time. The 11,482 recordings corresponded to more than 12 h of measurements. The total mean level was $5,494 \mu\text{W}/\text{m}^2$ (median 3,346, range 36.6-205,155). These results may be compared with our previous measurements.

We made our first measurements with the EME Spy 200 Exposimeter at the Stockholm Central Station in November 2015 (1). The results were based on 1,669 entries and yielded mean total RF radiation level $3,860 \mu\text{W}/\text{m}^2$ (median 921, range 5.8-155,263).

The next measurement included Stockholm Old Town in April 2016 (2). The results were based on 10,437 samples in total. The mean level of total RF-radiation was $4,293 \mu\text{W}/\text{m}^2$ (median 534, range 0-173,302).

We measured levels of RF-radiation in an apartment located at Östermalm, Stockholm. The results were based on

Table I. Predefined measurement frequency bands of EME Spy 200 Exposimeter. Frequency ranges.

Frequency band	Frequency Min, MHz	Frequency Max, MHz
FM	88	107
TV3	174	223
TETRA I	380	400
TETRA II	410	430
TETRA III	450	470
TV4 and 5	470	770
LTE 800, 4G (DL ^a)	791	821
LTE 800, 4G (UL ^b)	832	862
GSM 900+ UMTS 900, 3G (UL)	880	915
GSM 900+ UMTS 900, 3G (DL)	925	960
GSM 1800 (UL)	1,710	1,785
GSM 1800 (DL)	1,805	1,880
DECT	1,880	1,900
UMTS 2100, 3G (UL)	1,920	1,980
UMTS 2100, 3G (DL)	2,110	2,170
Wi-Fi, 2 GHz	2,400	2,483.5
LTE 2600, 4G (UL)	2,500	2,570
LTE 2600, 4G (DL)	2,620	2,690
WiMax	3,300	3,900
Wi-Fi 5GHz	5,150	5,850

^aTransmission from base station to mobile phone; ^bTransmission from mobile phone to base station. FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

74,531 entries for 6 different tours in June and August 2017. Also, balconies were measured (3). The study was initiated by concern of RF radiation from nearby base stations on the top of roofs. The mean RF radiation level was 3,811 $\mu\text{W}/\text{m}^2$ (median 1,313, range 15.2-112,318). Highest RF radiation level was obtained at a balcony outside the living room with mean value 24,886 $\mu\text{W}/\text{m}^2$ (median 22,256, range 72.0-112,318). As we discussed in the article these levels of RF radiation are not compatible with long-time living in the apartment, especially not for children.

The aim of this article is not to discuss in more detail results from measurements of RF radiation levels in other countries. For a more comprehensive review see our previous publications (1-4). In these publications we discuss also health risks and other biological effects from RF radiation. The levels in the present study are among the highest that we have measured in Stockholm so far. Obviously, they exceed the scientific benchmark on 30-60 $\mu\text{W}/\text{m}^2$ for potential health risks based on non-thermal effects as published in the BioInitiative

Table II. Stockholm city levels of radiofrequency radiation based on 11,482 entries, measurements 20170305-20170307, 20170413 and 20170416. Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0.

Frequency band	Mean	Median	Min	Max
FM	3.6	0.0	0.0	4,224.5
TV3	0.6	0.0	0.0	317.5
TETRA I	2.3	0.0	0.0	2,096.3
TETRA II	1.4	0.0	0.0	554.0
TETRA III	0.1	0.0	0.0	124.9
TV4 and 5	6.3	0.0	0.0	6,672.1
LTE 800 (DL)	750.9	243.5	0.8	80,034.6
LTE 800 (UL)	0.0	0.0	0.0	4.0
GSM + UMTS 900 (UL)	0.1	0.0	0.0	299.5
GSM + UMTS 900 (DL)	1,169.5	583.5	2.2	95,522.5
GSM 1800 (UL)	12.3	2.2	0.0	2,620.8
GSM 1800 (DL)	465.0	189.1	1.9	44,393.3
DECT	59.0	0.7	0.0	6,714.3
UMTS 2100 (UL)	0.0	0.0	0.0	10.5
UMTS 2100 (DL)	1,211.5	598.5	5.9	43,852.4
WIFI 2G	0.3	0.0	0.0	616.2
LTE 2600 (UL)	32.1	5.1	0.0	3,762.5
LTE 2600 (DL)	1,779.1	846.8	4.0	40,572.7
WiMax	0.0	0.0	0.0	0.8
WIFI 5G	0.1	0.0	0.0	88.8
Total	5,494.2	3,346.0	36.6	205,154.8

FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for microwave access.

Report (24). Based on chronic exposure an even lower level, 3-6 $\mu\text{W}/\text{m}^2$, with safety factor 10 was suggested for sensitive groups including children.

In contrast, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) based their target level on short-term (acute) exposure. It was established in 1998 (25) and updated in 2009 (26) without any change of the guideline 2 to 10 W/m^2 (2,000,000 to 10,000,000 $\mu\text{W}/\text{m}^2$) depending of frequency. Despite being outdated, considering only thermal effects, and not based on current knowledge, the ICNIRP guideline is used in many countries such as by the Swedish Radiation Safety Authority (SSM).

Most areas in our current study are only used by people when passing by. Thus, the high involuntary exposure is for a short time. However, some of the streets are popular for visitors, those going for shopping or strolling along the street just for pleasure. This might give more extended exposure. One contrast is the Hay Market. This is popular place for marketing

Table III. Stockholm city total levels of radiofrequency radiation for different locations, measurements 20170305-20170307, 20170413 and 20170416. Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0.

Location	n	Mean	Median	Min	Max
Stureplan	696	2,664.7	1,816.0	158.9	33,678.6
Biblioteksgatan, Norrmalmstorg, Hamngatan	2,473	5,000.4	3,477.9	36.6	53,681.2
Sergel plaza	1,651	7,767.6	6,466.5	66.6	50,897.3
Klarabergsgatan, Vasagatan, Tegelbacken, Rosenbad, Strömgatan to Drottninggatan	2,136	3,790.8	1,934.6	37.1	77,451.6
Drottninggatan to Kungsgatan	1,661	4,257.4	2,708.3	132.6	205,154.8
Kungsgatan	1,663	4,795.4	2,610.7	66.7	61,053.6
Hay market	1,202	10,728.5	8,577.7	335.4	68,814.6
Total	11,482	5,494.2	3,346.0	36.6	205,154.8

Table IV. Hay Market, Stockholm, levels of radiofrequency radiation in total based on 1,202 entries. Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0.

Frequency band	Mean	Median	Min	Max
FM	1.6	0.0	0.0	407.6
TV3	0.8	0.0	0.0	154.1
TETRA I	1.1	0.0	0.0	1,244.6
TETRA II	0.1	0.0	0.0	16.6
TETRA III	0.0	0.0	0.0	1.0
TV4 and 5	8.0	0.0	0.0	551.6
LTE 800 (DL)	1,081.8	495.0	26.5	30,771.4
LTE 800 (UL)	0.0	0.0	0.0	0.1
GSM + UMTS 900 (UL)	0.0	0.0	0.0	25.5
GSM + UMTS 900 (DL)	2,063.0	1,192.5	66.2	21,802.9
GSM 1800 (UL)	15.3	3.2	0.0	1,120.7
GSM 1800 (DL)	991.0	609.9	17.4	34,740.5
DECT	95.2	14.3	0.0	3,756.2
UMTS 2100 (UL)	0.0	0.0	0.0	10.5
UMTS 2100 (DL)	2,725.9	1,354.1	32.7	43,852.4
WIFI 2G	0.2	0.0	0.0	27.1
LTE 2600 (UL)	47.3	8.0	0.0	2,373.8
LTE 2600 (DL)	3,697.1	2,401.5	43.5	38,929.9
WiMax	0.0	0.0	0.0	0.3
WIFI 5G	0.1	0.0	0.0	11.6
Total	10,728.5	8,577.7	335.4	68,814.6

FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for micro-wave access.

Table V. Sergel Plaza, Stockholm, levels of radiofrequency radiation in total based on 1,651 entries. Analysis of all data ($\mu\text{W}/\text{m}^2$) treating values at detection limit as 0.

Frequency band	Mean	Median	Min	Max
FM	1.7	0.0	0.0	281.9
TV3	1.5	0.0	0.0	268.2
TETRA I	4.1	0.0	0.0	146.5
TETRA II	0.5	0.0	0.0	183.5
TETRA III	0.0	0.0	0.0	5.4
TV4 and 5	7.1	0.0	0.0	1,966.4
LTE 800 (DL)	1,047.2	450.2	2.2	23,052.3
LTE 800 (UL)	0.0	0.0	0.0	0.2
GSM + UMTS 900 (UL)	0.6	0.0	0.0	299.5
GSM + UMTS 900 (DL)	1,400.8	904.7	4.9	24,449.1
GSM 1800 (UL)	15.2	1.1	0.0	1,871.6
GSM 1800 (DL)	647.9	273.3	2.5	35,746.0
DECT	133.0	19.2	0.0	6,104.2
UMTS 2100 (UL)	0.0	0.0	0.0	3.4
UMTS 2100 (DL)	1,944.3	1,378.9	10.9	35,029.1
WIFI 2G	0.1	0.0	0.0	14.1
LTE 2600 (UL)	26.4	8.0	0.0	1,371.2
LTE 2600 (DL)	2,537.1	1,894.0	6.6	21,726.9
WiMax	0.0	0.0	0.0	0.4
WIFI 5G	0.1	0.0	0.0	13.0
Total	7,767.6	6,466.5	66.6	50,897.3

FM, frequency modulation; TV, television; LTE, long-term evolution; DL, downlink (transmission from base station to mobile phone); UL, uplink (transmission from mobile phone to base station); GSM, global system for mobile communications; UMTS, universal mobile telecommunications system; DECT, digital European cordless telecommunications; WiMAX, worldwide interoperability for micro-wave access.

of flowers, fruits, berries, etc. Thus, the dealers may during the whole day be exposed to high RF radiation. The mean level

was $10,728 \mu\text{W}/\text{m}^2$ which exceeds very much levels known to have biological effects.

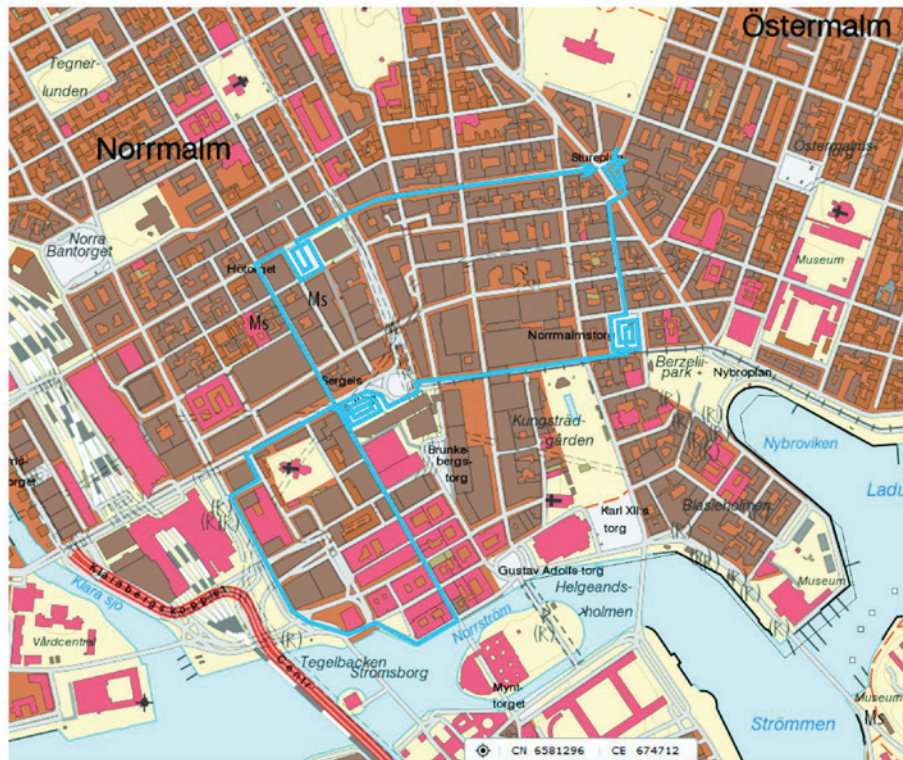


Figure 1. Stockholm city measurement tour, marked by blue; map by Lantmäteriet, Sweden.

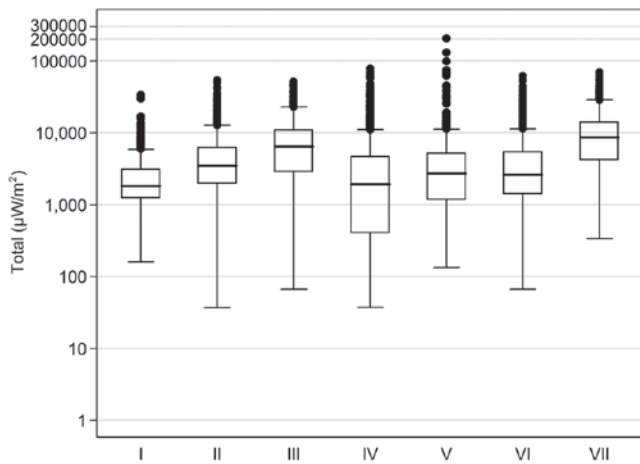


Figure 2. Box plot of total exposure in $\mu\text{W}/\text{m}^2$, logarithmic scale, measurements 20170305-20170307, 20170413 and 20170416 in Stockholm city. The median is indicated by a black line inside each box; the bottom and top of the boxes show first and third quartiles; the end of the whiskers are calculated as 1.5x interquartile range. Points represent outliers. I, Stureplan; II, Biblioteksgatan, Norrmalmstorg, Hamngatan; III, Sergel Plaza; IV, Klarabergsgatan, Vasagatan, Tegelbacken, Rosenbad, Strömgatan to Drottninggatan; V, Drottninggatan to Kungsgatan; VI, Kungsgatan; VII, Hay Market.

The results of this study point out unnecessarily high RF radiation areas in several parts of Stockholm city. Using high-power levels causes an excess health risk to many people. Even higher RF radiation is expected when 5G is implemented.

5G will use several different frequencies. According to The Swedish 'Post and Telestyrelsen' (The Swedish Post and Telecom Authority, PTS) the plan for 5G in Sweden is in the bands of 700 MHz, 3.4-3.6 GHz and 26.5-27.5 GHz. These

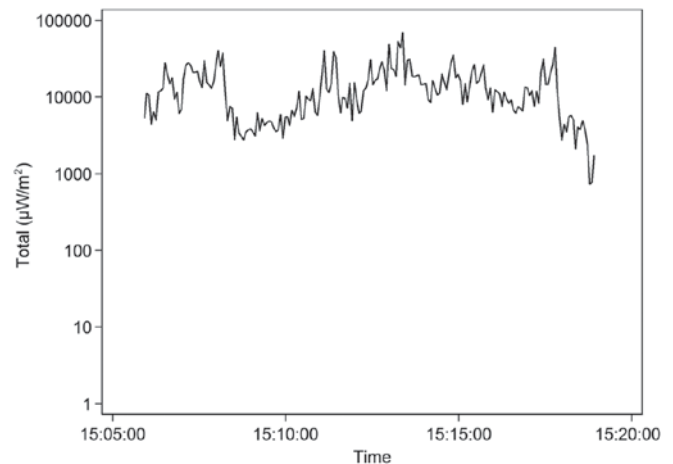


Figure 3. Time variation of measurement at the Hay Market 20170416 ($\mu\text{W}/\text{m}^2$ on a logarithmic scale; total mean exposure 13,763.8 $\mu\text{W}/\text{m}^2$ in this measurement).

frequency have wavelengths of 428.6 mm, 88.2-83.3 mm and 11.3-10.9 mm, respectively. Super high frequencies, like 26.5-27.5 GHz have wavelengths in the millimeter scale, and are named millimeter waves (MMW). Millimeter waves have low penetration depth into the body. Primarily skin and ocular effects have been seen. MMW may have effects on nerve endings and capillaries in the skin and through them influence deeper structures and functions in the body (27,28). Sweat ducts in the skin may act as helical antennas and respond to MMW for penetration (29,30). MMW can also have effects on bacterial growth and augmented antibiotic resistance (31), which can lead to difficulties to treat severe infections.

RF radiation from mobile phone base station expose the environment day and night. Long duration of exposure to RF radiation can be an important factor in adverse health effects even with exposure at lower power densities (32,33). There can also be a significant difference in sensibility to RF radiation between individuals (34). It seems that RF radiation from mobile phone base stations, mobile phones, wireless networks, smart meters and all other wireless devices can have adverse health effects and lead to neurobehavioral, hormonal and immunological effects and cancer (35).

The introduction of 5G will augment the total exposure and also the total amount of different frequencies that will expose the population. The total incidence of cancer is increasing in Sweden and daily papers often report about sleep disturbances, pain problems, burned-out syndromes, depression and more people on sick-leaves. There can be several different causes for this increase in ill health, but the population has never before been exposed to this amount of RF radiation. It does not seem to halt even with these levels of exposure since mobile phone industries and governments want to progress toward an even more digital and wireless world. More research is urgently needed to evaluate the exposure levels we already have and their possible medical consequences and the exposure levels we will get when 5G is implemented, see e.g. the 5G Appeal (5).

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Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

LHa and TK collected all the measurements. MC performed the statistical calculations, LHe contributed with the review of medical aspects from mobile phone base station studies and TK was responsible for technical and methodological aspects of the study. All authors participated in the writing of the manuscript, and have read and approved the final version of the manuscript.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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