Use of portable exposure meters for comparing mobile phone base station radiation in different types of areas in the cities of Basel and Amsterdam

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ABSTRACT

Background: Radiofrequency electromagnetic fields (RF-EMF) are highly variable and differ considerably within as well as between areas. Exposure assessment studies characterizing spatial and temporal variation are limited so far. Our objective was to evaluate sources of data variability and the repeatability of daily measurements using portable exposure meters (PEM).
Methods: Data were collected at 12 days between November 2010 and January 2011 with PEMs in four different types of urban areas in the cities of Basel (BSL) and Amsterdam (AMS).
Results: Exposure from mobile phone base stations ranged from 0.30 to 0.53 V/m in downtown and business areas and in residential areas from 0.09 to 0.41 V/m. Analysis of variance (ANOVA) demonstrated that measurements from various days were highly reproducible (measurement duration of approximately 30 minutes) with only 0.6% of the variance of all measurements from mobile phone base station radiation being explained by the measurement day and only 0.2% by the measurement time (morning, noon, afternoon), whereas type of area (30%) and city (50%) explained most of the data variability.
Conclusions: We conclude that mobile monitoring of exposure from mobile phone base station radiation with PEMs is useful due to the high repeatability of mobile phone base station exposure levels, despite the high spatial variation.

Keywords

Mobile phone base station, radiofrequency electromagnetic fields (RF-EMF), area characterization, mobile monitoring, portable exposure meter (PEM), variability

1. Introduction

The substantial increase and development of new telecommunication technologies in the last two decades resulted in a fundamental change of radiofrequency electromagnetic fields (RF-EMF) exposure patterns in the everyday environment (Frei et al., 2009b; Neubauer et al., 2007; Röösli et al., 2010). The Research Agenda of the World Health Organization (WHO) considered the quantification of personal RF-EMF exposure and identification of the determinants of exposure in the general population as a high priority research need (WHO, 2010). However, exposure quantification is complex due to the high variability of RF-EMF levels in the environment (Bornkessel et al., 2007; Frei et al., 2009a; Joseph et al., 2008; Röösli et al., 2010).

There are different strategies and methodologies to monitor RF-EMF exposure. In general, two types of measurement procedures have been developed, fixed-location and mobile monitoring. Fixed-location measurements with a spectrum analyzer are very accurate for determination of exposure at a specific point in time and space. However, this type of exposure assessment method is time and resource intensive in terms of equipment, costs and trained personnel (Bornkessel et al., 2010; Joseph et al., 2009). As a consequence, collecting data representing typical exposure levels over time in a wide geographic area is challenging if not impossible (Bornkessel et al., 2010). In contrast, portable exposure meters (PEM) allow collecting numerous measurements with relative little effort at different locations (Röösli et al., 2010). Such devices have been successfully applied in a few previous studies (Bolte and Eikelboom, 2012; Frei et al., 2009b; Joseph et al., 2010; Thuróczy et al., 2008; Usher, 2010; Viel et al., 2009).

Due to high spatial variation of RF-EMF around base stations (Bornkessel et al., 2007), exposure varies considerably within as well as between areas, resulting in complex exposure patterns and it is largely unknown how reproducible personal measurements are in a given area. Such information is, however, urgently needed when planning exposure monitoring in order to determine adequate sampling rates and possibly repeated measurements to obtain data that are representative of the true exposure.

In our analysis, we studied the spatial and temporal variability in RF-EMF exposure levels in different types of areas with concurrently conducted personal measurements in the cities of Basel and Amsterdam. We used repeated measurements in both cities to examine how repeatable measurements with PEMs are according to type of area, and to evaluate the suitability of PEM measurements for monitoring purposes.

2. Materials and methods

2.1 Study design

Data collection took place at the same dates and the same times of the day in Basel and Amsterdam between November 10^{th}, 2010 and January 27^{th}, 2011. Measurements in each area were taken every second week at two consecutive days on Wednesdays and Thursdays, respectively. On each measurement day, the timing of the area measurement sequence was shifted. This rotation scheme ensured having measurements in the morning, during noontime and in the afternoon for each area.

We selected typical areas in both cities, yet different types of urban areas (Table 1): business, downtown and residential areas. A measurement path of about 2 km length (Table 1) was chosen (online Figure 1 and 2) per area. We included a downtown area with a busy pedestrian zone. The business area contains business venues with large building complexes. The central residential areas are located in zones with higher buildings (4 to 5 floors) and more traffic as well as more people on the sidewalks. Typical non-central residential areas in Basel are located outside the city centre in quiet residential zones with building heights of about 2 to 3 floors and relatively large proportions of green space. In Amsterdam, one of the two non-central residential areas is situated partly in a quiet area (Sloterplas), whereas the second area is considered as a high-rise residential area with higher buildings (6 to 7 floors).

2.2 Measurements

For data collection in the city of Basel, we used a PEM of the type EME Spy 120 (SATIMO, Courtaboeuf, France, http://www.satimo.fr/) and in Amsterdam, a PEM of the type EME Spy 140. The portable device EME Spy 120 is capable of measuring 12 different frequency bands of RF-EMF, ranging from FM (frequency modulation, 88-108 MHz) to W-LAN (wireless local area network, 2400-2500 MHz). Its lower and upper sensitivity range is 0.0067 and 66.3 mW/m^2 (electric field strength between 0.05 and 5 V/m) respectively. The exposimeter EME Spy 140 measures 14 frequency bands of RF-EMF, ranging from FM to W-LAN 5G (5150 MHz to 5850 MHz). This device has a higher sensitivity range at the lower detection limit of 0.000067 to 66.3 mW/m^2 (electrical field strength between 0.005 and 5 V/m). The interval between two measurements was set to four seconds, which corresponds to a distance of about 4.4 to 6.8 meters, assuming a walking speed of approximately 4 km/h. Before September 2010 and after April 2011, accuracy checks of the devices were performed at the Swiss Federal Institute of Technology in Zurich (ETH). Results of the tests showed that accuracy of the devices did not change during the whole data collection period. However, we found indications that cross-talk occurred between DECT (Digital Enhanced Cordless Telecommunications) and GSM1800 (Global System for Mobile Communications) downlink signals for both, the EME Spy 120 as well as the EME Spy 140. Thus, we did not consider DECT when calculating total RF-EMF exposure levels.

For the measurements in Basel, the exposimeter was placed in a pushchair cart with a distance of about one meter to the assistant performing the measurements, at around one meter height above ground. The same was applied in Amsterdam, except that a bicycle cart was used and the assistant was walking beside, pushing the bicycle, ensuring about same walking speed in both cities. In both cities, the mobile phone of the assistant taking the measurements was turned off during measurements.

2.3 Statistical analysis and data management

Arithmetic mean values for each frequency band in each area at each day were separately calculated using the robust regression on order statistics (ROS) method (Röösli et al., 2008), since a large proportion of PEM measurements were censored (below the lower detection limit of the PEM). In order to have comparable results for Amsterdam and Basel, due to the use of two types of PEMs with different lower detection limits (EME Spy 120: 0.05 V/m; EME Spy 140: 0.005 V/m), we also censored Amsterdam data at 0.05 V/m to calculate mean values using ROS. In addition, the proportion of measurements above the thresholds of 0.5 and 1 V/m was determined to compare the distribution of peak exposure levels. All calculations were conducted using power flux density values and then back-transformed to electric field strengths (V/m), except for analysis of variance (ANOVA) calculations.

We focused on mobile phone base station downlink exposure, i.e. the sum of GSM900 (925-960 MHz), GSM1800 (1805-1880 MHz) and UMTS (Universal Mobile Telecommunications System, 2110-2170 MHz), as well as mobile phone uplink (handset) exposure: i.e. the sum of

GSM900 (880-915 MHz), GSM1800 (1710-1785 MHz) and UMTS (1920-1980 MHz). In this paper, total exposure is defined as the sum of all mobile phone uplink and downlink frequency bands as well as FM (88-108 MHz), TV3 (Television, 174-223 MHz), TETRAPOL (professional radio communication standard, 380-400 MHz), TV4/5 (470-830 MHz) and W-LAN (2400-2500 MHz). To evaluate the source of data variability, ANOVA calculations were conducted based on daily means of power flux density levels for all frequencies combined (total), as well as separately for downlink and uplink signals. For the ANOVA, explanatory variables were measurement day, time of the day (3 categories: 09:15-11:59; 12:00-12:59 and 13:00-16:50), type of area (central and non-central residential, downtown and business areas) and city (Basel vs. Amsterdam).

Summary statistics were calculated using R version 2.11.1. ANOVA was calculated using STATA version 10.1 (StataCorp, College Station, TX, USA) based on a balanced data set of arithmetic mean values.

Some technical failures occurred during data collection period (Amsterdam: failure of the device on the second measurement day (11 Nov 2011); missing GPS data for the 1st and 2nd measurement day (10 and 11 Nov 2010); Basel: uplink values were excluded for the 11th November (non-central residential area 2 and business area) and 23rd December 2010 (central residential area and downtown) and thus for calculation of total RF-EMF exposure, uplink values for these days were excluded).

3. Results

3.1 Comparison of mean RF-EMF exposure levels between areas

In total, 20,063 downlink and 18,700 uplink measurements were collected in all Basel's' areas and 28,183 uplink and downlink measurements in Amsterdam's' areas. Area-specific averages of exposure from all frequency bands combined (total RF-EMF) ranged from 0.09 V/m (non-central residential area in Basel) to 0.63 V/m (business area in Amsterdam) (Table 2). Highest total RF-EMF exposure levels occurred in the downtown and business areas (Table 2). Whereas lowest values were observed in non-central residential areas.

Similar to total RF-EMF exposure to mobile phone base stations (all downlink frequencies combined: sum of GSM900, GSM1800 and UMTS) was highest in the downtown and business areas and lowest in non-central residential areas (Table 3). In all areas, the GSM900 and GSM1800 bands were the main contributors to total downlink exposure.

Regarding peak values, a similar pattern was found as for average exposure values, with more peak values above 0.5V/m or 1V/m in the downtown and business area for total (all frequency bands combined) and downlink exposure levels (Table 3). Overall, measurements above 1 V/m were rare in all three downlink bands in all areas.

Exposure from mobile phone handsets (uplink) was considerably lower than downlink values in all areas. Peak values were rare and in Basel for all areas combined, the proportion of uplink measurements above 0.5 V/m was 0.05% for GSM900 and 0.12% for GSM1800. For Amsterdam, the respective proportions were 0.11% and 0.14%. In the UMTS band, no uplink measurements above 0.05 V/m occurred in Basel or in Amsterdam.

3.2 Analysis of data variability between areas

Exposure levels within areas had high spatial variability, the Figure 1 demonstrates, however, that exposure levels were similar on various measurement days and times of the day at the same location on the measurement path. Thus, repeated measurements showed a high reproducibility for mobile phone base station exposure (all downlink frequencies combined):

Figure 2 shows that average downlink exposure levels per area remained fairly constant during the measurement period between November 2010 and January 2011. This is confirmed by variance analyses (Table 4). Day of measurement as well as time of the day explained only a very small proportion of the mobile phone base station data variance (0.6% and 0.2%). Most of the observed data variance is explained by city (50%) and area (30%). Similar results were found for total RF-EMF exposure. For mobile phone handset exposure, day of measurement (3.5%) and time of the day (1.5%) explained somewhat more data variability.

4. Discussion

This study analysed the sources of data variability and quantified RF-EMF exposure levels in four different types of urban environments of two European cities based on repeated measurements with portable exposimeters following a standardized measurement protocol. We found that total (all frequency bands combined) mean exposure levels and exposure from mobile phone base stations were higher in downtown and business areas compared to residential areas. Exposure was highly spatially variable and varied considerably between the areas. However, temporal variability was low and we found good repeatability of measurements in the same area when conducting the measurements at different dates and different times of the day.

4.1 Comparison of exposure levels with other studies

RF-EMF exposure levels in our study were in accordance with studies of Joseph et al. (2008), who found downlink levels from GSM900 and GSM1800 in Ghent and Brussels of up to 0.52

V/m in outdoor areas as well as with Frei et al. (2009) with an average of total exposure of 0.28 V/m performed in Basel outdoors. The contribution of mobile phone base station signals to total RF-EMF exposure was about 89% in Basel and 81% in Amsterdam, whereas uplink exposure was low (Basel: 6% and Amsterdam: 4%). However, outdoor measurements of uplink exposure depend on time, weather conditions and place. An additional explanation might be that uplink exposure levels were somewhat underestimated since when walking with a bicycle or a pushchair cart, people keep in general more distance to a person as without. A small increased distance will considerably reduce the amount of uplink exposure. During rush hour, lunch hour as well as in places where people cumulate, such as at sidewalks of pubs, in shopping areas and the city center, exposure from mobile phone handsets was found to be higher compared to other areas (e.g. residential areas). Other studies have also reported mobile phone base station radiation exposure to be the dominant exposure source when being outdoors: Frei et al. (2009b) observed that in a Swiss population sample with personal measurements collected between 2007 and 2008, mobile phone base station signals accounted for about 52.6% of outdoor exposure levels. The proportion may be somewhat lower compared to our study, because in population survey studies, participants do not have to turn off their own mobile phone as in our study. A European comparison of personal RF-EMF exposure in urban areas is in line with our findings that exposure from mobile phone base stations in outdoor urban environments was important and dominating, particularly in measurement series performed in Belgium (around 90%) and in The Netherlands (approximately 80%) (Joseph et al., 2010). In these two countries, also the own mobile phone was switched off when collecting the measurements.

Within the mobile phone base station bands, UMTS exposure was considerably lower than GSM900 and GSM1800 exposure (Basel: 12%; Amsterdam: 10%). These results are in line with a study of Bornkessel et al. (2007) in Germany showing that for 85% of all measurement points, exposure in both GSM bands was higher than UMTS exposure. In a Swiss study conducted in public transports and cars results suggested that UMTS uplink exposure was considerably lower than GSM uplink exposure (Urbinello and Röösli, 2012).

Regarding base station densities in both cities, GSM base stations are in the majority. However, with mobile phones using web-based applications especially since the introduction of smartphones, UMTS (3rd Generation) as well as newer technologies have increased over the last years and will likely become more important in the future.

4.2 Interpretation

One important finding of our study is the high repeatability of mobile phone base station exposure measurements on the same route, although spatial variability of RF-EMF is high. We found high repeatability for area averages based on a measurement duration of approximately 30 minutes which corresponds to 450 data points. High repeatability was also observed for measurements at a given location on the path when relying on moving averages of 11 data points. Our ANOVA indicates that time of the day and date have little impact on recordings. Since we only measured during daytime at two work-days (Wednesday and Thursday), between November and January, we cannot exclude that differences between work days, weekends, holidays and seasons, as well as between daytime and evening measurements could be larger. In a personal RF-EMF measurement study conducted by Bolte and Eikelboom (2012) total mean exposure during evening (0.382 mW/m^2) was about twice the exposure than during daytime (0.183 mW/m^2) and about four times the exposure during night (0.095 mW/m^2). But at least partly, this difference is likely to be explained by different types of activities of the participants at different time of the day. We have not conducted measurements during the weekend and thus were not able to estimate data variability between workday and weekend. However, Frei et al. (2009b) and Viel et al (2011) found similar exposure values for weekend and workdays suggesting that this factor is not very relevant. Interestingly, high repeatability of measurements on the same route could also be confirmed when expanding the study period to 10 months (Beekhuizen et al., 2013). We also found little indications that repeatability depends on the data variability or the proportion of measurements above certain thresholds, since the pattern of the repeated measurements was similar in all four types of areas.

4.3 Strengths and limitations

To our knowledge, this is the first study that used a standardized measurement protocol with concurrently conducted data repeated measurement series from different types of urban areas to systematically evaluate repeatability of personal RF-EMF measurements. A further strength of the study was that PEMs were placed distant to the body in order to avoid shielding of the measurements by the own body, which has been demonstrated to result in an underestimation of the exposure (Iskra et al., 2010). Since, during measurements, the own mobile phone was turned off, our uplink values can be attributed to other peoples' mobile phone, which was not the case in previous personal exposure studies based on volunteers (Frei et al., 2009b; Viel et al., 2009), which is a limitation for source attribution (Urbinello and Röösli, 2012).

Our study also has limitations; the PEMs used in both cities were not of the same type and differed in their lower detection limit. However, we censored the Dutch data at the same detection limit as the Swiss data (0.05 V/m) to obtain comparable results and we excluded the two additional frequency bands for calculations of total RF-EMF exposure (i.e. WiMax

(Worldwide Interoperability for Microwave Access): 3400 to 3800 MHz and W-LAN 5G: 5150 MHz to 5850 MHz) measured by the EME Spy 140 used for data collection in Amsterdam. We also checked whether the summary statistics of the Dutch data differed depending on censoring at the detection limit of the EME Spy 120 or EME Spy 140 device, but found that not to be the case (data not shown). Uncertainty of the measurement accuracy of such portable devices has been investigated before (Bolte et al., 2011; Bornkessel et al., 2010; Lauer et al., 2012). Cross-talk from DECT into GSM1800 downlink signals may result in a slight overestimation of GSM1800 downlink exposure levels. While crosstalk between these two bands could potentially have a strong influence on individual measurement points, averages as presented in our analysis are not be expected to be strongly affected since DECT exposure is expected to be at rather low levels at outdoor sites. Most important, cross-talk-effects would neither affect our repeatability results nor the observed difference in downlink exposure between Basel and Amsterdam, since both devices are affected.

Ideally, one would be able to choose measurement paths that are representative of the exposure a population would have in the respective area, but it is unclear how this could be achieved. The selection of the areas and measurement paths through the different areas of the city determines to a large extent our RF-EMF measurement levels. The extent of this impact is difficult to quantify and thus the observed higher exposure levels in Amsterdam has to be interpreted with caution in terms of the general exposure situation in both cities. More comprehensive data collection is needed to compare exposure situation across cities and countries.

4.4 Conclusions

Our study indicates that RF-EMF measurements with PEMs allow collecting large amount of data in a short time period, resulting in robust data to characterize mean exposure levels in an urban area based measurements collected within 30 minutes. Our repeated measurement series show little temporal variation in exposure levels, minimizing the need for many repeated measurements. Thus, exposure surveys using PEMs may be suitable to monitor RF-EMF exposure in the everyday environment.

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Tables

Table 1: Overview of the selected areas.

Denotation	Basel: area name/measurement path length/density of base stations*	Amsterdam: area name/measurement path length/density of base stations*	Area characteristics
Decentral residential area 1	Im Langen Loh 2.3 km > 10 base stations	Sloterplas 2.2 km < 5 base stations	Building height: 2 to 3 floors Near a quiet area and along a busy street (only Amsterdam)
Decentral residential area 2	Byfangweg 2 km > 10 base stations	Plesmanlaan 1.9 km 5 – 10 base stations	Building height: 3 to 4 floors and quiet area (Basel) High-rise residential area with buildings up to 6-7 floors (Amsterdam)
Central residential area	Gundeldingen 2.3 km > 10 base stations	Albert Cuypstraat 1.7 km > 10 base stations	Building height: 4 to 5 floors Shops Residential Lot of activity in terms of pedestrian
Downtown	Barfüsserplatz/ Marktplatz 2.1 km > 10 base stations	Leidseplein 2 km > 10 base stations	Meeting point Pedestrian area with strolling people Traffic and many trams
Business area	Messeplatz 2.2 km > 10 base stations	Zuidas 2 km > 10 base stations	Conference venue/business place Large building complex

Base station density in three categories: < 5 base stations; 5-10 base stations; >10 base stations
Within a buffer of 500 m along the measurement path.

Table 2: Overview of average exposure as well as the percentage of values above the threshold of 0.5 V/m and 1 V/m, respectively for all frequency bands combined.

Exposure from all frequency bands combined*			**Arithmetic mean values [V/m]**	**Percentage of values over threshold**	
				0.5 V/m	**1 V/m**
		n	Total	Total	Total
All areas	*BSL*	20063	0.26	4.92%	0.57%
	AMS	28183	0.47	30.97%	2.64%
Decentral residential area 1	*BSL*	4302	0.09	0.05%	0.02%
	AMS	6110	0.43	19.26%	3.22%
Decentral residential area 2	*BSL*	3625	0.27	6.68%	1.74%
	AMS	5575	0.35	10.80%	0.27%
Central residential area	*BSL*	4608	0.19	2.13%	0.13%
	AMS	4817	0.35	12.21%	1.41%
Downtown	*BSL*	3866	0.32	7.89%	0.83%
	AMS	6030	0.55	43.20%	3.98%
Business area	*BSL*	3662	0.32	9.31%	0.33%
	AMS	5651	0.63	66.45%	3.96%

* Sum of all mobile phone uplink and downlink frequency bands, FM, TV3, TETRAPOL, TV4/5 and W-LAN.

Table 3: Overview of average exposure as well as the percentage of values above the threshold of 0.5 V/m and 1 V/m, respectively for mobile phone downlink frequency signals.

Mobile phone base station exposure			**Arithmetic mean values [V/m]**				**Percentage of values over threshold**					
							0.5 V/m			**1 V/m**		
		n	GSM 900	GSM 1800	UMTS	Total DL*	GSM 900	GSM 1800	UMTS	GSM 900	GSM 1800	UMTS
All areas	*BSL*	20063	0.13	0.19	0.08	0.24	4.61%	2.45%	0.07%	0.40%	0.36%	None
	AMS	28183	0.27	0.30	0.14	0.43	5.66%	10.18%	0.38%	0.37%	0.77%	0.11%
Decentral residential area 1	*BSL*	4302	0.02+	0.05	0.07	0.09	None	None	None	None	None	None
	AMS	6110	0.23	0.34	0.03+	0.41	4.06%	10.74%	None	0.15%	2.16%	None
Decentral residential area 2	*BSL*	3625	0.05	0.26	0.04+	0.26	0.06%	5.68%	None	None	1.49%	None
	AMS	5575	0.28	0.10	0.16	0.34	5.88%	None	0.34%	0.13%	None	0.02%
Central residential area	*BSL*	4608	0.09	0.12	0.09	0.18	0.74%	0.33%	None	0.04%	None	None
	AMS	4817	0.18	0.24	0.12	0.33	3.11%	4.19%	0.15%	0.42%	None	0.02%
Downtown	*BSL*	3866	0.16	0.24	0.10	0.30	1.27%	2.61%	None	0.21%	0.36%	None
	AMS	6030	0.33	0.38	0.17	0.53	8.57%	17.73%	0.48%	1.01%	1.06%	0.02%
Business area	*BSL*	3662	0.21	0.18	0.10	0.30	3.60%	1.12%	0.19%	0.22%	None	None
	AMS	5651	0.29	0.37	0.16	0.49	5.77%	16.69%	0.90%	0.12%	0.39%	None

* Downlink (exposure from mobile phone base stations)

+Below the sensitivity level of the exposimeter. Results are tenuous.

Table 4: Analysis of variance of daily mean exposure levels expressed as power flux density for total RF-EMF, downlink and uplink frequency band.

Source	d.f.	Explained variance*	F	p
Total				
Measurement day	11	0.30	0.15	0.10
Time of the day⁺	2	0.18	0.51	0.60
City	1	44.84	247.92	<0.001
Area	4	32.93	45.52	<0.001
Whole model	18	83.54	25.66	<0.001
Downlink				
Measurement day	11	0.59	0.33	0.98
Time of the day⁺	2	0.20	0.61	0.55
City	1	47.37	292.5	<0.001
Area	4	31.31	48.34	<0.001
Whole model	18	85.26	29.25	<0.001
Uplink				
Measurement day	11	3.62	0.9	0.54
Time of the day⁺	2	1.51	2.06	0.13
City	1	39.41	107.63	<0.001
Area	4	15.88	10.84	<0.001
Whole model	18	67.41	10.23	<0.001

* Percentage of total variance

⁺ 3 categories: 09:15-11:59; 12:00-12:59 and 13:00-16:50

Figures

Figure 1: Figure 1: Repeatability of mobile phone base station measurements (downlink) of one EME Spy 140 PEM for each area in Amsterdam: The graphs show the moving average of the electric field strengths along the whole measurement paths on 10 measurement days (no data for the 1st and 2nd measurement day, 10 and 11 Nov 2010). Moving averages were taken over 11 successive measurements, corresponding to a measurement interval of 44 seconds.

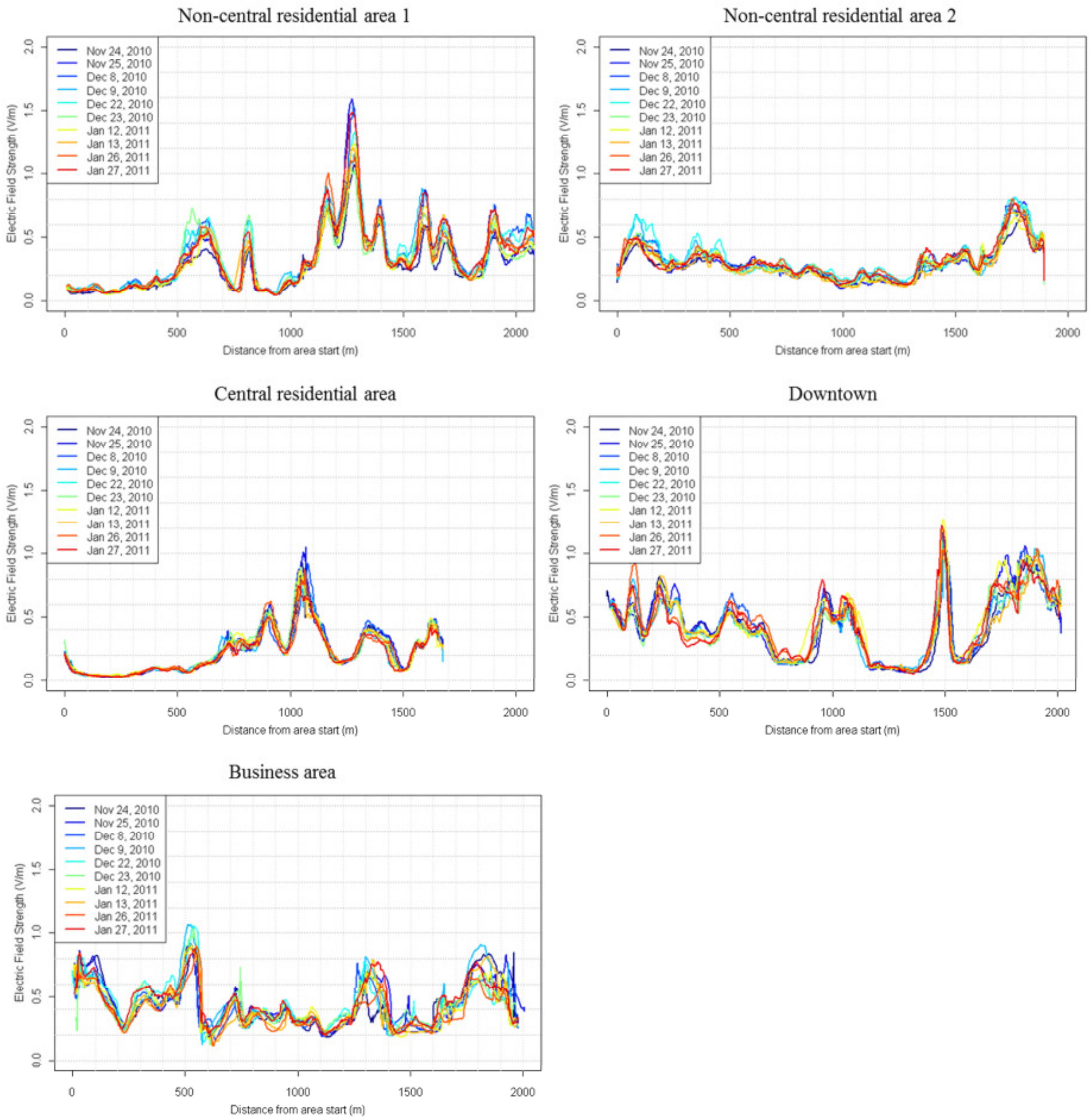
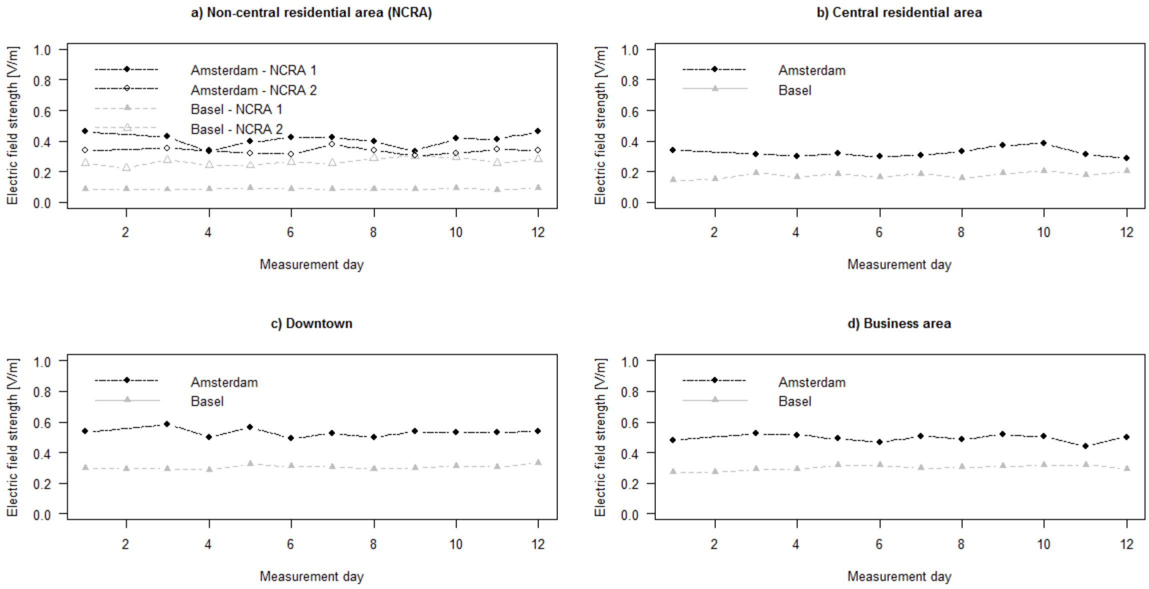
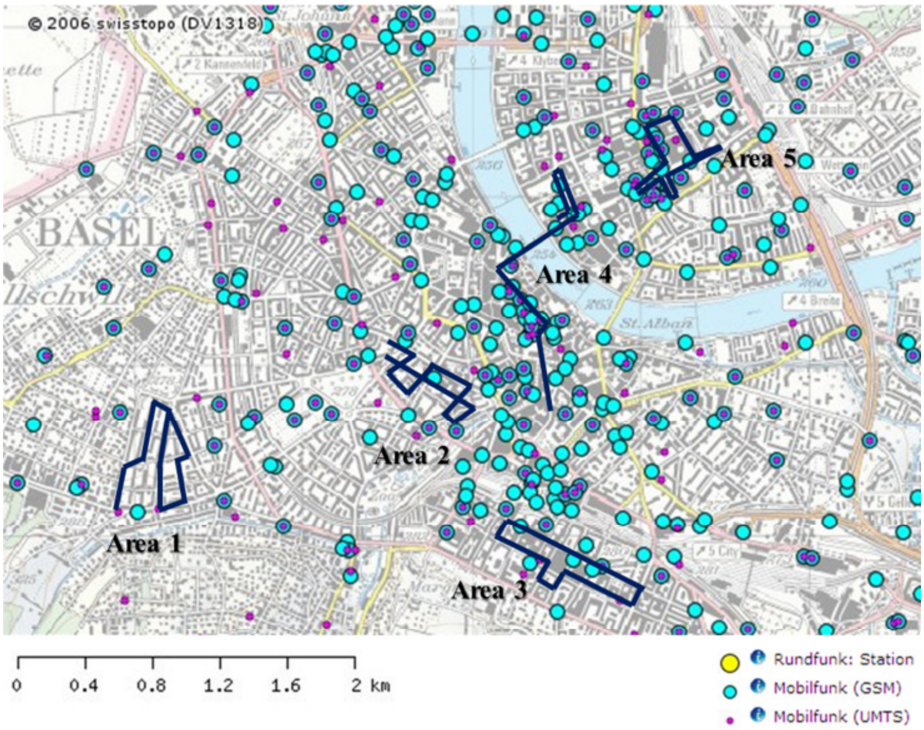


Figure 2: Average mobile phone base station exposure (downlink) per measurement day according to type of area (no data for the 2nd measurement day in Amsterdam).



Online Figure 1



Online Figure 2