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Spatial and Temporal Distribution of Polycyclic Aromatic Hydrocarbons and Elemental Carbon in Bakersfield, California

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Abstract

Despite increasing evidence that airborne polycyclic aromatic hydrocarbon (PAH) exposures contribute to adverse health outcomes for sensitive populations, limited data are available on short-term intraurban spatial distributions for use in epidemiologic research. Exposure assessments for airborne PAHs are uncommon because air sampling for PAHs is a labor-, equipment-, and time-intensive task. To address this gap we measured wintertime PAH concentrations during 2010-2011 in Bakersfield, California, USA, a major city in the Southern San Joaquin Valley. Specifically, 58 96-hour integrated PAH samples were collected during 4 time periods at 14 locations from November 2010 to January 2011; duplicates were collected at two sites. We also collected elemental carbon (EC) at the same 14 sites and analyzed the two time periods with the highest ambient PAH pollution. We used linear regression models to quantify the relationship between potential spatial and temporal predictors of PAH concentrations. We found that wintertime PAH concentrations in Bakersfield, CA, are best predicted by meteorological variables and traffic proximity. Our model explains a moderate amount of the variability in the data (R^2=0.58), likely reflecting the major sources of PAHs in Bakersfield. We also observed that PAH concentrations were more spatially variable than EC concentrations. Comparing our data to historical monitoring data at one location in Bakersfield showed that the relatively low PAH concentrations during the 2010-2011 winter in Bakersfield is part of a long-term trend in decreasing PAH concentrations.

Keywords

Air pollution; Polycyclic aromatic hydrocarbons; Elemental Carbon; Bakersfield; San Joaquin Valley; California

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1. INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) have long been known to be carcinogenic (International Agency for Research on Cancer 1987; International Agency for Research on Cancer 1989), but an extensive literature is developing that also implicates PAHs as toxic agents in adverse health outcomes from subclinical immunological changes through asthma and wheeze (den Hartigh et al. 2010; Diaz-Sanchez et al. 1994; DiazSanchez et al. 1996; Gale et al. 2012; Hew et al. 2014; Jedrychowski et al. 2007; Jedrychowski et al. ; Liu et al. 2013; Nadeau et al. 2010; Padula et al. 2014a; Padula et al. 2014b; Perera et al. 2003; Perera et al. 2009; Schober et al. 2007). Previous work the San Joaquin Valley of California, showed that increased PAH exposure is associated with increased preterm birth (Padula et al. 2014b), increased wheeze (Gale et al. 2012), and decreased pulmonary and immunological function in children (Hew et al. 2014; Nadeau et al. 2010; Padula et al. 2014a). In addition to epidemiologic evidence, *ex vivo* and *in vitro* human research has demonstrated that PAHs cause immunological changes to the functioning of regulatory T-cells (Liu et al. 2013) and basophils (Schober et al. 2007). Despite this increasing evidence that PAH exposure contributes to adverse health outcomes for sensitive populations limited data are available on daily and seasonal intra-urban spatial distributions for individual exposure estimates in the context of epidemiologic cohort studies.

PAHs are a class of compounds characterized by fused aromatic rings that form when organic matter undergoes incomplete combustion. PAHs generally exist in complex mixtures of combustion products such as soot, diesel and gasoline exhaust, and wood and tobacco smoke. They exist in ambient air as gases (gas-phase) and adsorbed to particulate matter (particle-phase or particle-bound). PAHs are produced by both diesel and gasoline fuel combustion (Cadle et al. 1999; Marr et al. 1999; Riddle et al. 2007; Rogge et al. 1993), as well as biomass burning (Bari et al. 2010; Jenkins et al. 1996; Schauer and Cass 2000). Because air sampling for PAHs is a labor-, equipment-, and time-intensive task, urban air monitoring has been extremely limited for epidemiology (Jedynska et al. 2014; Noth et al. 2011) and for spatial-temporal modeling for source identification (Krudysz et al. 2009; Melymuk et al. 2013).

As part of our on-going work to understand the role of PAH exposures in health outcomes in the San Joaquin Valley, we measured wintertime PAH and elemental carbon (EC) concentrations during 2010-2011 in Bakersfield, California, USA, a major city in the Southern San Joaquin Valley. Bakersfield is located in the southern San Joaquin Valley Air Basin (SJVAB); it is hemmed in by the Southern Sierra Nevada Mountains in the East, the Tehachapi Mountains on the south, and the Coast Range Mountains in the West. Pollution flowing into the SJVAB from the San Francisco Bay Area and Sacramento, as well as emitted by stationary and mobile sources within the valley, is often trapped by these mountain ranges. Monitoring sites in and near Bakersfield record among the highest ozone and $PM_{2.5}$ concentrations in the United States (California Air Resources Board 2008; US EPA 2015). The United States Environmental Protection Agency has designated Bakersfield as an extreme nonattainment area for the ozone (8-hour) and a serious nonattainment area $PM_{2.5}$ (US EPA 2015). Our primary goal was to build a spatial-temporal regression model for wintertime PAH concentrations in Bakersfield that can be used for individual-level

exposure assessment in an epidemiology study. Secondary goals were to compare the spatial variability of PAHs to EC and to explore the longer-term time trends in PAH concentrations in Bakersfield using historical data from the California Air Resources Board's Air Toxics program (California Air Resources Board 2008).

2. METHODS

2.1 PAH sampling method and evaluation

A two-stage version of the personal respirable particulate sampler developed by Lee et al. (2006) and modified by Fruin et al. (2014), was used to sample PAHs with aerodynamic diameter less than a 2.5 μm at 5 L/min. Three quartz fiber filters (PallFlex Tissuquartz™) impregnated with XAD4 were used in series to collect gas phase and particle-bound PAHs.

Prior to field sampling, sampler performance was evaluated in a diesel bus garage. The bus garage houses four diesel buses that serve the University of California, Berkeley campus. The bus garage was open, with buses running, beginning at 7am each day and closed for the day at 7 pm. Busses entered and exited the garage at various times during the day. The bus garage was also near a busy intersection. This site was selected because we expected it would have moderately high concentrations of PAHs. We collected sequential 24-hour samples concurrent with 96-hour samples; all samples were collected in triplicate. The average of the 4 sequential 24-hr samples was compared to the 96-hour integrated samples. Flow rates were checked before and after sample collection, as well as daily for the 96-hour samples.

2.2 Bakersfield Sample Collection

We selected 14 sites to achieve broad spatial coverage across the city (Figure 1). Sampling was conducted on the roofs of single story buildings at 12 public schools, in the large open backyard of one private residence, and at the California Air Resources Board's central air monitoring site (BCA at 5558 California Avenue, Bakersfield on the roof of a single story building). We collected 96-hour samples of PAHs and EC four times from November 2010 to January 2011; duplicate samples were collected at two sites (BCA and Bakersfield High School). At the BCA site, we also monitored continuous particle-bound PAH of 3-rings or greater using the PAS2000 monitor (EcoChem Analytics, League City, TX).

EC samples were collected on PallFlex Tissuquartz™ filters using a separate leg of the sampler described above, at a 5L/min flow rate with a 2.5 μm cutpoint. Prior to sampling, filters were baked at 900°C for 3 hours to remove any carbon residue.

2.3 Lab Analysis and Quality Evaluation

Filter samples were extracted by sonication in dichloromethane followed by vacuum filtration. The extracts were concentrated for analysis under nitrogen. Analyses were performed on a Hewlett Packard model 6890 Gas Chromatograph equipped with a 30 m (50%-Phenyl)-methylpolysiloxane fused silica capillary column and a 5972 Mass Selective Detector operating in the selected ion-monitoring mode for enhanced sensitivity. The filters were analyzed for 10 PAHs – fluoranthene (FLT), pyrene (PYR), benz[a]anthracene (BAA),

chrysene (CHR), benzo[a]pyrene (BAP), benzo[b]fluoranthene (BBF), benzo[k]fluoranthene (BKF), benzo[ghi]perylene (BGP), indeno[1,2,3-cd]pyrene (IDP), and dibenz[a,h]anthracene (DBA). Sample results were adjusted for both blank filter concentrations and for limit of quantitation. The limit of quantitation (LQ) was specific to individual PAH and day of laboratory analysis. The average LQ was 1.5 ng or 0.05 ng/m^3 per filter sample, and the range was 1 - 2.5 ng or 0.03 – 0.09 ng/m^3. For purposes of calculation, samples less than the LQ were assigned half the LQ. Filters were checked for breakthrough from the front and middle filters to the back filter.

Elemental carbon samples were analyzed by the Desert Research Institute (Reno, NV) using the IMPROVE/TOR method (Chow et al. 1993). We selected two time periods for analysis that were coincident with the highest PAH concentrations. Samples were blank-corrected using field blanks.

There were four 24-hour samples for comparison between the collocated filter-based ∑10PAH concentrations and the real-time continuous particle-bound PAH concentration, as measured by the PAS2000, at the BCA site. Because of the low number of samples, we examined only the correlation between the two methods.

2.4 Comparison to historical measurements at BCA site

To provide context for the observed data, we compared winter average concentrations of five individual particle phase PAHs (BGP, BAP, BBF, BKF, and IDP) at the BCA site with historical filter-based PAH samples collected from 1995-2004 as part of the California Air Resources Board's Air Toxics program (California Air Resources Board 2008). DBA was measured but we excluded it from our analysis because multiple years had averages below the reported limits of detection. The 1995-2004 winter averages were derived from 24-hr samples collected once every 12th day in the November-January period (i.e. 6 to 8 days per year) with 10 μm inlets. The limit of detection for the Air Toxics PAH samples is 0.05 ng/m^3, which is the same as the mean LQ in the 2010-2011 samples. In comparing these historical data to our 2010-2011 data, we assume that the PAH mass is all captured within the $PM_{2.5}$ size fraction, as we used an inlet with 2.5 μm cut point (Allen et al. 1996; Kawanaka et al. 2004; Marr et al. 1999). We also compared the ∑10PAH filter-based PAH concentrations at the BAC site with contemporaneous continuous PAH and $PM_{2.5}$ monitor data.

2.5 Spatial-temporal modeling of PAH

We used linear regression models to quantify the relationship between temporal and spatial predictor variables and ∑10PAH concentrations in Bakersfield. We used meteorology data collected at the BCA site specific to each sampling period for the following meteorological variables – mean wind speed (mph), mean temperature, mean relative humidity (%), total precipitation (inches). For spatial variables, geographic information was collected, compiled and processed in ArcGIS 10 (ESRI, Redlands, CA) and, when necessary, further data calculations were completed in SAS 9.3 (SAS, Cary, NC). Traffic-related spatial variables, including proximity to highways, were defined using road data from the Kern County Department of Engineering, Surveying, and Permit Services. We included traffic volume

density using a 300m falloff function to model decay. Land use data were obtained from the California Department of Water Resources countywide California Land & Water Use surveys from Kern County (2006). Land use types evaluated were urban, vacant urban (including parking lots), commercial, general industrial, oil refineries, and extractive industries. Data from the United States 2010 Census dataset were selected for transportation, home fuel use, or socioeconomic characteristics. All block-group and census tract variables were assigned using location of sampling. Full list of variables is presented in the online supplement, Table S1. Covariates in the final model were required to be statistically significant at an alpha level of 0.05. Residual analysis on the model included an examination of the quantile-quantile and histogram plots for normality, and examination of the residual versus predicted scatterplot for absence of structure. Additionally, correlations between the covariates were checked for collinearity.

3. RESULTS

3.1 Sampler Evaluation

For all 10 PAHs analyzed, the average concentration of the 96-hour samples collected in triplicate was within ±30% of the average concentration of the 4 sequential 24-hour samples, the mean normalized bias was −6% and the mean normalized error was ±9% (Table 1). There was good repeatability for all 10 PAHs; the 24- and 96-hour triplicate samples had low average coefficients of variation (CVs), 0.14 and 0.13, respectively. Likewise, the average percent of PAH present on the back filter (of three filters) for both the 24- and 96-hour samples was low – an average of 10% for all samples.

The 4 collocated samples of the filter-based ∑10PAH concentrations and the real-time continuous particle-bound PAH concentration, as measured by the PAS2000, at the BCA site were highly correlated with a Pearson correlation coefficient of 0.95. However, the mean of the 96-hour filter-based ∑10PAH concentrations was consistently lower than the 96-hr average concentrations of continuous particle-bound PAHs. This was the expected outcome as the PAS2000 instrument measures all particle-bound PAHs with three or more rings, whereas the filter-based method quantifies only 10 individual PAHs.

3.2 Bakersfield sample analysis

Fifty-eight 96-hour PAH samples were collected during 4 sampling periods at 14 locations, including duplicate samples collected at 2 locations. All samples were blank corrected by individual PAH with the blank correction ranging from 0.006 – 0.04 ng/m^3. Individual PAH concentrations were relatively low during all sampling periods, with 87% below 1 ng/m^3. Because of the generally low concentrations, we focused on the sum of the 10 PAHs measured, or ∑10PAH, for our analyses. Duplicate samples were collected during all 4 sampling periods at two locations: Bakersfield High School and the BCA site. The Pearson correlation coefficient for ∑10PAH between pairs of duplicates was 0.93, and the CV for the set of duplicates was 0.22 (as calculated using Jones & Payne 1997). Break through from the two front filters to back filter was not evaluated for individual PAHs because the concentrations on the days examined were too low. For the two samples where the ∑10PAH

was over 1 ng/m^3, the concentration on the third filter was 16% of that on the first and second filters.

Thirty-two 96-hour EC samples were analyzed for the two sampling periods starting December 1, 2010 and December 13, 2010 at the same 14 locations, including duplicate sample collection at BCA and Bakersfield High School locations. All samples were blank corrected using 5 blanks that had an average of 0.58 μg or 0.02 μg/m^3. Similar to the PAH concentrations, the EC concentrations during the sampling periods were low: over 85% of sample concentrations were less than 1 μg/m^3 (Table 2). The Pearson correlation coefficient between pairs of duplicates was 0.88, and the CV for the set of duplicates was 0.12.

3.3 Comparison to historical PAH measurements at BCA site

We observed a downwards trend within the November-January average concentrations of selected individual PAHs from 1995-2004 at the BCA station in Bakersfield and continuing to our 2010-2011 average observations (labeled 2010 in Figure 2). The 2010-2011 fall/winter average concentrations of BGP, IDP, BKF, BAP, and BBF are 42%, 33%, 20%, 18%, and 3% lower than the 2001-2005 average concentrations, respectively.

3.4 Spatial distribution of PAH and EC

For the two sampling periods with both ∑10PAH and EC, we observed the highest variability in the observed spatial distribution of ∑10PAH concentrations, as measured with the CV, during the period with higher overall concentrations - December 1-4, 2010. EC and ∑10PAH concentrations during this period were significantly correlated (Pearson correlation coefficient=0.32). Additionally, the EC concentrations show a much smaller 90th-to-10^{th} percentile ratio than ∑10PAH, indicating lower spatial variability in EC concentrations across the study area (Table 2). When the concentrations of ∑10PAH and EC were normalized by the respective BCA concentrations, it is apparent that ∑10PAH has a greater variability than EC across our measured sites (Figure 3).

3.5 Spatial-temporal modeling of PAH

Of the five meteorological variables evaluated, two were statistically significant predictors of ∑10PAH concentrations: mean temperature and mean relative humidity (Table 3). Of the spatial variables evaluated individually, only the binary variable indicting if a sample had been collected upwind of California State Route 99 was a significant predictor of ∑10PAH concentrations (Table 3). However, after accounting for temporal variability and upwind sampling location, mean traffic density within 2km of the sampling location was also significant in the final linear model (Table 4). The best linear model for ∑10PAH concentrations was moderately explanatory of wintertime ∑10PAH concentrations with an R^2 of 0.58. The predicted ∑10PAH concentrations from the model are more dependent on the temporal parameters than the spatial ones. For example, when the model is specified for a rainy period, the spatial variability is greatly reduced (Figure 4).

4. Discussion and Conclusion

We found that wintertime ∑10PAH concentrations in Bakersfield, CA are best predicted by meteorological variables and traffic density. Our model explains a moderate amount of the variability in the data, likely reflecting the major sources of PAHs in Bakersfield. In particular, the spatial distribution of modeled ∑10PAH concentrations clearly shows the influence of highways in Bakersfield. This finding agrees with our previous work on the main predictors of PAH concentrations in Fresno, another major city in the San Joaquin Valley. Our spatial-temporal model of airborne PAHs with 4-, 5-, and 6-rings (fluoranthene, benz[a]anthracene, chrysene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, indeno[1,2,3-cd]pyrene, and dibenz[a,h]anthracene) also showed meteorological variables (e.g. wind speed) and traffic proximity to be important predictors (Noth et al. 2011). Similarly, our spatial model of airborne phenanthrene, a more volatile PAH, showed traffic proximity to be an important predictor (Noth et al. 2013).

The spatial distribution of both the ∑10PAHs and EC in Bakersfield showed that relatively higher concentrations were observed in the city center, where exhaust and emissions from transit and rail sources are expected to be strongest. The ∑10PAHs showed a larger spatial variability than EC among the 14 sites. During the highest of the 4 sampling periods, the 90^{th}:10^{th} percentile ratio for ∑10PAHs was approximately an order of magnitude higher than that for EC (19.7 vs 1.6, respectively). This indicates that while EC is generally highly correlated with PAHs, they do not exhibit the same sensitivity to neighborhood-level sources. The low-to-moderate correlation (Pearson correlation coefficient = 0.32) between the concentrations of the two pollutants at the 14 sites in our network also shows that PAH and EC are not capturing the same sources with the same level of sensitivity. This higher spatial variability of PAHs is not unexpected as PAHs and EC are primarily associated with vehicle exhaust, but PAHs are additionally generated through incomplete combustion from biomass burning and industrial processes such as oil refining (Zhang and Tao 2009).

The co-located PAS2000 measurements were consistently higher concentration than the filter-based ∑10PAH concentrations at the BCA site, but this is expected because the PAS2000 monitor responds to more compounds, including 3-ring PAHs as well as other 4-, 5-, and 6-ring compounds not included in our ∑10PAH. However, despite these differences in analytes detected, there was good correlation between the ∑10PAH and PAS2000 measurements. However, the correlation of the 96-hr ∑10PAHs concentrations with EC concentrations was lower than observed in other areas (Tager et al. 2006), perhaps indicating a different mixture of source contributions (e.g., gas and diesel vehicles) in Bakersfield or change in emissions over time (Fujita et al. 2007; Lurmann et al. 2015).

Comparison with historical special study data also provides assurance that the 96-hr sampler provides results generally consistent with the routinely collected historical data. Integrated 48-hour PM_{10} PAH concentrations for the sum of 9 of the 10 PAHs in our set in the winter of 1995-1996 at BCA were 17 ng/m^3 for December 26-28, 1995 and 23 ng/m^3 for January 4-6, 1997 in the IMS 1995 Study (Schauer and Cass 2000). These concentrations are significantly higher than what we observed in 2010-2011. BGP, IDP, and BAP are primarily associated with light-duty vehicle emissions, whereas BKF is associated with both light-day

and heavy-duty vehicle emissions(Cadle et al. 1999; Marr et al. 1999; Riddle et al. 2007). The larger reductions in ambient concentrations of BGP, IDP, and BAP are consistent with large reductions in light-duty vehicle emission during this decade (Lurmann et al. 2015). BBF is not usually associated with motor vehicle emissions and it does not exhibit any trend in this period. However, some of the difference can be explained by targeting of high pollution episodes in IMS1995 Study whereas we sampled during rather typical pollution periods. Nevertheless, there are periods with extreme differences, for example the January 1997 PAH concentrations are roughly an order of magnitude higher than our January 2011 concentrations. Annual average PAH concentrations ($PM_{2.5}$ size fraction) reported from every-6^{th}-day samples collected at BCA during the California Regional $PM_{2.5}/PM_{10}$ Air Quality Study (CRPAQS) during 2000 and 2001 show significantly lower concentrations for all 10 PAHs (Rinehart et al. 2006) than our 2010-2011 data. This is expected because the CRPAQS data reflects the full annual average, including the lower pollution summer season, whereas our data were all collected during the higher pollution fall/winter season. Previous sampling in Fresno by this research group using the PAS2000 continuous monitor has shown very low PAH concentration in summer and significant decreasing trend over time in concentrations (Hammond et al. 2010; Noth et al. 2011; Tager et al. 2006).

In summary, we found that traffic characteristics and meteorology each play an important role in characterizing PAH concentrations in Bakersfield, CA. We have also shown that the relatively low PAH concentrations we observed in Bakersfield during December 2010 and January 2011 are part of a general decreasing trend in PAH concentrations observed in the Bakersfield starting in 1995.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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List of abbreviations

EPA	United States Environmental Protection Agency
IARC	International Agency for Research on Cancer
PAH	Polycyclic aromatic hydrocarbons
EC	Elemental carbon
CV	coefficient of variation

FLU	fluoranthene
PYR	pyrene
BAA	benz[a]anthracene
CHR	chrysene
BBF	benzo[b]fluoranthene
BKF	benzo[k]fluoranthene
BAP	Benzo[a]pyrene
ICP	Indeno[1,2,3-cd]pyrene
DBA	dibenz[a,h]anthracene
BGP	benzo[ghi]perylene

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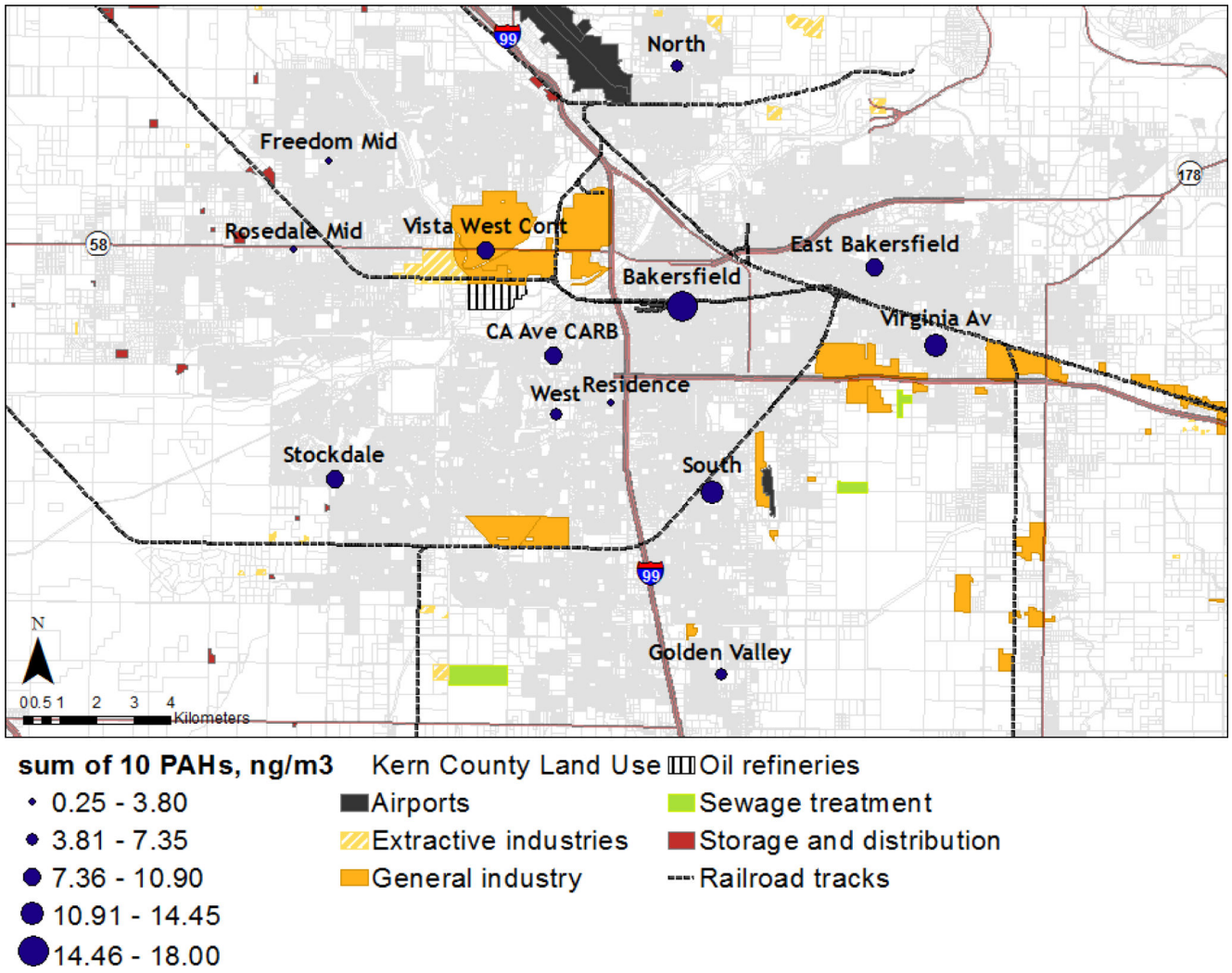
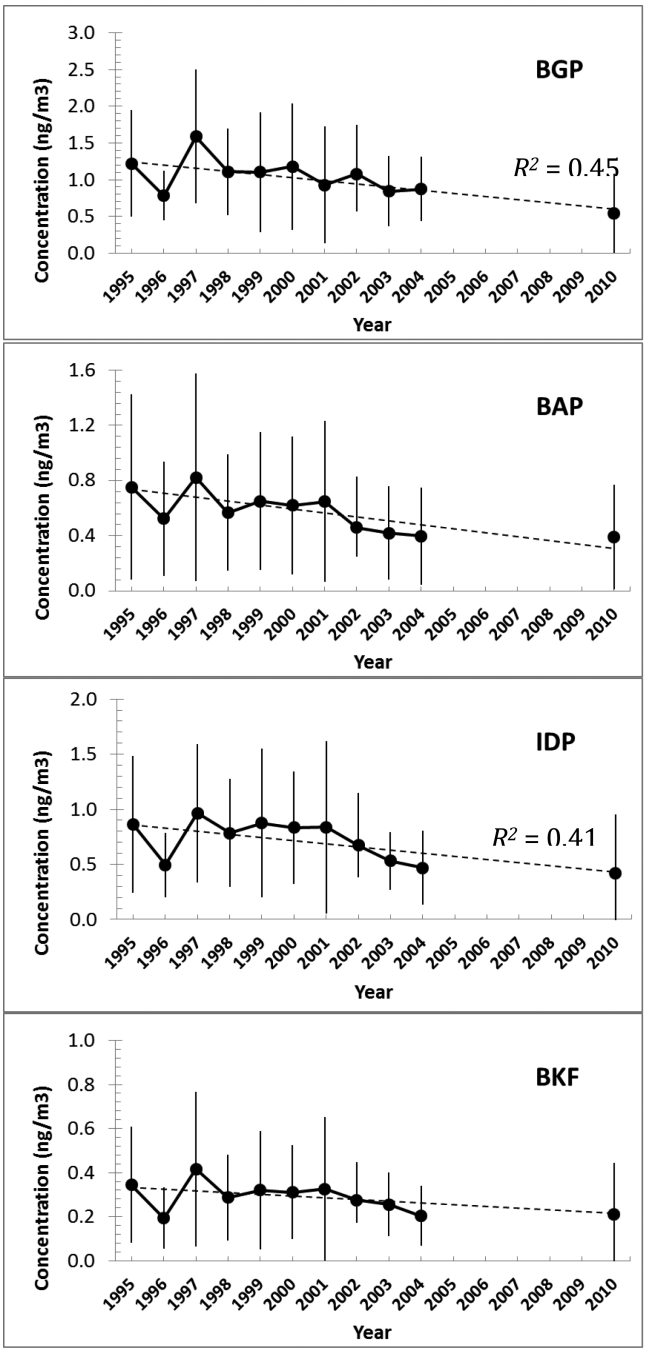


Figure 1. The highest variability in the spatial distribution of ∑10PAH concentrations was during the sampling period with the highest overall concentrations

Locations and concentrations of 96-hour PAH samples (ng/m^3) collected starting on 12/1/2010, Bakersfield CA.



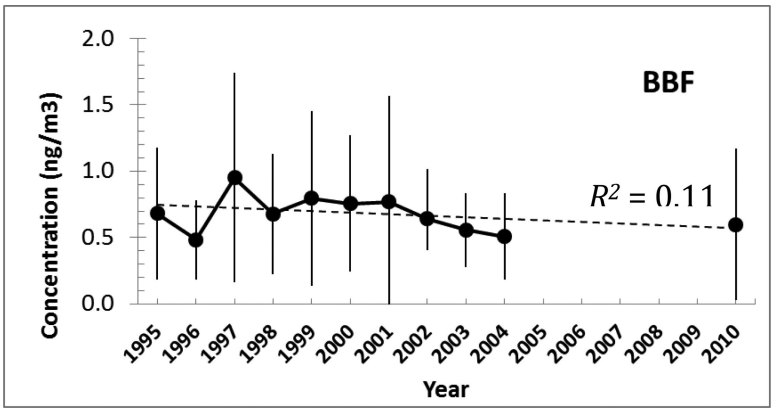


Figure 2. PAH concentrations in Bakersfield are generally decreasing over time

Concentrations of selected PAHs in Bakersfield at the CARB California Ave. Monitoring Station in November-January in 1995-2004 and in 2010/2011. The 1995-2004 data were collected on 6 to 8 days per season and year with a 10 μm inlet. The 2010/2011 data were collected on 16 days with a 2.5 μm inlet. The dashed line indicates the linear trend ($0.11 < R^2 < 0.55$). Vertical lines show range of minimum and maximum concentrations.

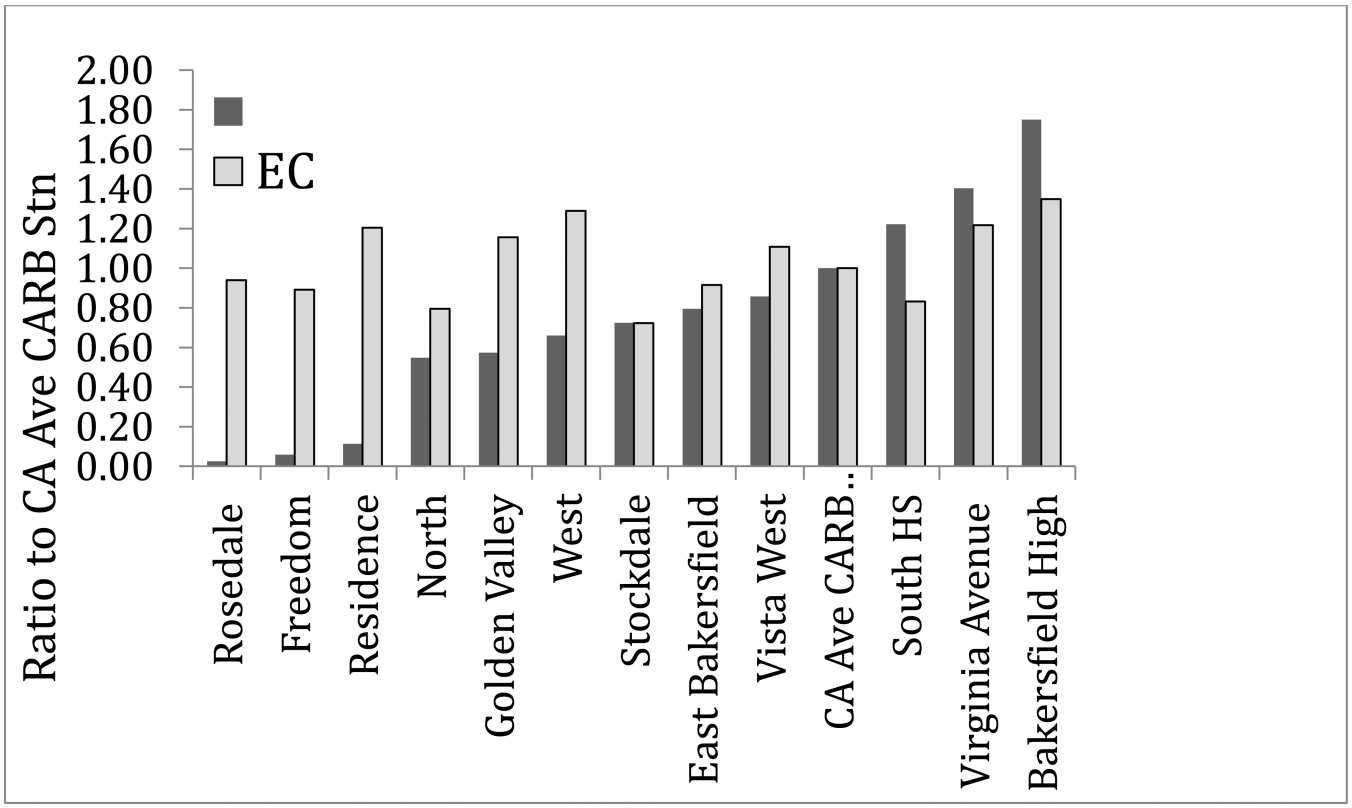


Figure 3. The spatial variability of PAHs is greater than that of elemental carbon

The ratio between the sampling location and the CA Ave CARB station of the sum of 10 PAHs (ng/m^3) (black bars) and elemental carbon (μg/m^3) (light bars) is shown for 12/1-12/4/2010.

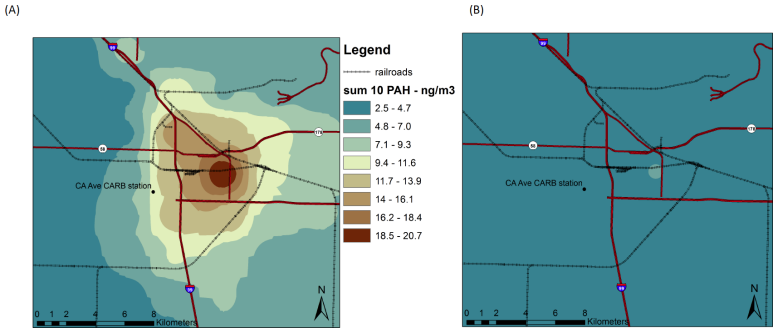


Figure 4.

Temporal variables are stronger predictors in the model than spatial variables. The maps below show the regression results (interpolated for purpose of smooth display) for the sum of 10 PAHs (ng/m^3) on a day with moderate temperature (50 deg F) and (A) dry conditions and (B) rainy conditions. This shows the heavy influence of rain on modeled PAH concentrations.

Table 1

Data and comparison of 24-hour and 96-hour PAH concentrations (ng/m^3) measured in a diesel bus garage. All samples collected in triplicate.

PAH (ng/m^3)	Days 1-4 Mean (SD) of 24-hr samples	Days 1-4 integrated 96-hr sample mean (SD)	96-hr percent of 24-hr mean
Fluoranthene	2.73 *(0.26)*	2.65 *(0.18)*	97%
Pyrene	3.42 *(0.31)*	3.08 *(0.17)*	90%
Benz[a]anthracene	0.33 *(0.09)*	0.27 *(0.02)*	84%
Chrysene	0.31 *(0.08)*	0.39 *(0.08)*	124%
Benzo[b]fluoranthene	0.58 *(0.28)*	0.67 *(0.08)*	116%
Benzo[k]fluoranthene	0.19 *(0.05)*	0.14 (0.02)	72%
Benzo[a]pyrene	0.39 *(0.07)*	0.38 *(0.03)*	99%
Indeno[1,2,3-cd]pyrene	0.75 *(0.73)*	0.74 *(0.16)*	98%
Dibenz[a,h]anthracene	0.24 *(0.15)*	0.20 *(0.05)*	82%
Benzo[ghi]perylene	0.71 *(0.14)*	0.61 *(0.02)*	87%

Table 2

Sum of 96-hour mean concentrations of 4-, 5- and 6-ring PAHs (ng/m^3) and EC (μg/m^3) by location and sampling period.

	Sum of 10 PAHs (ng/m^3)				EC (μg/m^3)	
Location	**Nov. 18-21, 2010**	**Dec. 1-4, 2010**	**Dec 13-16, 2010**	**Jan. 4-7, 2011**	**Dec. 1-4, 2010**	**Dec 13-16, 2010**
Bakersfield High School	6.04	18.00	7.58	2.06*	1.12	0.76
Virginia Avenue Elementary School	4.34	14.44	4.78	--	1.01	--
South High School	5.18*	12.57	4.92	1.07*	0.69	0.41
California Ave. CARB AQM Station	5.32	10.29	2.93*	0.85*	0.83	0.44
Vista West High School	3.65*	8.82	3.15	1.44*	0.92	0.63
East Bakersfield High School	4.75*	8.18	4.93	--	0.76	0.41
Stockdale High School	1.69*	7.45	2.26	0.70*	0.60	0.34
West High School	3.23	6.79	4.83	1.39*	1.07	0.40
Golden Valley High School	4.20	5.91	5.21*	4.57*	0.96	0.29
North High School	3.13*	5.64	4.95*	1.18*	0.66	0.26
Residential location	--	1.17*	6.12	1.04*	1.00	0.43
Freedom Middle School	3.48*	0.60*	2.58	--	0.74	0.43
Rosedale Middle School	3.31*	0.25*	2.46	0.75*	0.78	0.30
Highland High School	3.17	--†	--†	--†	--†	--†
Mean for sample period	3.96	7.70	4.37	1.50*	0.86	0.43
Standard deviation for sample period	1.16	5.32	1.60	1.15	0.17	0.14
Coefficient of variation for sample period	0.29	0.69	0.37	0.76	0.19	0.34
90th:10th percentile ratio	1.7	19.7	2.4	3.3	1.6	2.1

*One or more individual species concentrations include in the sum are less than 0.05 ng/m^3.

†Equipment vandalized during December 1-4 sampling, site not used subsequently

Table 3

Selected Individual Temporal and Spatial Predictor Covariates for log-transformed Σ10PAH concentrations.

Covariate Type	Covariate	Range	Parameter estimate	P-value	R^2
Temporal	Mean temperature (°F)	42.4 - 53.9	0.103	0.002	0.20
	Relative humidity (%)	67.5 - 86	−0.0383	0.02	0.12
	Total precipitation (inches)	0 - 0.07	5.88	0.25	0.03
	Mean wind (mph)	2.3 - 4.5	−0.130	0.41	0.02
Spatial	Located upwind of CA 99	Yes/No	−0.73	0.01	0.15
	Industrial land use within 2km	Yes/No	0.51	0.11	0.06
	Fraction of homes In census block group that use gas heating fuel	0.50-0.83	−1.45	0.22	0.03
	Closest road to residence is smallest road type	Yes/No	−0.35	0.23	0.03
	Number of highways within 2km	0-2	0.11	0.60	0.01
	Mean traffic density within 2km	13-100	0.013	0.03	0.11
	Total population in census block group	85-7,396	0.00	0.73	0.00

Table 4

Final wintertime model for prediction of log-transformed Σ10PAH concentrations, R^2=0.58.

Model	β ± SE	P-value
Intercept	−9.85 ± 2.12	<0.0001
Mean temperature	0.23 ± 0.05	<0.0001
Total precipitation	−20.6 ± 6.18	0.002
Location upwind of CA 99	−0.73 ± 0.21	0.001
Mean traffic density within 2 km	0.016 ± 0.006	0.009