

Spatial distribution of pollen-induced symptoms within a large metropolitan area—Berlin, Germany

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Abstract Large spatial differences in the distribution of three allergologically relevant pollen types for Central Europe—birch, grass, and mugwort—are revealed within a large metropolitan area—Berlin, Germany. The purpose of the study is an examination of the hypothesis that these different pollen exposure conditions can cause different degrees of pollen-induced symptoms within the city. Pollen data from 14 gravimetric traps and one volumetric trap in Berlin and anonymously reported pollen-induced symptom data from the online-based self-documentation tool “Patient’s Hayfever Diary” (PHD) are used for the analysis of temporal and spatial variations of the severity of the overall total symptoms. Geographically localised symptom data are linked to the nearest pollen trap. Statistical analysis is performed using Kendall’s Tau-b. Higher amounts of monitored birch and grass

pollen in the peripheral areas of Berlin induce stronger symptoms in PHD users located within suburbs than those located in the city centre. There is no statistical relationship between the varying presence of mugwort pollen in the air and the severity of symptoms. Spatial differences in the pollen-induced symptom severity within a large city coinciding with spatial differences in birch and grass pollen depositions are shown for the first time. Therefore, pollen data from a single trap may not provide an appropriate explanation for differences in pollen-induced symptoms across the city. More detailed and reliable information about the exposure to allergenic pollen can be addressed by installing further traps in order to improve the knowledge about pollen exposure within cities.

Keywords Pollen allergy · Pollen-induced symptoms · Spatial distribution · Large city · Allergenic pollen · Berlin

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1 Introduction

Allergic diseases are widespread within the global population—approximately 10–30% of adults and around 40% of children suffer from allergic rhinitis (Pawankar et al. 2013). In the German population, medically diagnosed allergic rhinitis is stated for approximately 10.3% of children as well as

adolescents (Schmitz et al. 2012) and around 14.8% of adults (Langen et al. 2013).

One of the most common causes of allergic rhinitis is pollen (Pawankar et al. 2013). Therefore, airborne pollen is continuously monitored with 7-day volumetric spore traps (Hirst 1952) placed at rooftop levels at about 40 stations in Germany and about 400 stations in Europe. Frequently, just one pollen trap is operated within a city which is deemed to be representative for the entire urban area, regardless of the city size, the variety of the urban living spaces, and environmental conditions (land use, heterogeneity in urban green, etc.). Since 2010, more than 50% of the world's population have been living in cities. By 2050, that percentage will rise to 66% (UN 2015). Consequently, larger parts of the population will be exposed to specific amounts of certain pollen types at the same time. Thus, a better understanding of pollen exposure within cities, its causes and risks, becomes more important. There are a few studies listed in Werchan et al. (2017a) which consider the aspect of heterogeneity in cities by operating a pollen monitoring network with two, three, or more traps within one city (e.g. Emberlin and Noris Hill 1991; Ishibashi et al. 2008; Hjort et al. 2011; Weinberger et al. 2016). Nevertheless, most of these networks were/are not operated permanently; they only served/serve temporarily as research devices. An important result that most of the listed investigations had in common is the fact that there are similarities in the pollen composition and the seasonality of certain pollen types within a studied city. However, differences in concentrations/sedimentations of certain pollen types occur to a greater or lesser extent. These are often linked to influences of local sources of urban vegetation.

It is widely confirmed that the development of allergy symptoms in patients with allergic rhinoconjunctivitis against pollen is affected by the degree of exposure to the allergen (Frenz 2001; Takasaki et al. 2009; Brito et al. 2011; Kiotseridis et al. 2013). There are different methods and scales to measure the effects of pollen exposure on symptom severity of allergic rhinoconjunctivitis (e.g. Grouin et al. 2014; Bastl et al. 2014; Florack et al. 2016). There are also certain platforms/systems enabling people suffering from pollen allergy to document their symptom severities for the affected organs (eyes, nose, and lungs) in order to obtain information about their disease, support allergologists in determining an appropriate therapy,

and assess the efficacy of immunotherapy. One of the systems in wide use is the freely available web-based tool Patient's Hayfever Diary (PHD) which has also been available in Germany since 2009 (Berger et al. 2011; Karatzas et al. 2014; Bastl et al. 2014). The PHD enables hay-fever sufferers to anonymously report their daily symptoms online or via the apps "Pollen" (Pollenwarndienst 2017) or "Husteblume" (TK 2017), supplemented with the geographical location data for the occurring symptoms, in particular the region, postal code, or GPS coordinates. Combining the PHD data (symptoms and location of the user) and the pollen data (types and amounts) allows the analysis of the occurrence and the intensity of symptoms in a certain geographical area or/and a certain time period (Karatzas et al. 2014; Bastl et al. 2015) and facilitates personalised symptom forecasts for PHD users (Berger et al. 2013; Kmenta et al. 2014; Voukantsis et al. 2015).

In our previous study from 2014 (Werchan et al. 2017a), a network of stationary gravimetric pollen traps within the large metropolitan area of Berlin (Germany) was established at 14 locations within the city and continuously operated for 33 weeks in order to study the spatial distribution of the three most allergologically relevant pollen types for Germany—birch (*Betula*), grasses (Poaceae), and mugwort (*Artemisia*). Temporal variations and substantial differences occurred in the spatial distribution of these pollen types within the city which could result in varying severity levels of pollen-induced symptoms in allergy sufferers within such a geographical area.

The goal of this study is the comparison of the pollen levels detected with the 14 gravimetric pollen traps located throughout the metropolitan area of Berlin during the 2014 pollen season to the pollen-induced symptoms PHD users reported from the city. We seek to reveal the influence of spatial differences in the amount of airborne allergenic pollen within the city of Berlin on the symptom severity of allergic rhinoconjunctivitis. Our research may contribute to a broader understanding of the spatial distribution of pollen-induced symptoms within a large city and point out the practical use of pollen monitoring networks with stations placed across a large metropolitan area.

2 Materials and methods

2.1 Study area

Berlin is the capital city of Germany and located 29.5–115 metres above sea level in the North German Plain in the northeast of the country. The climate of the city is described as maritime temperate—Cfb (Kottek et al. 2006). Berlin is the most populated (3.5 million inhabitants) and largest city (892 km²) in Germany. Approximately 40% of the Berlin area consists of open spaces, e.g. parks, forests, bodies of water, agricultural areas (Amt für Statistik Berlin-Brandenburg 2016). An approximate share of 15–18% of the Berlin population is affected by pollen allergy, corresponding to 525,000–630,000 inhabitants (Bergmann et al. 2012).

2.2 Pollen data

Depositions of allergenic birch (*Betula*), grasses (Poaceae; including *Cerealia*), and mugwort (*Artemisia*) pollen were monitored with self-constructed gravimetric pollen traps inspired by the Durham trap (Durham 1946; Werchan et al. 2017a). Fourteen traps were located at street level (around 2.5 metres above ground) at fourteen sites across Berlin (Fig. 1). The traps were continuously operated for 33 weeks from 11 March 2014 through 28 October 2014 and changed weekly (Werchan et al. 2017).

In addition, weekly birch, grass, and mugwort pollen concentrations from the volumetric pollen trap (Hirst 1952) installed at a rooftop (23 metres above ground level) in the centre of Berlin (the reference monitoring station of the German Pollen Information Service Foundation) were used for comparison purposes.

The pollen seasons for the three pollen types based on pollen data from gravimetric traps were determined on the basis of the definition from Jäger et al. (1996) defining the beginning and the end of each season as the days (as the weeks in our study) when 1 and 95% of the annual pollen total have been reached, respectively.

2.3 Pollen-induced symptom data

Pollen-induced symptom data from the city of Berlin for the time of the 2014 birch, grass, and mugwort

pollen seasons were extracted from the database of the Patient's Hayfever Diary (PHD)—a freely available web-based system characterised by the fact that individuals suffering from pollen allergy and/or pollen-induced asthma can report their specific symptoms in the eyes, nose, and lungs (bronchi). The anonymously entered symptom data are available on a daily basis and combined with information about the location (postal code or geographical coordinates) where the PHD users experienced the symptoms.

Daily symptoms are quantified numerically: 0 = no problems, 1 = mild problems, 2 = moderate problems, and 3 = severe problems. Four (4) specific symptoms are differentiated for each affected organ (e.g. eyes: itching, redness, foreign body sensitisation, and tear flow). The possible maximum value per organ is seven (7). Thus, based on the symptom data entered, a total symptom value between 0 (no symptoms) and 21 (maximum manifestation of symptoms on all three organs at the same time) can be calculated, summarised as the total symptom score (TSS) of all affected organs, also referred to as the overall total symptom (OTS) value. The OTS was used for the calculations of relationships between the expression of symptoms of PHD users and the three chosen pollen types.

2.4 Preparation of pollen-induced symptom data

- Daily entries of individual PHD users were averaged into weekly values ("symptom week") in order to compare the OTS values with weekly gravimetric and volumetric pollen data.
- A minimum number of 4 daily PHD user entries within 1 week were required in order to constitute a "symptom week". If the available PHD data of an individual PHD user exceeded a single "symptom week", the average of a minimum number of 3 daily PHD user entries was considered sufficient to form two and more symptom weeks. Weeks with less than three out of seven daily entries within one "symptom week" were excluded from further calculations.
- Every "symptom week" of an individual PHD user was characterised by reports from the same postal code.
- There were a few users reporting symptoms from two Berlin postal codes within a one-week period.

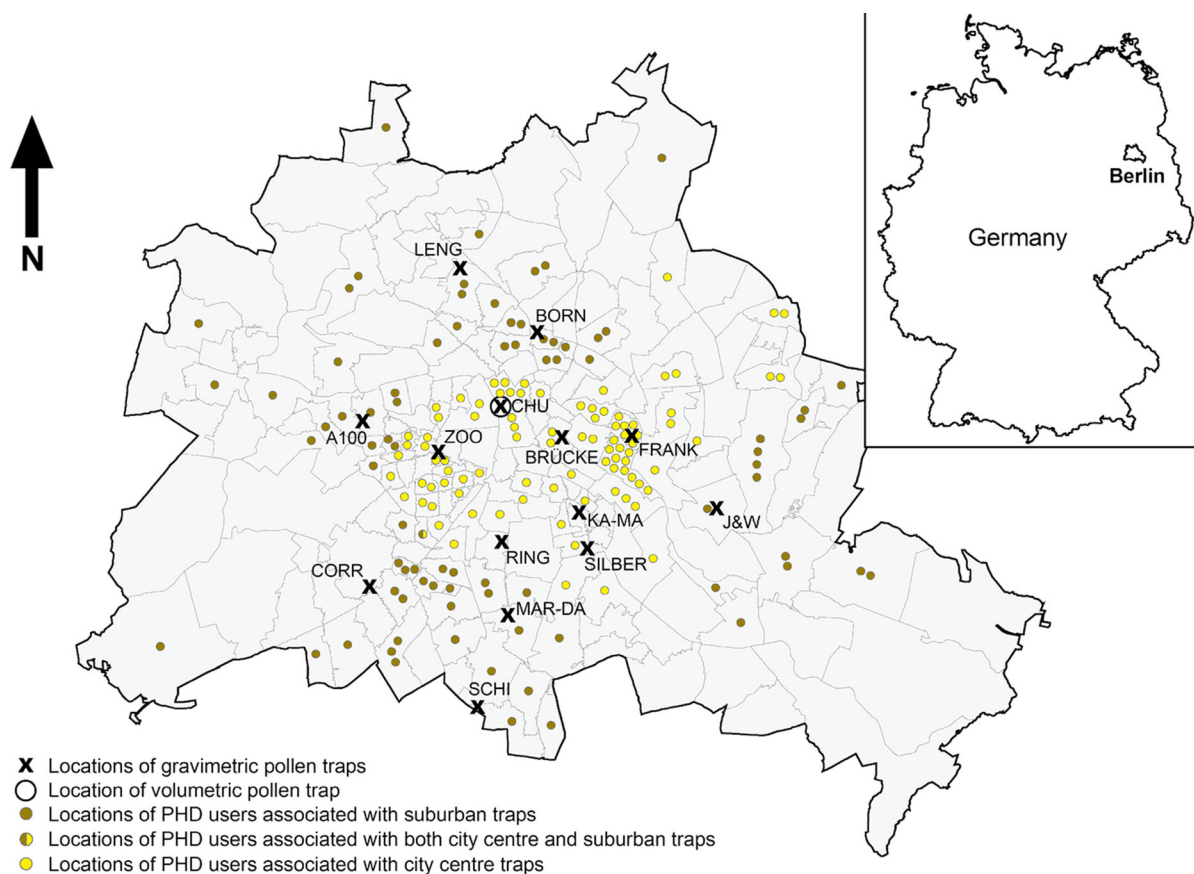


Fig. 1 Distribution of 170 PHD user positions within Berlin during the birch pollen season: 163 PHD users resulting in 90 city centre user positions (light yellow) and 81 suburban user positions (brown); identical weekly symptom data of one user

used in both groups; 6 users appeared in two different postal codes; 1 user in three different postal codes. *Source map:* Geoportal Berlin/Postleitzahlen 2015

In case of 4 daily reports from one postal code and 3 daily reports from another postal code or 3 daily reports from one postal code and 3 daily reports from another postal code, the weekly pollen-induced OTS of the PHD user was assigned to both of the two corresponding pollen traps.

- All “symptom weeks” of a specific PHD user in a specific postal code were geographically allocated to the nearest of the fourteen gravimetric pollen traps. In some cases, two different traps had the approximate same distance (a difference of 60 m or less) to a PHD user. Thus, symptom values from this specific postal code were associated with the pollen data of these two traps.

At the end of the procedure, all users formed a total of fourteen “user groups” (based on the location where

users experienced their symptoms) for the respective fourteen gravimetric pollen monitoring stations.

The often low number of PHD users within each of the 14 user groups impeded a statistically meaningful analysis between the fourteen groups.

- Two newly formed groups of PHD users were implemented, following the division of traps into two groups based on their distance from the geographical centre of the city (Werchan et al. 2017a)—a “city centre group” (BRÜCKE, CHU, FRANK, KA-MA, RING, SILBER, ZOO) and a “suburban group” (A100, BORN, CORR, J&W, LENG, MAR-DA, SCHI) (Figs. 1, 2, 3).
- The PHD users were assigned to these two groups based on their original association to the nearest of the fourteen pollen traps. For example, PHD users originally assigned to the BRÜCKE pollen trap

became part of the newly formed “city centre group”, etc.

- Symptom data of the fourteen user group members that were assigned to two traps and whose traps now belonged to the same of the two newly formed groups were used just once. There was one exception: symptom data of one PHD user in the birch pollen season were used for both of the newly formed groups because of the assignment of this user to two traps, one belonging to the “city centre group”, the other being associated with the “suburban group” (Fig. 1).
- Weekly symptoms of individual PHD users of the “city centre group” were compared to the weekly pollen concentrations from the volumetric trap and the average of the weekly pollen sedimentations detected by the seven city centre traps.
- Weekly symptoms of individual PHD users of the “suburban group” were compared to the weekly pollen concentrations from the volumetric trap and the average of the weekly pollen sedimentations of the seven suburban traps.
- Weekly symptoms of individual PHD users from all over Berlin were compared to weekly pollen concentrations from the volumetric trap and the average of the weekly pollen sedimentations from the fourteen gravimetric traps.

2.5 Statistical analyses

Symptom and pollen data were analysed using Kendall’s Tau-b correlation analysis. Kendall’s coefficient is more robust in small samples than the frequently used Spearman’s R, and it is used in non-normalised interval-sized variables (Gibbons 1993). In addition, the statistical sharpness of both dimensions is comparable. The statistical and graphical data analyses were performed in Microsoft® Office Excel, IBM SPSS Statistics 24, and Adobe Photoshop CS2.

3 Results

3.1 Pollen seasons

In Berlin, the 2014 birch pollen season lasted 8 weeks: 11 March through 06 May 2014, the grass pollen season 16 weeks: 15 April through 05 August 2014,

and the mugwort pollen season 12 weeks: 24 June through 16 September 2014.

3.2 PHD users

In 2014, 163 PHD users reported at least 1 week of evaluable symptom data within the city of Berlin during the birch pollen season, 149 PHD users (148 from Berlin, 1 from Brandenburg) submitted data during the grass pollen season, and 71 PHD users (70 from Berlin, 1 from Brandenburg) provided data during the mugwort pollen season.

Specific PHD users of the birch pollen group could be part of the grass pollen group, and specific PHD users of the grass pollen group could be part of the mugwort pollen group due to the continuity of their symptoms and/or the continuity of their use of the PHD.

3.3 Comparison of pollen-induced symptom data and pollen concentrations/sedimentations

3.3.1 Birch

The greater proximity to rural areas resulted in a higher birch pollen deposition in the suburban area (mean 326.0 pollen grains; average weekly maximum of seven suburban traps 1,395.7 pollen grains) in contrast to the city centre (mean 242.7 pollen grains; average weekly maximum of seven city centre traps 997.4 pollen grains) and thus, to a corresponding decrease in the OTS values from the periphery in the direction of the city centre (Table 1, Fig. 4). For example, the OTS of city centre PHD users that were significantly positively ($p < 0.05$) and positively ($p > 0.05$) correlated with the average of the weekly pollen sedimentations of the city centre traps reached a maximum of 7.9, while the OTS of suburban users reached a maximum value of 8.8 (Table 1, Fig. 4). The weaker birch pollen season in the city centre was reflected in a lower OTS of PHD users located in the city centre. In contrast to that, the stronger birch pollen season outside the city centre resulted in higher OTS (Table 1, Fig. 4).

The OTS values displayed as curves in Fig. 4 show the highest scores by week with the maximum birch pollen concentration/sedimentation (week 4). The correlations between the average weekly OTS of PHD users that were significantly positively

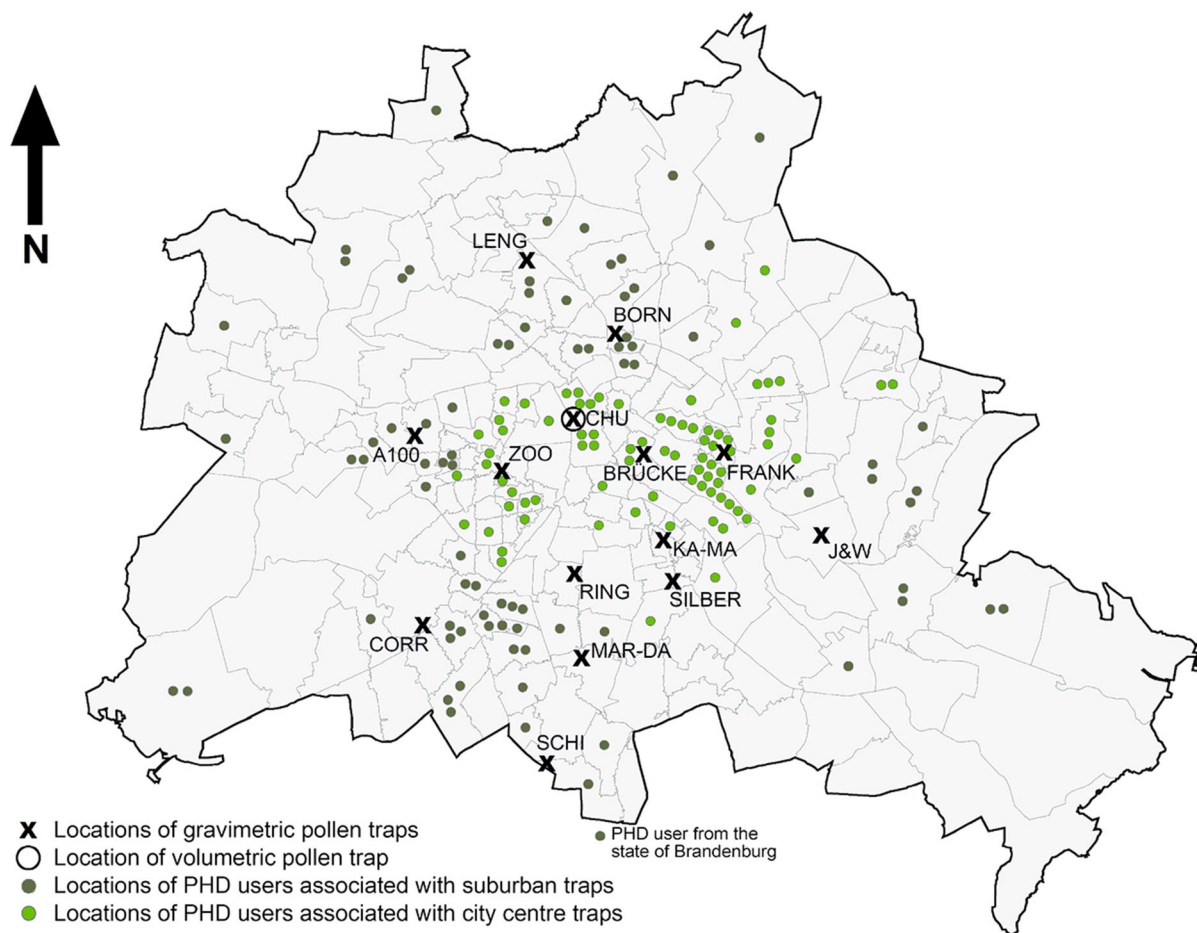


Fig. 2 Distribution of 159 PHD user positions within Berlin during the grass pollen season: 149 PHD users resulting in 80 city centre user positions (light green) and 79 suburban user

positions (green); 6 users appeared in two different postal codes; 2 users in 3 different postal codes. *Source map:* Geoportal Berlin/Postleitzahlen 2015

($p < 0.05$) and positively ($p > 0.05$) correlated with the corresponding weekly pollen concentrations/sedimentations from 1) the whole of Berlin, 2) the city centre, and 3) the suburban area and a) weekly pollen data from the volumetric trap (1 + a, 2 + a, 3 + a), b) average weekly pollen data from all 14 gravimetric traps (1 + b), c) average weekly pollen data from seven gravimetric city centre traps (2 + c), and d) average weekly pollen data from seven gravimetric suburban traps (3 + d) were in all cases significant ($p < 0.05$) and positive (Table 2). For the single volumetric trap, the correlation coefficients were in general slightly lower than the coefficients of the network of gravimetric traps (Table 2).

3.3.2 Grass

During the 2014 grass pollen season, the PHD users of the “suburban group” were more strongly exposed to grass pollen than the PHD users of the “city centre group”: (a) suburban group average = 31.4 pollen grains and maximum pollen deposition = 112.3 pollen grains; (b) city centre group average = 26.9 pollen grains and maximum pollen deposition week = 89.3 pollen grains (Table 1). Correspondingly, allergic symptoms during the grass pollen season were more pronounced among suburban users than among city centre users, e.g. OTS values of significantly positively ($p < 0.05$) and positively ($p > 0.05$) correlated suburban users (based on the correlation with the

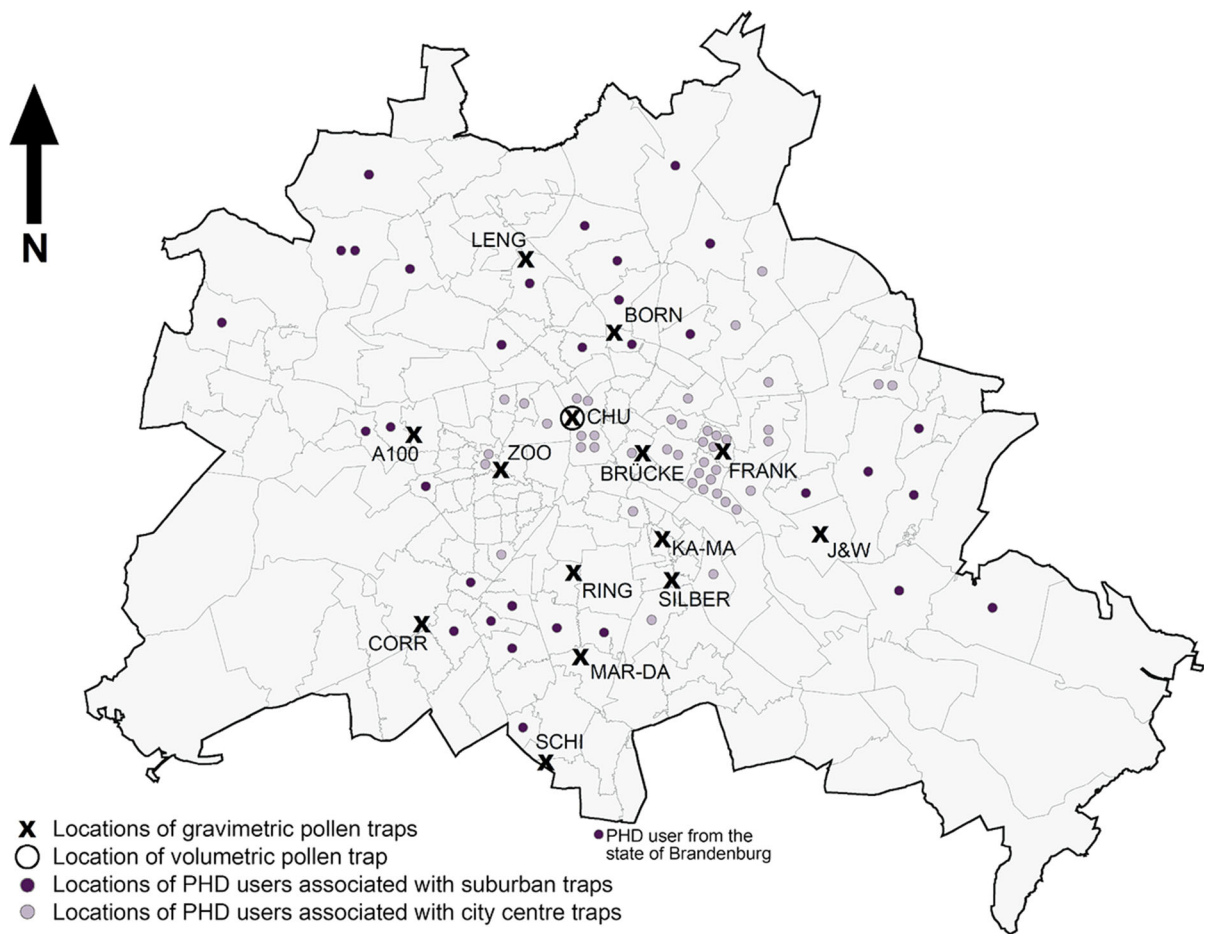


Fig. 3 Distribution of 76 PHD user positions within Berlin during the mugwort pollen season: 71 PHD users resulting in 33 city centre user positions (light violet) and 43 suburban user

positions (violet); 5 users appeared in two different postal codes
Source map: Geoportal Berlin/Postleitzahlen 2015

average weekly pollen data from the city centre/suburban gravimetric traps) were on average 4.4 and reached a maximum of 6.9. In comparison, the values for city centre users were 3.3 (average) and 5.2 (maximum), respectively (Table 1).

The OTS values displayed as curves in Fig. 5 showed the highest scores during the period with the highest grass pollen depositions—weeks six through ten. The correlations between the average weekly OTS of PHD users that were significantly positively ($p < 0.05$) and positively ($p > 0.05$) correlated with the corresponding weekly pollen concentrations/sedimentations from 1) the whole of Berlin, 2) the city centre, and 3) the suburban area and a) weekly pollen data from the volumetric trap (1 + a, 2 + a, 3 + a), b) average weekly pollen data from all 14 gravimetric

traps (1 + b), c) average weekly pollen data from seven gravimetric city centre traps (2 + c), and d) average weekly pollen data from seven gravimetric suburban traps (3 + d) were in all cases significant ($p < 0.05$) and positive (Table 3). For the single volumetric trap, the correlation coefficients were in general slightly higher than the coefficients of the network of gravimetric traps (Table 3).

3.3.3 Mugwort

During the 2014 study, very high mugwort pollen counts occurred in a few gravimetric traps located in different parts of Berlin independently from the vicinity to rural areas (Werchan et al. 2017a). In contrast, traps located in between these traps

Table 1 Basic descriptive statistics (minimum [min], maximum [max], mean, and standard deviation [std]) for weekly average pollen levels and weekly average OTS values for birch, grass, and mugwort during their pollen seasons (birch = 8 weeks, grass = 16 weeks, mugwort = 12 weeks) for the

peripheral (suburban) and the central (city centre) areas of the city with their associated user groups for a single volumetric trap (upper half of table) and for the network of 14 gravimetric traps divided into 7 city centre and 7 suburban traps (lower half of table)

Weekly symptoms and weekly pollen from volumetric trap	City centre users				Suburban users			
	Min	Max	Mean	Std	Min	Max	Mean	Std
Birch								
Pollen	17.0	9940.0	2596.0	3264.8	17.0	9940.0	2596.0	3264.8
Avg. of weekly OTS of all users	3.22	7.35	4.36	1.42	3.83	8.10	5.13	1.43
Avg. of weekly OTS of users ≥ 3 weeks	3.12	6.28	4.03	1.09	3.93	7.82	5.00	1.31
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	0.90	7.56	3.89	2.24	2.93	9.31	5.85	1.79
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	3.03	7.83	4.56	1.64	3.78	8.61	5.14	1.66
Grass								
Pollen	1.0	652.0	212.9	218.3	1.0	652.0	212.9	218.3
Avg. of weekly OTS of all users	2.55	4.53	3.47	0.49	1.90	5.70	3.87	1.09
Avg. of weekly OTS of users ≥ 3 weeks	2.52	4.10	3.40	0.42	1.75	5.65	3.80	1.09
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	0.84	7.51	3.36	2.02	0.57	11.45	6.08	2.95
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	1.81	5.42	3.35	1.06	1.50	7.01	4.20	1.61
Mugwort								
Pollen	0.0	106.0	48.5	41.2	0.0	106.0	48.5	41.2
Avg. of weekly OTS of all users	2.26	3.59	2.67	0.43	1.71	3.68	2.69	0.77
Avg. of weekly OTS of users ≥ 3 weeks	2.26	3.59	2.62	0.43	1.68	3.96	2.74	0.88
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	3.34	5.00	4.19	0.63	0.00	7.68	4.10	2.94
Weekly symptoms and average of weekly pollen from gravimetric traps	City centre users				Suburban users			
	Min	Max	Mean	Std	Min	Max	Mean	Std
Birch								
Pollen	7.3	997.4	242.7	326.4	8.4	1395.7	326.0	460.7
Avg. of weekly OTS of all users	3.22	7.35	4.36	1.42	3.83	8.10	5.13	1.43
Avg. of weekly OTS of users ≥ 3 weeks	3.12	6.28	4.03	1.09	3.94	7.82	5.00	1.31
Avg. of weekly OTS of sign. positively ($p < 0.05$)corr. users ≥ 3 weeks	0.90	7.40	3.72	2.17	2.14	10.69	4.87	2.61
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	3.23	7.87	4.61	1.66	3.93	8.83	5.27	1.71
Grass								
Pollen	0.4	89.3	26.9	28.9	0.7	112.3	31.4	35.9
Avg. of weekly OTS of all users	2.55	4.53	3.47	0.49	1.90	5.70	3.87	1.09
Avg. of weekly OTS of users ≥ 3 weeks	2.52	4.10	3.40	0.42	1.75	5.65	3.80	1.09
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	0.56	6.76	3.18	1.86	0.57	13.39	6.22	3.34
	1.62	5.18	3.28	1.08	1.90	6.87	4.41	1.54

Table 1 continued

Weekly symptoms and average of weekly pollen from gravimetric traps	City centre users				Suburban users			
	Min	Max	Mean	Std	Min	Max	Mean	Std
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks								
Mugwort								
Pollen	0.7	14.1	6.1	5.3	0.0	18.5	5.4	6.0
Avg. of weekly OTS of all users	2.26	3.59	2.82	0.41	1.71	3.68	2.93	0.71
Avg. of weekly OTS of users ≥ 3 weeks	2.26	3.59	2.75	0.41	1.68	3.96	2.96	0.78
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	0.43	6.25	2.95	2.48	1.71	4.71	3.50	1.28
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	2.62	5.15	3.97	0.92	0.50	8.26	4.59	2.23

avg = average; sig. = significantly; corr. = correlated; n.a. = not available; users ≥ 3 weeks denotes users with at least 3 weeks of available symptom data during the pollen season of birch, grass, or mugwort

frequently exhibited very low counts of mugwort pollen. Differences in the mean and maximum mugwort pollen sedimentation values between the suburban and the city centre trap groups remained small, with the group of suburban traps achieving a higher maximum (18.5 vs. 14.1 pollen grains) and the group of city centre traps reaching a higher mean value (6.1 vs. 5.4 pollen grains) (Table 1). The higher average weekly OTS values (maximum, mean) of significantly positively ($p < 0.05$) and positively ($p > 0.05$) correlated suburban users (associated with the weekly pollen sedimentation average from suburban gravimetric traps) in contrast to city centre users (associated with city centre traps) displayed in Fig. 6 and Table 1 are based on a very low number of users—7 PHD users from the suburbs and 14 PHD users from the city centre (Table 4). The seasonal OTS curves in Fig. 6 show the highest scores nearly independent from the highest mugwort pollen values.

The correlations between the average weekly OTS of PHD users that were significantly positively ($p < 0.05$) and positively ($p > 0.05$) correlated with the corresponding weekly pollen concentrations/sedimentations from 1) the whole of Berlin, 2) the city centre, and 3) the suburban area and a) weekly pollen data from the volumetric trap (1 + a, 2 + a, 3 + a), b) average weekly pollen data from all 14 gravimetric traps (1 + b), c) average weekly pollen data from seven gravimetric city centre traps (2 + c), and d) average weekly pollen data from seven gravimetric

suburban traps (3 + d) were except one correlation (1 + b) only weakly positive ($\tau = 0.121$ to 0.394). The correlation (1 + b) between the average weekly OTS of users from the whole of Berlin that were significantly positively ($p < 0.05$) and positively ($p > 0.05$) correlated and the average weekly pollen sedimentations of all 14 gravimetric traps, reaching a correlation coefficient of $\tau = 0.595$ which is considered statistically significant (with a p value of 0.007). The correlation coefficients were generally slightly higher for the comparison of the pollen-induced symptoms to pollen data from the network of gravimetric traps than for the comparison to pollen data from the single volumetric trap (Table 4).

4 Discussion

During our previous study in 2014, we measured remarkable spatial variations of pollen sedimentations of birch, grass, and mugwort pollen across Berlin assumed to cause allergic symptoms of different degrees within the city (Werchan et al. 2017a). Our present study for the first time attempts to compare the differences in the spatial distribution of allergenic pollen and the intensity of allergic symptoms on an intra-urban scale of a single city. Pollen depositions of the two most important allergenic pollen types for Germany—birch and grass—have been found to be lower in the city centre than in the suburban areas,

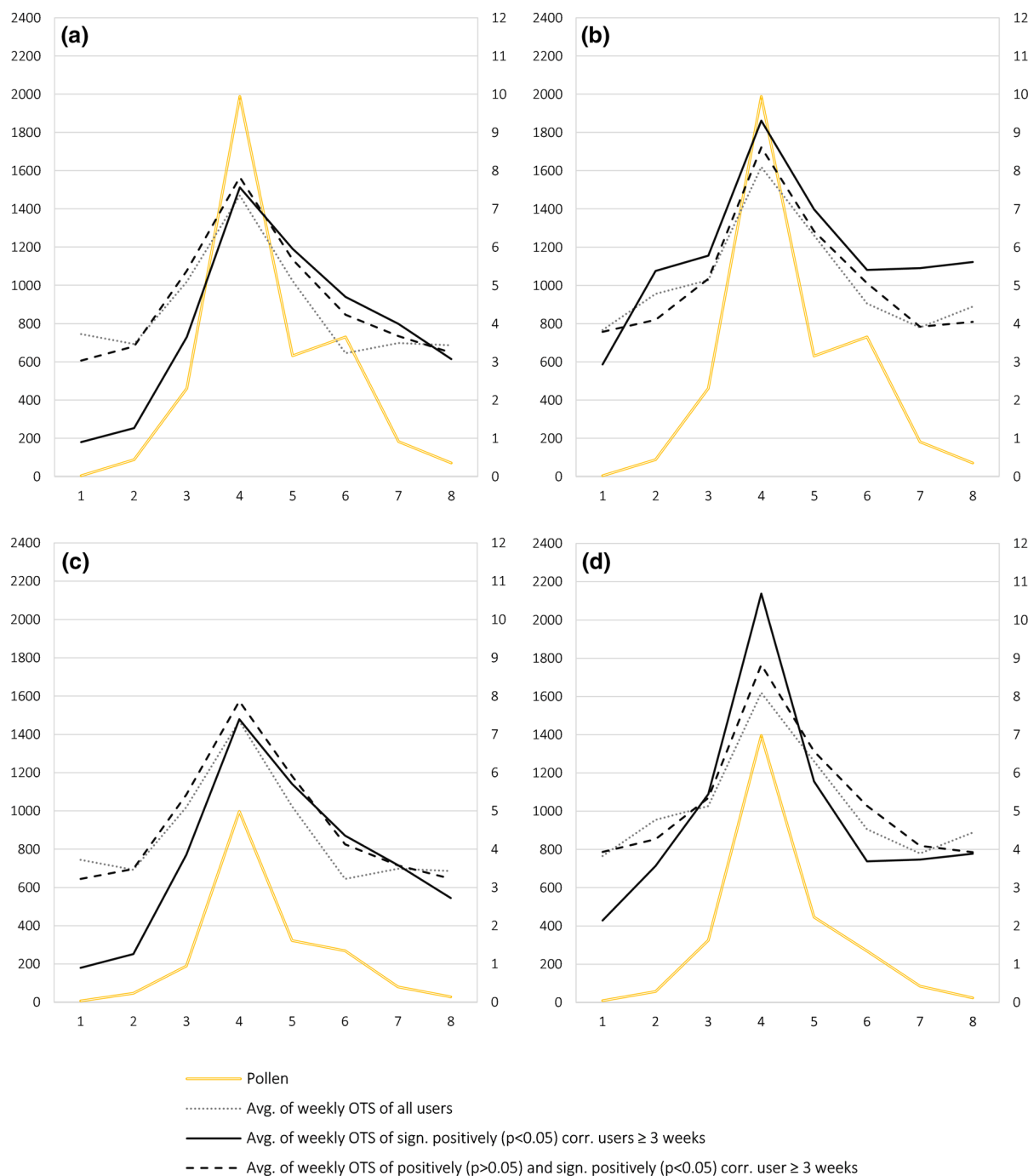


Fig. 4 Average of the weekly overall total symptom (OTS) values and average of the weekly birch pollen throughout the entire birch pollen season (8 weeks, 11 March–05 May 2014) for **a** the volumetric trap and city centre users; **b** the volumetric trap and suburban users; **c** seven gravimetric city centre traps and city centre users; **d** seven gravimetric suburban traps and

suburban users. The left y-axis indicates the number of birch pollen, the right y-axis the OTS values. avg. = average; sig. = significantly; corr. = correlated; users ≥ 3 weeks denotes users with at least 3 weeks of available symptom data during the birch pollen season

Table 2 Kendall's Tau-b correlation coefficients (τ) between the weekly OTS and the weekly birch pollen counts with p value (two-sided) and the number of users, calculated for one

volumetric trap (left side of table) and a network of seven or fourteen gravimetric traps, respectively (right side of table)

Weekly symptoms and weekly pollen from volumetric trap				Weekly symptoms and average of weekly pollen from gravimetric traps			
All users/pollen from one volumetric trap	No. of users	τ	p	All users/pollen from 14 gravimetric traps	No. of users	τ	p
Avg. of weekly OTS of all users	170	0.571*	0.048	Avg. of weekly OTS of all users	170	0.643*	0.026
Avg. of weekly OTS of users ≥ 3 weeks	113	0.643*	0.026	Avg. of weekly OTS of users ≥ 3 weeks	113	0.714*	0.013
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	10	0.786**	0.006	Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	14	0.857**	0.003
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	83	0.857**	0.003	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	82	0.857**	0.003
City centre users/pollen from one volumetric trap	No. of users	τ	p	City centre users/pollen from 7 city centre traps	No. of users	τ	p
Avg. of weekly OTS of all users	90	0.357	0.216	Avg. of weekly OTS of all users	90	0.429	0.138
Avg. of weekly OTS of users ≥ 3 weeks	58	0.357	0.216	Avg. of weekly OTS of users ≥ 3 weeks	58	0.429	0.138
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	7	0.786**	0.006	Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	8	0.929**	0.001
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	39	0.857**	0.003	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	40	0.929**	0.001
Suburban users/pollen from one volumetric trap	No. of users	τ	p	Suburban users/pollen from 7 suburban traps	No. of users	τ	p
Avg. of weekly OTS of all users	81	0.643*	0.026	Avg. of weekly OTS of all users	81	0.786**	0.006
Avg. of weekly OTS of users ≥ 3 weeks	55	0.571*	0.048	Avg. of weekly OTS of users ≥ 3 weeks	55	0.714*	0.013
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	3	0.571*	0.048	Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	9	0.714*	0.013
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	43	0.714*	0.013	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	45	0.857**	0.003

*Denotes significance level of < 0.05 and **denotes significance level of < 0.01 ; avg. = average; sig. = significantly; corr. = correlated; users ≥ 3 weeks denotes users with at least 3 weeks of available symptom data during the mugwort pollen season

corresponding with weaker pollen-induced symptoms reported by city centre PHD users and more severe symptoms reported by suburban PHD users.

Different studies have already shown pollen concentration–response functions, characterised by pollen concentrations above a certain level becoming harmful to allergy sufferers (e.g. Frenz et al. 2001, Waisel et al. 2004; Kiotseridis et al. 2013; Caillaud et al.

2014). Based on the assumption of a trend distinguishable from our results for higher birch and grass pollen loads towards the peripheral areas of the city, it seems likely that the exposure-driven reactions to these allergens also become more severe in the direction of the outskirts of the city.

Such conclusions cannot be drawn from the mugwort pollen sedimentation. The differences in the

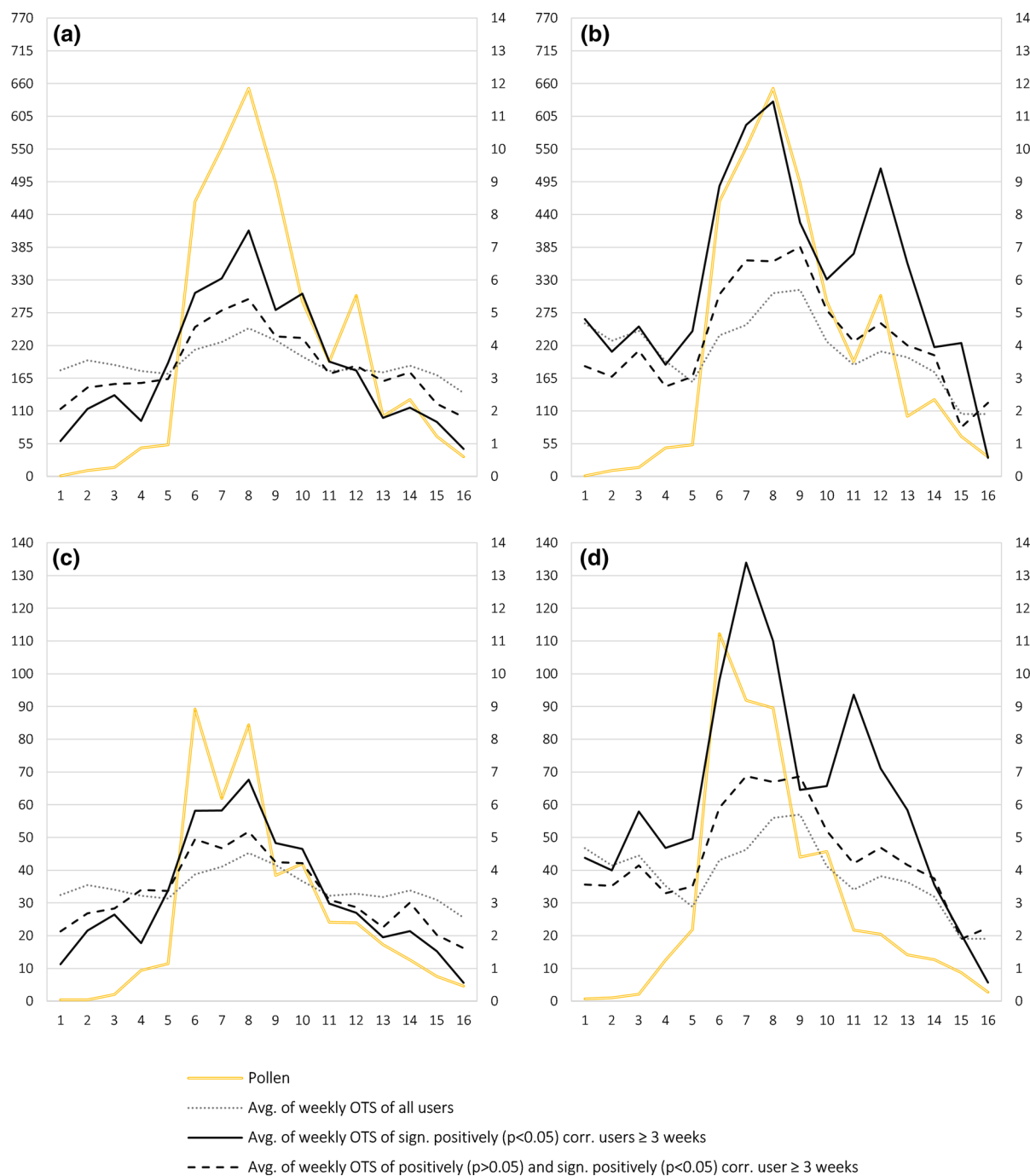


Fig. 5 Average of the weekly overall total symptom (OTS) values and average of the weekly number of grass pollen throughout the entire grass pollen season (16 weeks, 15 April–05 August 2014) for **a** the volumetric trap and city centre users; **b** volumetric trap and suburban users; **c** seven gravimetric city centre traps and city centre users; **d** seven gravimetric suburban

traps and suburban users. The left y-axis indicates the number of grass pollen, the right y-axis the OTS values. avg. = average; sig. = significantly; corr. = correlated; users ≥ 3 weeks denotes users with at least 3 weeks of available symptom data during the grass pollen season

Table 3 Kendall's Tau-b correlation coefficients (τ) between the weekly OTS and the weekly grass pollen counts with p value (two-sided) and the number of users, calculated for one

volumetric trap (left side of table) and a network of seven or fourteen gravimetric traps, respectively (right side of table)

Weekly symptoms and weekly pollen from volumetric trap				Weekly symptoms and average of weekly pollen from gravimetric traps			
All users/pollen from one volumetric trap	No. of users	τ	p	All users/pollen from 14 gravimetric traps	No. of users	τ	p
Avg. of weekly OTS of all users	159	0.367*	0.048	Avg. of weekly OTS of all users	159	0.317	0.087
Avg. of weekly OTS of users ≥ 3 weeks	113	0.333	0.072	Avg. of weekly OTS of users ≥ 3 weeks	113	0.767**	0.000
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	13	0.683**	0.000	Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	15	0.733**	0.000
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	55	0.767**	0.000	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	55	0.700**	0.000
City centre users/pollen from one volumetric trap	No. of users	τ	p	City centre users/pollen from 7 city centre traps	No. of users	τ	p
Avg. of weekly OTS of all users	79	0.483**	0.009	Avg. of weekly OTS of all users	79	0.427*	0.022
Avg. of weekly OTS of users ≥ 3 weeks	59	0.433*	0.019	Avg. of weekly OTS of users ≥ 3 weeks	59	0.444*	0.017
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	10	0.683**	0.000	Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	11	0.678**	0.000
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	29	0.817**	0.000	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	31	0.644**	0.001
Suburban users/pollen from one volumetric trap	No. of users	τ	p	Suburban users/pollen from 7 suburban traps	No. of users	τ	p
Avg. of weekly OTS of all users	80	0.283	0.126	Avg. of weekly OTS of all users	80	0.183	0.322
Avg. of weekly OTS of users ≥ 3 weeks	54	0.300	0.105	Avg. of weekly OTS of users ≥ 3 weeks	54	0.200	0.280
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	3	0.617**	0.001	Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	3	0.633**	0.001
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	26	0.633**	0.001	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	26	0.583**	0.002

*Denotes significance level of < 0.05 and **denotes significance level of < 0.01 ; avg. = average; sig. significantly; corr. = correlated; users ≥ 3 weeks denotes users with at least 3 weeks of available symptom data during the grass pollen season

mugwort OTS values between the suburban users and the city centre users do not mirror the real situation of the pollen distribution within the city. High mugwort pollen loads are very dependent on the existence of extended pollen sources on a local scale (Werchan et al. 2017a). Consequently, adjacent pollen traps (less than 4 km apart) exhibited mugwort pollen deposition differences by a factor of 10 during the 2014 pollen

season. Those differences in close proximity make comparisons among groups of traps or groups of users rather questionable.

However, the pollen data of the network of 14 gravimetric traps reflected the reported symptoms during the 2014 mugwort pollen season better than the pollen data of a single volumetric trap. On that note, even if the correlation coefficients between

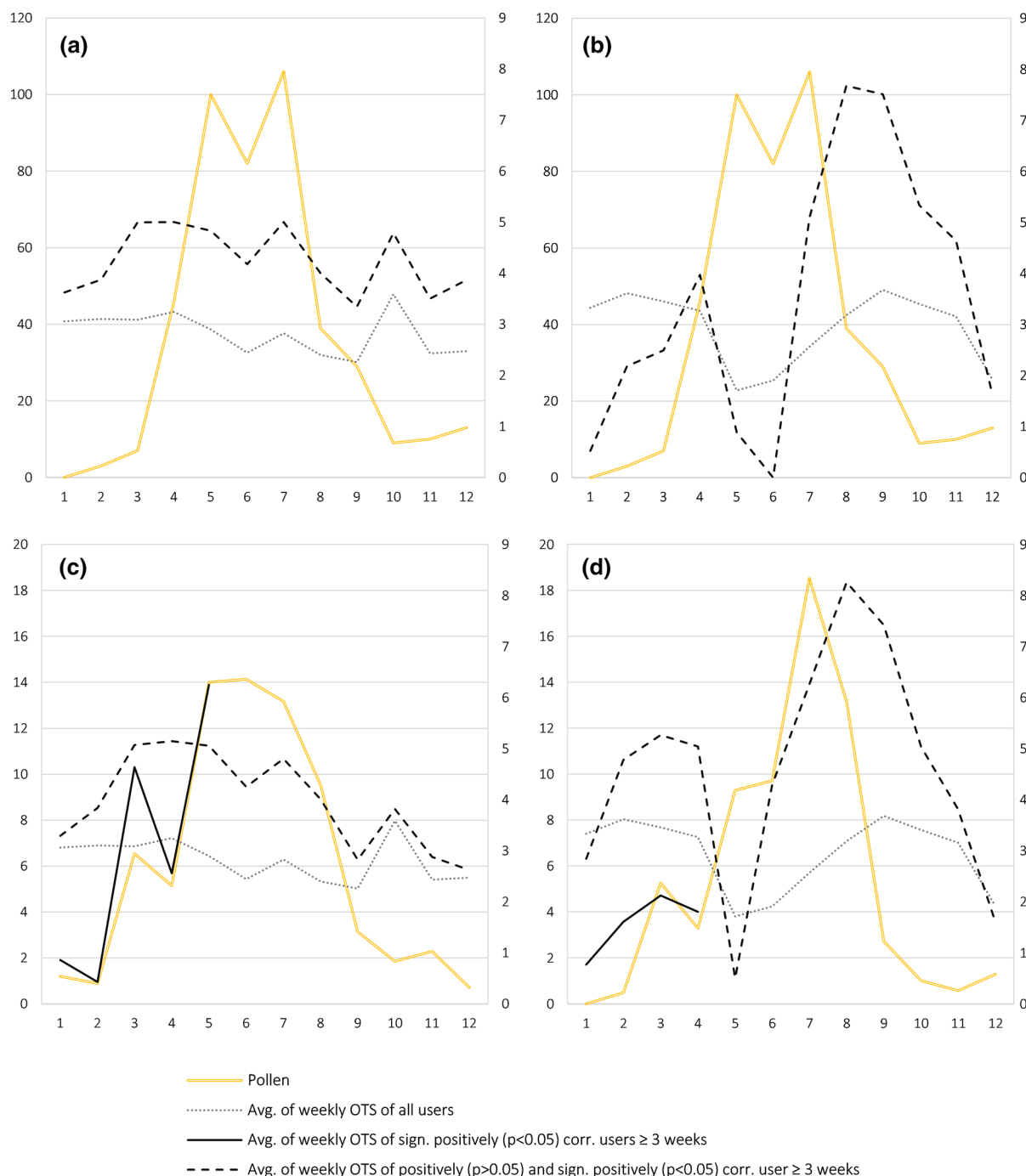


Fig. 6 Average of the weekly overall total symptom (OTS) values and average of the weekly number of mugwort pollen throughout the entire mugwort pollen season (12 weeks, 24 June–16 September 2014) for **a** the volumetric trap and city centre users; **b** the volumetric trap and suburban users; **c** seven gravimetric city centre traps and city centre users; **d** seven

gravimetric suburban traps and suburban users. The left y-axis indicates the number of mugwort pollen, the right y-axis the OTS values. avg. = average; sig. = significantly; corr. = correlated; users ≥ 3 weeks denotes users with at least 3 weeks of available symptom data during the mugwort pollen season

Table 4 Kendall's Tau-b correlation coefficients (τ) between the weekly OTS and the weekly mugwort pollen counts with p value (two-sided) and the number of users, calculated for one

volumetric trap (left side of table) and a network of seven or fourteen gravimetric traps, respectively (right side of table)

Weekly symptoms and weekly pollen from volumetric trap				Weekly symptoms and average of weekly pollen from gravimetric traps			
All users/pollen from one volumetric trap	No. of users	τ	p	All users/pollen from 14 gravimetric traps	No. of users	τ	p
Avg. of weekly OTS of all users	76	− 0.333	0.131	Avg. of weekly OTS of all users	76	− 0.290	0.192
Avg. of weekly OTS of users ≥ 3 weeks	55	− 0.333	0.131	Avg. of weekly OTS of users ≥ 3 weeks	55	− 0.290	0.192
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	0			Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	1	1.000*	
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	21	0.364	0.100	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	21	0.595**	0.007
City centre users/pollen from one volumetric trap	No. of users	τ	p	City centre users/pollen from 7 city centre traps	No. of users	τ	p
Avg. of weekly OTS of all users	43	− 0.182	0.411	Avg. of weekly OTS of all users	43	− 0.182	0.411
Avg. of weekly OTS of users ≥ 3 weeks	33	− 0.152	0.493	Avg. of weekly OTS of users ≥ 3 weeks	33	− 0.152	0.493
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	0			Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	1	1.000*	
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	15	0.364	0.100	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	14	0.394	0.075
Suburban users/pollen from one volumetric trap	No. of users	τ	p	Suburban users/pollen from 7 suburban traps	No. of users	τ	p
Avg. of weekly OTS of all users	33	− 0.485*	0.028	Avg. of weekly OTS of all users	33	− 0.303	0.170
Avg. of weekly OTS of users ≥ 3 weeks	22	− 0.455*	0.040	Avg. of weekly OTS of users ≥ 3 weeks	22	− 0.273	0.217
Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	0			Avg. of weekly OTS of sign. positively ($p < 0.05$) corr. users ≥ 3 weeks	1	1.000*	
Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	6	0.121	0.583	Avg. of weekly OTS of sign. positively ($p < 0.05$) and positively ($p > 0.05$) corr. users ≥ 3 weeks	7	0.333	0.131

*Denotes significance level of < 0.05 and **denotes significance level of < 0.01 ; avg. = average; sig. = significantly; corr. = correlated; users ≥ 3 weeks denotes users with at least 3 weeks of available symptom data during the birch pollen season

pollen and pollen-induced symptoms suggested that a single (volumetric) trap alone might satisfactorily answer the course of the symptoms of all PHD users in the whole of Berlin, the different levels of allergy symptoms for birch and grass in both (city centre

and suburban) user groups cannot be explained and predicted by the results of just one pollen trap. Thus, our findings underline the fact that differences in pollen composition and the possible range of pollen exposure within large cities like Berlin

will be better addressed by the installation of additional pollen monitoring stations, e.g. in the way of a temporary network of passive traps (like in our study). Such a network is relatively easy to establish and can give an overview of pollen sedimentation hotspots of different pollen types in the city, provide a basis for further actions, validate as well as verify the relevance and explanatory power of the single volumetric trap, or facilitate determining site(s) for permanent installations of further volumetric trap(s).

Besides a pollen trap in the city centre, it is proposed to operate further trap(s) within suburban areas of the city as well as in an area close to the outskirts of the city in order to reflect a wide spectrum of possible phenological and climatological conditions as well as differences in land use and vegetation composition.

However, there are still uncertainties as to the relationship between the pollen concentration recorded even by a network of pollen traps and the real personal exposure (Penel et al. 2017). A possible solution for recording spatial differences on the scale of a single person could be the use of a standardised portable personal pollen sampler (e.g. Mitakakis et al. 2000; Werchan et al. 2017b).

Data limitations are a general problem in statistical evaluations. For example, individual users experiencing very strong or very mild symptoms may induce a high impact on the average OTS value, e.g. when comparing the presented small user groups from the city centre and the suburban areas during the mugwort pollen season, resulting in a possible negative or positive misinterpretation of the relationships between pollen and the symptoms in different parts of the city.

Another methodological issue of our study is the fact that the used OTS values completely relied upon self-reported allergic symptoms from the users of the PHD. There is a potential for recall bias and/or a misclassification of reports (Austin et al. 1998; Fan et al. 2006) and/or a very limited number of datasets and/or the spatial assignment of the reported symptoms which might be only half the truth as the location of a PHD user may significantly vary throughout a day, e.g. between the city centre and the periphery due to spatial mobility. The continuously growing number of PHD user reports would make further verifications of the presented results more feasible and more reliable.

5 Conclusion

The presented research demonstrates that differences in the severity of pollen-induced symptoms within one city are based on and explained by the uneven spatial distribution of pollen monitored by a network of fourteen gravimetric pollen traps located throughout the city. Lower depositions of allergenic birch and grass pollen detected within the city centre of Berlin coincides with lower pollen-induced symptom scores reported by users of the Patient's Hayfever Diary from this area, whereas higher pollen depositions in the suburban areas are followed by higher symptom scores. Regarding the mentioned percentage of the global (10–30%), German (14.8%) and Berlin (15–18%) populations suffering from allergic rhinitis and the growing percentage of residents in urban areas (already around 54%), the quality of the information about pollen exposure within cities as well as its causes and risks is in need of improvement. Differences in the pollen composition and the possible range of pollen exposure within large cities with a character similar to Berlin would be better addressed by installing additional pollen monitoring stations. Additionally, those responsible for planning and managing urban greening should take into consideration the presented results and the allergenic potential of plants in order to improve the quality of life of the people affected by pollen allergy living in cities.

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