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Methyl-Bromide and asthma emergency department visits in California, USA from 2005 to

2011

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Abstract

Objective: Urban monitors of MBr, not typically near application sites, are used to investigate the impact of ambient concentrations on asthma Emergency Department (ED) visits. *Methods:* 4262 ED visits from August to February of 2005 to 2011 in Central and Southern California were selected from California's Office of Statewide Health Planning and Development (OSHPD). A bidirectional-symmetric case cross-over study design using conditional logistic regression model was used to obtain the odds ratio (OR) and 95% confidence interval associated with a 0.01 ppb (interquartile range) increase in MBr. *Results:* The population sample was comprised of 46.0% male and 53.9% females. Ethnic groups included 32.0% Non-Hispanic White, 23.5% Non-Hispanic Black, and 44.4% Hispanic. Age distribution was between 2-5 years old (11.6%), 6-18 years old (23.5%), 19-40 years old (29.3%), 41-64 years old (24.1%), and 65 or older (6.9%). There was a positive association between MBr and asthma ED visits among Non-Hispanic Blacks [OR: 1.065 (95% confidence intervals: 1.019, 1.108)] and Hispanics [OR: 1.107 (95% confidence intervals: 1.043, 1.173)], while Non-Hispanic Whites did not have an association with asthma ED visits. Positive association between MBr and asthma ED visits was found only among 6 to 18 [OR: 1.071 (95% confidence intervals: 1.016, 1.125)] years old. *Conclusion:* An increase in MBr concentration was found to be associated with an increase of the odds of having asthma ED visits in California among 6 to 18 years old and disproportionately affects Non-Hispanic Blacks and Hispanics over Non-Hispanic Whites.

Keywords: Methyl Bromide; pesticide air toxicants; central and southern California; asthma ED visits

Introduction

Methyl bromide (MBr) is a fumigant used for pest control in structures and as a crop treatment since the 1890s [1]. MBr is an organic halogenated aliphatic hydrocarbon which is a colorless, odorless and highly volatile gas in the ambient air temperature and can be easily absorbed through inhalation [2]. In California, MBr has been used in the pre-plant treatment of soil in fields and greenhouses to control nematodes, insects, weeds, bacteria, and fungi. MBr is a pesticide of restricted use in the United States and is limited only for certified applicators. Strict regulation of MBr was implemented due to its environmental toxicity. In 1994, the U.S. Clean Air Act and the United Nations Environment Programme Montreal Protocol classified MBr as an ozone depleting substance. Consequently, the U.S. Environmental Protection Agency (U.S. EPA) restricted the U.S. production and importation of MBr, aiming to completely ban the pesticide by 2001. However, in 1998 the U.S. Congress passed legislation to extend the use of MBr until 2005. The U.S. EPA published a final rule on the exemptions for quarantine and pre-shipment uses of MBr as amendments for the Clean Air Act [3]. Furthermore, EPA published a rule on critical use exemption to allow specific farmers to apply MBr under certain conditions [4]. This critical use exemption authorized select farmers to apply MBr for pre-plant fumigation of strawberry production fields. That exemption expired at the end of 2016, and the only remaining critical use exemption for field soil fumigations was for preparing fields for planting strawberries for agricultural production [4]. Therefore, MBr is still being applied in California by farmers but under limited conditions with eventual complete prohibition anticipated under current regulatory policy.

In agricultural areas, MBr is volatilized into the air after application into the soil causing potential risk of exposure of inhalation [5]. Studies in agricultural workers and the general population living near sites where the pesticide was used indicated that these populations may be

excessively burdened by respiratory diseases due to exposure to MBr [5-7]. However, the association between ambient concentrations of MBr air toxicant and respiratory disease has been difficult to examine due to the scarcity of ambient concentration measurements, population-based studies, and insufficient information in human case reports. While multiple studies have been published specific to dose response focused on human toxicity at or near the application site where exposure is dominated by physical characteristics such as drift [5, 8-9], there have been limited epidemiological studies on population level ambient exposure. In a study by Gharibi et al., 2019, the association between 1, 3-Dichloropropene, and asthma ED visits indicated a significantly positive association. There are many (only a few mentioned here) studies indicating significantly positive association between the criteria pollutants, PM_{2.5}, NO₂ and asthma ED visits and hospitalization [11-15].

Toxicological measurements to establish safe levels of exposure to MBr have been derived from experimental animal studies. Animal studies have found evidence of respiratory tissue damage after inhalation of MBr in numerous species. Experimental research in rats and mice demonstrated that respiratory signs and symptoms depend on both the concentration of MBr in air inhaled and the duration of exposure. These respiratory effects include severe irritation of respiratory mucous membranes and cell damage with change in the normal cell function, especially in the nasal cavity [16-18]. Additionally, there is evidence of cumulative toxicity of MBr [19-21] with high affinity for the lungs [22]. In humans, pesticides may produce cellular damage when aerosols or gases act as respiratory irritants and inflammation promoters, resulting in changes in respiratory function and irritative symptoms [23]. Therefore, we hypothesize that MBr may act as asthma exacerbation trigger agent.

In this study, it is hypothesized that short time exposure to MBr is associated with asthma ED visits. Hence, the association between short term exposure to MBr and asthma ED visits in Central and Southern California from August to February of 2005 to 2011 is investigated by applying a bidirectional symmetric case-crossover method. In addition, the model is adjusted for concurrently present air pollutants, including 1, 3-Dichloropropene, NO₂ (Nitrogen Dioxide), PM_{2.5} (Particulate matter with diameter of less than 2.5 micrometer) and meteorological factors (temperature and relative humidity). The potential effect modification of sex (female or male), race (Non-Hispanic Whites, Non-Hispanic Blacks, or Hispanics) and age (i. e. 2-5, 6-18, 19-40, 41-64 or ≥ 65) were analyzed.

Material and Methods

Data and Participants

The data relating to asthma ED visits is secondary data obtained from California's Office of Statewide Health Planning and Development (OSHPD). The dataset contains information on individual patient records including patient ZIP code, gender, birthdate, principal language, service date, diagnoses, cause of injury, treatments/procedures, and expected source of payment. The data are submitted every three months by EDs to OSHPD. We selected patient records using the International Classification of Diseases, 9th Revision (ICD-9) codes to include only those who had ED visits due to ICD-9 code 493 for primary diagnosis (not symptoms) of asthma visits (National Center for Health Statistics, 2011) [24]. Multiple visits by a single person cannot be identified because visits do not include information to link a person longitudinally.

Study Design

To investigate the association between asthma ED visits and the concentration of MBr, a bidirectional-symmetric case cross-over design was applied. In this design, the exposure of

patients on the day of the ED visit (matched every two weeks to MBr concentrations) was compared to 4 referent days (two referents days before a visit and 2 after the visit when MBr measurements were available). For example, if a patient visited the ED on September 30th, there are two control days before (i. e. September 2nd and 16th) and two control days after (i. e. October 14th and 28th). Cases were included only if they occurred on a day of sampling. These intervals control for seasonal trends and lessen autocorrelation issues [25-26]. In this design, the effects of potential confounding caused by individual characteristics, such as age, sex, and race, are limited and time trends are controlled via selecting control periods in both directions from the event day. An assumption of bidirectional symmetric case crossover design is that the cases are still at risk after an event [24]. For studies on air pollution as the exposure, the exposure is exogenous. Therefore, the exposure is available for both before and after the event days [27]. Another assumption for the study design applied in this work is that all the event days have two referent days before and two after the event. In order to meet this assumption, the cases at the edge of the study were dropped so all the cases have the same number of referent times.

Exposure Assessment

MBr ambient concentrations were obtained from the Environmental Protection Agency Outdoor Air Exposure database. A total of 14 monitoring stations in 10 California counties were used (Table 1).

“approximate location of Table 1”

MBr concentrations are measured as a daily (24 hour mean) sample taken once every two weeks. 1, 3-D was sampled at the same time for selected sites. Daily-average values were collected for NO₂, PM_{2.5}, temperature, and relative humidity. Since the meteorological factors follow a

nonlinear relationship with the events, we controlled for these factors via restricted cubic splines (RCS) with 3 knots while the pollutants were controlled linearly.

A patient was assigned a MBr exposure if the ZIP Code geographic center was within a 10 km radius of a MBr sampling location. A total of 172 individual ZIP Codes were included in this study. Geographical assignment was performed using QGIS V. 2.14.20.

Statistical Analysis

To estimate the association between MBr and asthma ED visits as an outcome, Conditional Logistic Regression was used. The bidirectional symmetric case-crossover analysis using conditional logistic regression is as follows:

$$l_c(\beta) = \sum_{k=1}^n Y_k \times \left\{ \beta \cdot \left((MBr_{(k)ED}), (PM_{2.5(k)ED}), (NO_{2(k)ED}), (1, 3 - D_{(k)ED}), (Spline(T_{(k)ED})), (Spline(RH_{(k)ED})) \right) \right. \\ \left. - \log \left[\sum_{j=-2, j \neq 0}^2 \exp \left(\beta \cdot \left((MBr_{(k)ED+(14 \times j)}), (PM_{2.5(k)ED+(14 \times j)}), (NO_{2(k)ED+(14 \times j)}), (1, 3 - D_{(k)ED+(14 \times j)}), (Spline(T_{(k)ED+(14 \times j)})), (Spline(RH_{(k)ED+(14 \times j)}))) \right) \right] \right\}$$

Where, Y_k is the daily count of asthma events on k-th day;

$\beta = \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$, and β_7 refers to the coefficient for each covariate. In addition,

$MBR_{(k-l)ED}, PM_{2.5(k-l)ED}, NO_{2(k-l)ED}, (1, 3 - D_{(k)ED}), spline(T_{(k-l)ED}), spline(RH_{(k-l)ED})$ stand for the covariates for the case; and,

$MBR_{(k-l)ED+(14 \times j)}, PM_{2.5(k-l)ED+(14 \times j)}, NO_{2(k-l)ED+(14 \times j)}, 1, 3 - D_{(k)ED+(14 \times j)}, spline(T_{(k-l)ED+(14 \times j)}), spline(RH_{(k-l)ED+(14 \times j)})$ are covariates for the four matched controls.

β_5 and β_7 each represents two coefficients of temperature and relative humidity variables provided by restricted cubic spline (RCS) where k-knots (i. e. 3 knots in our study) provide k-1 variables (i. e. the linear variable itself and k-2 cubic variables).

The results are based on a 0.01 ppb (the interquartile range of MBr) increase in the concentration of MBr during August to February of 2005-2011. Table A. 1 shows the sum of the applied MBr for each month for all years (2005-2011) in the selected 10 counties of California. The months of August to February were selected to focus on because these months experienced the highest concentrations of MBr in the ambient air (Figure A. 1). All analyses were performed using STATA V. 14 (College Station, TX); and, the figures were made using MATLAB R2017b.

Results

Descriptive Analysis of the Hospital Data

A total of 35876 ED visits were recorded during the study period; however, only 4262 of the total visits matched with the days with pesticide data. The study population was comprised of 46.0% male and 53.9% female (Table 2). Ethnic groups were separated as 32.0% Non-Hispanic Whites, 23.5% Non-Hispanic Blacks, and 44% Hispanics (Table 2). The population in this study was between the age of 2 and 5 years old (11.6%), 6 and 18 years old (23.5%), 19 and 40 years old (29.3%), 41 and 64 years old (24.1%), and 65 or more years old (6.9%) (Table 2). The mean age was 31.3 (21.2). Among the 4262 ED visits matched with the days with pesticide data, some of the records for race/ethnicity and age were missing; hence, they were removed for analysis of stratification by age and race/ethnicity.

“approximate location of Table 2”

Descriptive analysis of the air pollutants

The mean concentration of MBr between 2005 and 2011 in the study area was 0.03 ppb, with a minimum and maximum of 0.02 ppb and 1.6 ppb, respectively (Table 3). MBr was found to negatively correlate with NO₂ and temperature, and positively correlated with PM_{2.5} and relative humidity (Table A. 2).

“approximate Location of Table 3”

The association between MBr ambient air concentrations and asthma ED visits

In the unadjusted model, a 0.01 ppb increase in the concentration of MBr at the event day was associated with a 4.1% [OR: 1.041 (95% confidence intervals: 1.010, 1.072)] increase in the odds of having an asthma ED visit (Table 4). OR increased by 1.5% [OR: 1.056 (95% confidence intervals: 1.015, 1.098)] when adjusted for temperature and relative humidity. A 0.01 increase in the concentration of MBr at the event day was found to be associated with 7.1% [OR: 1.071 (95% confidence intervals: 1.029, 1.108)] increase in the odds of having an asthma ED visit when adjusting for meteorology and other pollutants (1,3-D, PM_{2.5}, NO₂, temperature, and relative humidity).

“approximate location of Table 4”

Stratification for sex, race/ethnicity, and age

A 0.01 ppb increase in the concentration of MBr at the event day is associated with 5.9% [OR: 1.059 (95% confidence intervals: 1.028, 1.088)] and 3.0% [OR: 1.030 (95% confidence intervals:

1.006, 1.055)] increase in the odds of having an asthma ED visit among females and males, respectively (Table 5). Stratification by race produced no positive association between MBr and asthma ED visits among Non-Hispanic Whites. However, the associations between MBr and Non-Hispanic Blacks and Hispanics were positive, but higher for Hispanics. A 0.01 ppb increase in the concentration of MBr at the event day was found to be associated with 6.5% [OR: 1.065 (95% confidence intervals: 1.019, 1.108)] and 10.7% [OR: 1.107 (95% confidence intervals: 1.043, 1.173)] increase in the odds of having asthma ED visits among Non-Hispanic Blacks and Hispanics, respectively. Age stratification analysis showed the association between MBr and asthma ED visits were positive for 6 to 18 year old patients. A 0.01 ppb increase in the concentration of MBr at the event day was associated with 7.1% [OR: 1.087 (95% confidence intervals: 1.016, 1.125)] increase in the odds of having an asthma ED visit for 6 to 18-year old in California.

“approximate location of Table 5”

Discussion

The association between more prevalent air pollutants (e.g. NO₂, PM_{2.5}, O₃ etc.) in the environment and asthma ED visits or hospitalization is well established [11-15]. However, to the best of our knowledge, this is the first epidemiological population-based study on the association between MBr and asthma ED visits. The findings suggest that an increase in MBr concentration may increase the odds of an asthma ED visit; these associations varied depending on race and age. The dearth of MBr ambient air monitoring data makes population based studies challenging. Assessing ambient concentrations with bi-weekly measurements and little spatial coverage limits the certainty of human health effects. For example, in this study there was no way to attribute

proximity to application to actual exposure, which may account for the variance in ED visits with ethnicity. But, without further study it is impossible to understand if there is a social justice component to exposure.

MBr has been shown to trigger respiratory responses in exposed people [5]. In addition, the damage due to inhalation of MBr has been documented in laboratory research resulting in injury and inflammation in the respiratory tracts of animals [28]. Furthermore, it has been shown that long term exposure to MBr can result in developing serious chronic health problems [7, 29].

The results suggest that sex is not a modifier of the association between exposure to MBr and asthma ED visits. There is limited evidence on whether the risk factors for asthma vary by sex. The type of toxicity due to inhalation of pesticides may produce tissue damage, mucous membrane irritation and inflammation [23]; these mechanisms occur similarly in both sexes. Even though a few studies have aimed to find differences between sexes in terms of asthmatic rates, the results varied depending on age [30-31]. Studies on asthmatic symptoms found that males have higher rates of asthmatic wheezing in childhood; however, females show predominant rates during adolescence [30-31]. Therefore, sex as a modifier in asthmatic responses should be further investigated.

Moreover, it is possible that age has a more important role in asthma, compared to sex. At a given concentration of a chemical in the air, children will receive higher exposures per unit body weight than adults because of the higher breathing rate per unit body weight. It can be implied that because children have a greater inhalation-to body weight ratio, the risks to children are consistently greater than for adults [32]. Additionally, asthma may burden young populations due to lung immaturity [33], and hormonal changes [30]. The results in this manuscript showed MBr

is positively associated with asthma ED visits among 6 to 18 years old. This is in line with what has Schwartz et al. (2015) reported [34].

There was a positive association between MBr and asthma ED visits among Blacks and Hispanics but not Whites. Minority populations suffer increased rates of asthma prevalence [35-36]. The reasons for these racial disparities are not fully understood. However, environmental exposure modifications have shown improvement and control of asthma [37-40]. Therefore, this result may be explained by the difference in environmental exposure among racial groups. A study conducted by Schwartz et al. (2015) on pesticide exposure, childhood asthma and environmental justice among Mexican-American farmworkers in San Joaquin Valley found Hispanics and other minority groups lived nearby the agricultural areas, resulting in more asthmatic events among them [34]. The findings also suggest that Hispanics and Blacks who are exposed to MBr have higher odds of having asthma ED visits.

Strength and Limitations

The other concomitantly present pollutants (i. e. $PM_{2.5}$, NO_2 and 1, 3-D) were controlled for in the regression analysis. In addition, the study design used in this work limits the effect of invariant confounders (i. e. sex, smoking, occupational history, and genetics) which vary between groups [41].

The sampling of MBr was conducted by EPA once every two weeks. It is noteworthy that the sampling of MBr was conducted by the California Air Resources Board and air districts throughout California once every two weeks. These measurements are used to determine MBr concentrations statewide and warehoused by the EPA. There is a possibility that some of the ED visits at the event day occurred due to the exposure to MBr at previous days before the event day. In addition, the ambient air can be a mixture of pollutants and an individual can be exposed

to different types of pollutant simultaneously. To consider the combination effect of a group of pollutants, a multipollutant model is a topic that needs further study. There was a potential for exposure misclassification (i.e. poor correlation between the MBr levels measured at fixed sites and personal exposure). For example, the point location was estimated as the center of the ZIP code, and a 10 km radius around the monitoring station measurement was assumed to be representative. There was a potential for misclassification of asthma cases when only using the first diagnosis code, rather than the first 2 or 3. It has been shown that other conditions (e. g. infection) may exacerbate asthma and using the primary billing code would exclude such visits [42]. However, using the other diagnosing codes (i. e. second and third diagnosing codes for asthma) may sacrifice specificity in capturing asthma ED visits; for example, there are ED cases (e. g. sprains and fractures) which are non-related visits with a secondary diagnosis of asthma. MBr application has been slated to end for many years. Exemptions for certain agricultural uses have consistently been granted. With a planned discontinuance of use, ambient monitoring will not be a priority. But, while usage continues and population level exposure effects are not researched and understood, application levels could easily change. Even with the obvious limitations discussed above, this study suggests ambient concentrations at current levels warrant more rigorous research and should currently be considered having a detrimental impact to human health.

Conclusion

An increase in MBr ambient air concentration increased the odds of having an asthma ED visit in central and southern California from August to February (2005-2011). Limited study on the respiratory effects of MBr and lack of ambient air monitoring data makes it difficult to understand the impact to public health. Without further more comprehensive studies, MBr should

be assumed to have an impact on ED visits for asthma at current ambient concentrations. Additional population-based studies are needed to understand better the association between MBr as a pesticide air toxicant and asthma. Considering the interspecies variability in the respiratory tissues between animals and humans, additional information and human health risk assessment for MBr exposure is required. The use of MBr should continue to be evaluated to limit exposures according to population health characteristics.

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Compliance with ethical standards

Ethics approval and consent to participate The study was approved by the State of California Committee for the Protection of Human Subjects. The data used in this analysis does not contain any personal identifiable information. Informed consent was not required because data were anonymous. Additional safeguards included physical and electronic barriers to data access and encryption.

Consent for publication Not Applicable

Conflict of Interest The authors declare that they have no conflict of interest.

Financial disclosure

The authors have no financial relationships relevant to this article to disclose.

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Table 1. Methyl bromide monitoring stations.

Site Name	Latitude	Longitude	Basin Name
Stockton-Hazelton Street	37.95167	-121.269	San Joaquin Valley
Chico-Manzanita Avenue	39.7575	-121.842	Sacramento Valley
El Cajon-Redwood Avenue	32.79083	-116.943	San Diego
North Long Beach	33.82417	-118.189	South Coast
Azusa	34.1364	-117.924	South Coast
Burbank-W Palm Avenue	34.1758	-118.317	South Coast
Chula Vista	32.6314	-117.059	San Diego
Riverside-Rubidoux	34.00056	-117.415	South Coast
Simi Valley-Cochran Street	34.2761	-118.684	South Coast Central
Los Angeles-North Main Street	34.0664	-118.227	South Coast
Roseville-N Sunrise Blvd	38.74611	-121.265	Sacramento Valley
Fresno-1st Street	36.7819	-119.773	San Joaquin Valley
Calexico-Ethel Street	32.6761	-115.483	Salton Sea
Bakersfield-5558 California Avenue	35.35667	-119.063	San Joaquin Valley

Table 2. Characteristics of asthma ED visits from 2005 to 2011 in central and southern California, USA (n=4262)

Characteristics	# of Visits (%)
Sex	
<i>Female</i>	2299 (53.9)
<i>Male</i>	1963 (46.0)
Race	
<i>White</i>	1223 (32.0)
<i>Black</i>	901 (23.5)
<i>Hispanic</i>	1696 (44.4)
Age	
<i>2-5</i>	497 (12.7)
<i>6-18</i>	1005 (24.6)
<i>19-40</i>	1251 (30.5)
<i>41-64</i>	1031 (25.1)
<i>>=65</i>	297 (7.1)
#Total	4262 (100)

Note: The ED visits due to asthma with missing Race or Age information were dropped while stratifying for them.

Table 3. Air pollutants summary for August to February (2005-2011) at central and southern California monitoring sites, USA

Variable	Standard		Minimum	Percentile			Maximum
	Mean	Deviation		25	50	75	
^a MBr _(ppb)	0.03	0.05	0.01	0.01	0.02	0.03	1.6
^b PM _{2.5} (µg/m ³)	25.2	23.3	0.0	8.2	16.3	31.7	82.5
^c NO ₂ (ppb)	26.8	23.1	0.0	14.3	21.15	31.1	187.2
^d 1, 3-D _(ppb)	0.06	0.03	0.04	0.05	0.05	0.06	0.84
Relative Humidity (%)	63.5	20.1	5.0	47.4	68.2	78.6	99.9
Temperature (°C)	15.4	6.1	-3.5	11.1	14.2	19.8	33.3

^a MBr: Methyl Bromide;

^b PM_{2.5}: Particulate matter with diameter of less than 2.5 micrometer (daily-average);

^c NO₂: Nitrogen dioxide (daily-average)

^d 1, 3-D: 1,3-Dichloropropene;

Table 4. Odds Ratio (OR) for Methyl Bromide (MBr) and asthma emergency room visits in central and southern California between 2005 and 2011.

Models	MBr _(ppb)
	OR (95% CI)
Unadjusted Event day	1.041 (1.010, 1.072)
Adjusted for temperature and Relative humidity	1.056 (1.015, 1.098)
Adjusted for 1, 3-D, temperature and Relative humidity	1.037 (1.005, 1.091)
Adjusted for PM _{2.5} , temperature and Relative humidity	1.074 (1.032, 1.117)
Adjusted for NO ₂ , temperature and Relative humidity	1.082 (1.023, 1.140)
Adjusted for 1, 3-D, PM _{2.5} , NO ₂ , temperature and Relative humidity	1.071 (1.029, 1.108)

Abbreviations: CI, confidence interval; OR, odds ratio; Temperature and Relative Humidity were adjusted using restricted cubic splines (RCS) with 3 knots

Table 5. Odds Ratio (OR) for Methyl Bromide (MBr) and asthma ED visits in Central and Southern California between 2005 and 2011 stratifying for sex, race, and age.

Strata	MBR _(ppb)
	OR (95% CI)
<i>^a Stratification for Sex</i>	
Female	1.059 (1.028, 1.088)
Male	1.030 (1.006, 1.055)
<i>^a Stratification for Race</i>	
White	0.991 (0.862, 1.117)
Black	1.065 (1.019, 1.108)
Hispanic	1.107 (1.043, 1.173)
<i>^a Stratification for Age</i>	
2 to 5	1.024 (0.997, 1.052)
6 to 18	1.071 (1.016, 1.125)
19 to 40	1.009 (0.905, 1.114)
41 to 64	0.983 (0.942, 1.022)
>=65	0.887 (0.787, 0.989)

Abbreviations: CI, confidence interval; OR, odds ratio;

^a Stratification analysis was conducted by adjusting for 1,3-D, PM_{2.5}, NO₂, temperature (RCS) and relative humidity (RCS)

Appendices

Table A. 1. Monthly total tons of Methyl Bromide applied each year in the 10 counties ^a of California, USA

Methyl Bromide (ton)	2005	2006	2007	2008	2009	2010	2011	Total/month (ton)
January	80.4	75.5	60.1	57.6	40.6	22.5	10.3	347.0
February	96.5	64.8	41.5	21.7	19.9	18.5	22.3	285.2
March	46.1	31.8	48.5	80.8	87.8	46.3	22.6	364.0
April	59.0	47.3	49.2	118.2	73.9	90.7	75.1	513.4
May	71.4	44.6	60.0	19.3	12.0	37.6	37.9	282.8
June	104.2	72.3	50.1	22.2	26.6	32.0	28.6	336.0
July	143.9	142.5	92.7	45.2	153.1	76.3	34.2	687.9
August	200.1	160.5	120.4	81.5	48.9	31.2	21.1	663.7
September	142.5	86.0	58.6	51.8	28.0	26.4	21.5	414.8
October	71.9	54.4	39.2	58.1	38.3	14.8	18.3	295.0
November	98.0	89.0	97.0	17.8	33.4	23.1	32.2	390.6
December	198.5	142.0	138.0	95.4	66.4	64.2	23.1	727.6
Total/year (ton)	1312.6	1010.7	855.2	669.5	628.9	483.7	347.2	

^a counties : Butte; Fresno; Imperial; Kern; Los Angeles; Placer; Riverside; San Diego; San Joaquin; Ventura

Source: California Environmental Health Tracking Program, California Department of Public Health. Agricultural Pesticide Mapping Tool.

Data from California Department of Pesticide Regulation Pesticide Use Report Database, 1991-2015. 2017. Online at www.cehtp.org/pesticidetool.

Table A. 2. Correlation between the concentration of MBr, PM_{2.5}, NO₂, 1,3-Dichloropropene and meteorological factors for all data (2005 to 2011).

Variable	MBr	PM _{2.5}	NO ₂	1, 3-D	Relative Humidity	Temperature
^a MBr (ppb)	1.0000					
^b PM _{2.5} (µg/m ³)	0.0150	1.0000				
^c NO ₂ (ppb)	-0.0613*	0.4476*	1.0000			
^d 1, 3-D (ppb)	0.1723*	0.0591*	-0.0353*	1.0000		
Relative Humidity (%)	0.1637*	-0.0012	-0.2844*	0.0650*	1.0000	
Temperature (°C)	-0.0991*	0.1111*	0.3390*	-0.0879*	-0.1827*	1.0000

*P < 0.01 **P < 0.05

^aMBr: Methyl Bromide (daily-average in every two weeks sampling);

^bPM_{2.5}: Particulate matter with diameter of less than 2.5 (daily-average);

^cNO₂: Nitrogen dioxide (daily-average)

^d1, 3-D: 1,3-Dichloropropene (daily-average in every two weeks sampling);

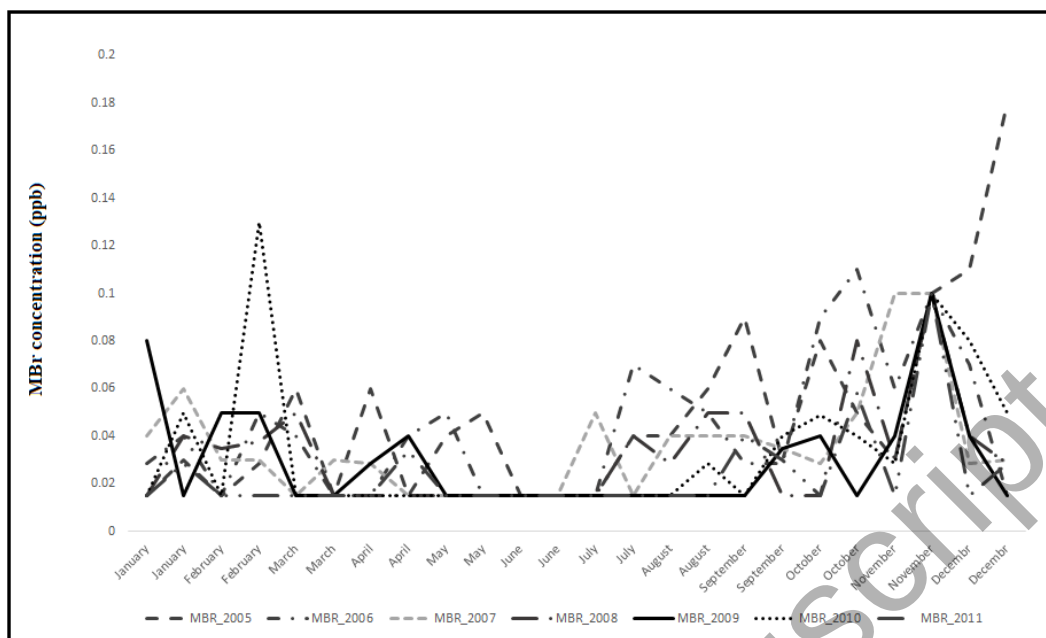


Figure A. 1. The monthly concentration of MBr in the ambient air for the years 2005 to 2011 in Central and Southern California.

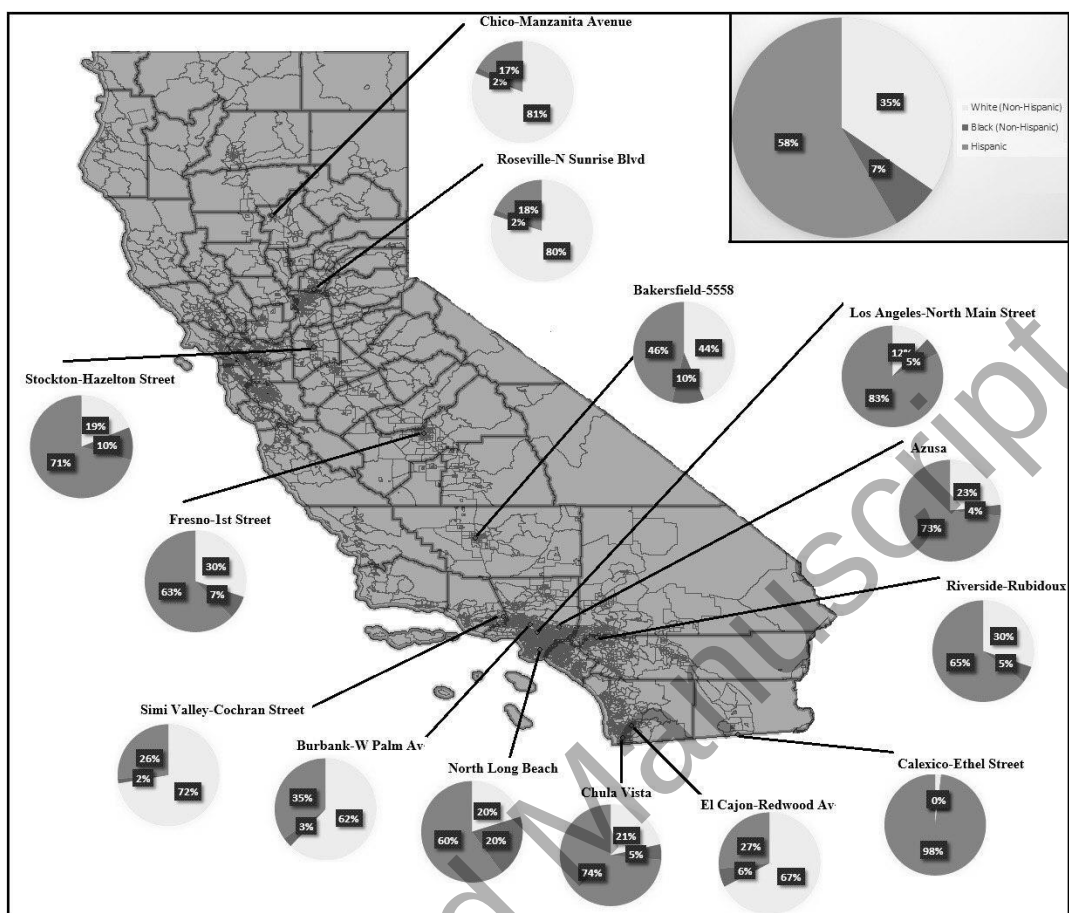


Figure A. 2. The sampling stations and race/ethnicity-based population at the sampling stations