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Comparative Assessment of Pollutant Concentrations and Meteorological Parameters from TCEQ CAMS Sites at Houston and Rio Grande Valley Regions of Texas, USA in 2016

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Abstract

Spatial and temporal heterogeneity in pollutant concentrations exists at the intra-urban level. In this research work, the concentrations of various pollutants and meteorological parameters are characterized between various central ambient monitoring sites at Houston, TX, and the Rio Grande Valley Regions of South Texas. Meteorological (temperature, relative humidity, wind speed and direction) and pollutant (O_3, SO_2, CO, NO_2, and various PM species) concentrations were downloaded from the appropriate Texas Commission on Environmental Quality (TCEQ) Central Ambient Monitoring Station (CAMS) sites for the year 2016. Correlation Analyses and Coefficient of Divergence (COD) analyses suggest that statistically significant differences occur between the various TCEQ CAMS sites in the Houston Region. Findings from this study will help the various stakeholders involved in assessing the overall air pollutants exposure burden for the local populations.

Keywords

Air Pollution, Urban, Spatial Heterogeneity, Particulate Matter, NO_2, Texas

1. Introduction

Air pollution is a global health concern. In many areas around the world, and more specifically in the United States of America, the air pollution exposures of the local populations are estimated using the central air pollution monitoring stations [1] [2] [3]. These monitoring stations are mandated by the USEPA and the local environmental departments to characterize the air pollution trends of the six criteria air pollutants as outlined in the Clean Air Act of 1970 and the subsequent amendments of 1990 and thereafter [4] [5].

In Texas, the Texas Commission on Environmental Quality (TCEQ) Central Ambient Monitoring Stations (CAMS) sites monitor various criterial air pollutants such as fine and coarse particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3). Simultaneously, meteorological parameters such as wind speed, wind direction, temperature, relative humidity, barometric pressure, and solar radiation are measured. These pollutants and meteorological parameters are measured on an hourly basis. Air pollution levels differ considerably at the intra-city and inter-city levels [6] [7] [8]. Comparative assessment research work amongst the various TCEQ monitoring sites has demonstrated the spatial non-homogeneity in air pollution levels [9].

The research work presented here compares the air pollutant characteristics between two areas of Texas. The two chosen areas were the Houston Metropolitan Area and the Rio Grande Valley Region of South Texas. The comparative analyses were undertaken between the various TCEQ CAMS sites in these two regions.

In urban areas, traffic emissions are a dominant source of air pollution and some of the pollutants of concern are CO, $PM_{2.5}$, benzene (C_6H_6), and other toxic air contaminants [10]. Adverse acute and chronic health effects from traffic-related air pollution (TRAP) on vulnerable population groups such as pregnant women, children, and the elderly have been well documented [10] [11]. Severity of exposure depends on the time and location of exposure, and the emission concentrations present in the microenvironment. Populations living close to major roadways are at greater risk of the unfavorable effects of TRAP [11] [12]. TRAP concentrations fluctuate considerably in time and space near roadways. Fine Particulate Matter ($PM_{2.5}$) exhibits least-pronounced gradients whereas gaseous pollutants such as NO_2 have more pronounced gradients from these major highways and roadways [13]. Season (temperature and wind patterns) and temporal patterns are additional factors that vary TRAP spatially in urban areas.

Characterization of Common Air Pollutants

Airborne PM is heterogenous mixture of liquid and solid particles in the air. Suspended particles are diverse in chemical composition (e.g. nitrates, sulfates, biological compounds, organic compounds, metals, elemental and organic carbon) and aerodynamic size (e.g. PM_1, $PM_{2.5}$, PM_4, and PM_{10}) [14]. Particles' inhaling and transport ability depend on the aerodynamic diameter in micrometers (μm). The EPA mainly generalizes the particles in two sizes: fine particulate matter $PM_{2.5}$ (less than 2.5 μm) and coarse particulate matter PM_{10} (less than 10 μm). Inhaled fine particles have the propensity to travel and penetrate further up the respiratory tract. Effective filtering from nasal-breathing interferes with coarse particles, thus, lodging them in the trachea or bronchi [14] [15]. Exposure to PM poses greater danger than other pollutants such as ground-level ozone.

Particulate matter exposure can result in many respiratory health conditions such as airways irritation, wheezing, coughing [8] [14] [16] [17] [18]. Health effects correlated with traffic air pollution are studied amongst communities to prevent over exposure in sensitive communities [6] [7]. The wear-tear of vehicle components such as tires and brake pads and the combustion of fossil fuels are key sources of $PM_{2.5}$ [14] [19] [20]. Another criteria air pollutant—ground level ozone warrants attention. The ozone in the stratosphere filters the harmful ultraviolet rays of the sun thereby protecting; however, ground level ozone is a pollutant of concern [21] [22]. The photochemical reactions of oxides of nitrogen (NOx: NO, and NO_2) and volatile organic compounds (VOCs) producing higher levels of ozone, exceeding the natural background level. Anthropogenic and biogenic emissions are responsible for the VOCs, NOx, and CO. $PM_{2.5}$ from primary emission sources are accountable for ozone formation when reacting with free radicals such as HO_2 [22].

2. Study Design and Methods

2.1. Site Selection

Five TCEQ CAMS sites in the Rio Grande Valley (CAMS 43, 80, 323, 1023, & 1046) and five TCEQ CAMS sites in Houston (CAMS 35, 55, 108, 113, 416) were selected based on their respective locations such that a robust spatiotemporal characterization of their pollutant concentrations could be determined. CAMS 43 is in John H. Shary Elementary School near the Edinburg Main Canal. CAMS 80 is in the University of Texas Rio Grande Valley (UTRGV) Brownsville campus near the U.S.-Mexican border adjoining the Fort Brown Resaca. CAMS 323 is in South Padre Islands, exposed to coastal pollutants and located in the UTRGV labs near a trailer park. CAMS 1023 in Harlingen is located near a neighborhood park. CAMS 1046 is off a major highway near the Edinburg Main Canal. As for the Houston CAMS sites, CAMS 35 is housed in a neighborhood park, while CAMS 55/113 is located near a main road and railroad. CAMS 108 is off a main road and middle school. CAMS 416 is near a main road intersection and an elementary school.

Figure 1 and **Figure 2** are the Google Earth Images of the various TCEQ CAMS sites in the Rio Grande Valley and the Houston area, respectively. **Table 1** & **Table 2** show the common air pollutants, temperature, and meteorology at each CAMS site in Rio Grande Valley and Houston, respectively. TCEQ provides hourly air pollution data and meteorological parameters. Common air pollutants recorded in the RGV CAMS sites include ozone and $PM_{2.5}$, whereas most of the Houston CAMS sites log carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, $PM_{2.5}$, and PM_{10}. Selected data for the year 2016 was downloaded from the TCEQ website for the various stations in the two regions and analyzed.

2.2. Topography and Meteorology

The Rio Grande Valley and Houston areas are relatively close to the Gulf of

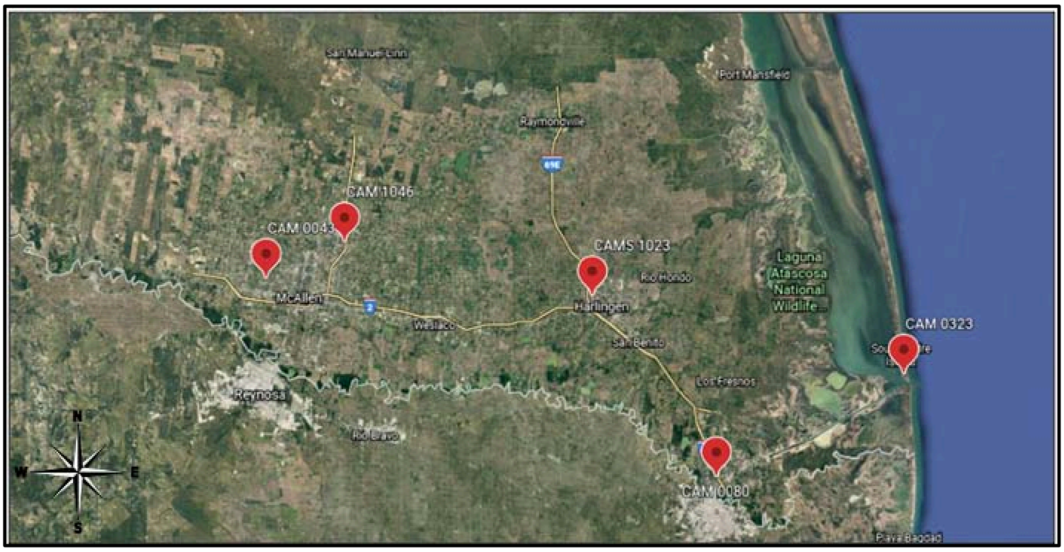

Figure 1. Map of the study area, including the TCEQ CAMS sites in the Rio Grande Valley, South Texas.

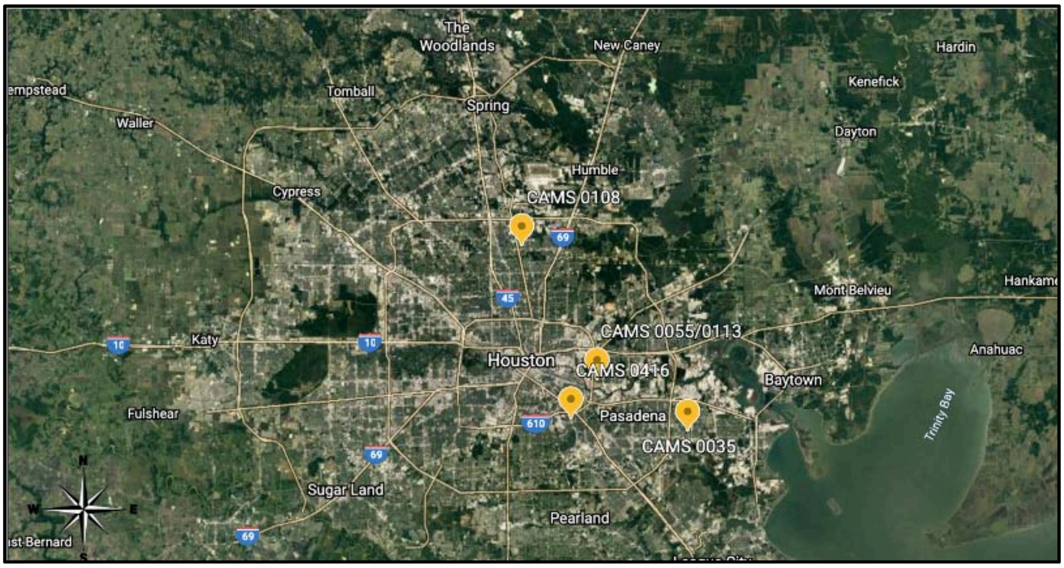

Figure 2. Map of the study area, including the TCEQ CAMS sites in Houston, Texas.

Table 1. Logged air pollutants in the Rio Grande Valley, TX TCEQ CAMS sites.

RGV	C43	C80	C323	C1023	C1046
O_3	x			x	
CO					
RWS	x	x	x	x	x
RWD	x	x	x	x	x
OT	x	x	x	x	x
SR	x	x			
PM_{10}					
$PM_{2.5}$ (Acceptable)			x		

Table 2. Logged air pollutants in the Houston, Tx TCEQ CAMS sites.

Houston	C35	C55/113	C108	C416
CO	x	x		
SO_2	x	x		x
NO_2		x	x	x
O_3	x	x	x	x
RWS	x	x	x	x
RWD	x	x	x	x
OT	x	x	x	x
RH	x	x	x	x
$PM_{2.5}$ (Acceptable)	x	x		x
PM_{10}	x			
$PM_{2.5}$	x			

Mexico. Warm waters such as the Gulf of Mexico are prone to form hurricanes affectively scheduling a hurricane season (June 1st till November) on the Texas coast. However, hurricanes have and may continue to occur during every month of hurricane season [23]. Downtown Houston is approximately 50ft above sea level. Summertime is humid and semitropical, whereas winters are mild [24]. The Rio Grande Valley is a subtropical environment with humid summers [25]. Buildings and homes are vulnerable to hurricane force winds in these focused regions. Winds from the Gulf of Mexico carry large amounts of moisture in the air, resulting in high levels of humidity [26]. The wind roses for the two regions during the entire study period are shown in **Figure 3** & **Figure 4**, with the highest frequency of wind speeds logged in between 0.5 and 2.1 m/s. Meteorological conditions provoke the quality of the air with winds and hurricanes upturning the environment. As such, these wind roses for both the regions help interpret the various frequencies of wind speed in the two regions, were produced to interpret averaged wind speed in the region.

2.3. Sampling Methods

Data for the entire year of 2016 (January 1st-December 31st) was downloaded from the TCEQ CAMS site regions. The CAMS Site in Houston labeled C55 is the same monitor as C113, only updated through the years. All CAMS sites are outdoors and data for carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, PM ($PM_{2.5}$, and PM_{10}), and meteorological parameters (temperature, relative humidity, wind direction and speed) were downloaded. Data field measurements were analyzed with statistical data analyses to find correlations and trends.

2.4. Statistical Data Analysis

Descriptive statistics of collected data was processed in SPSS for Windows, v.24.0 (SPSS, Inc. Chicago, IL, USA) and Microsoft Excel 2019 for advanced statistical

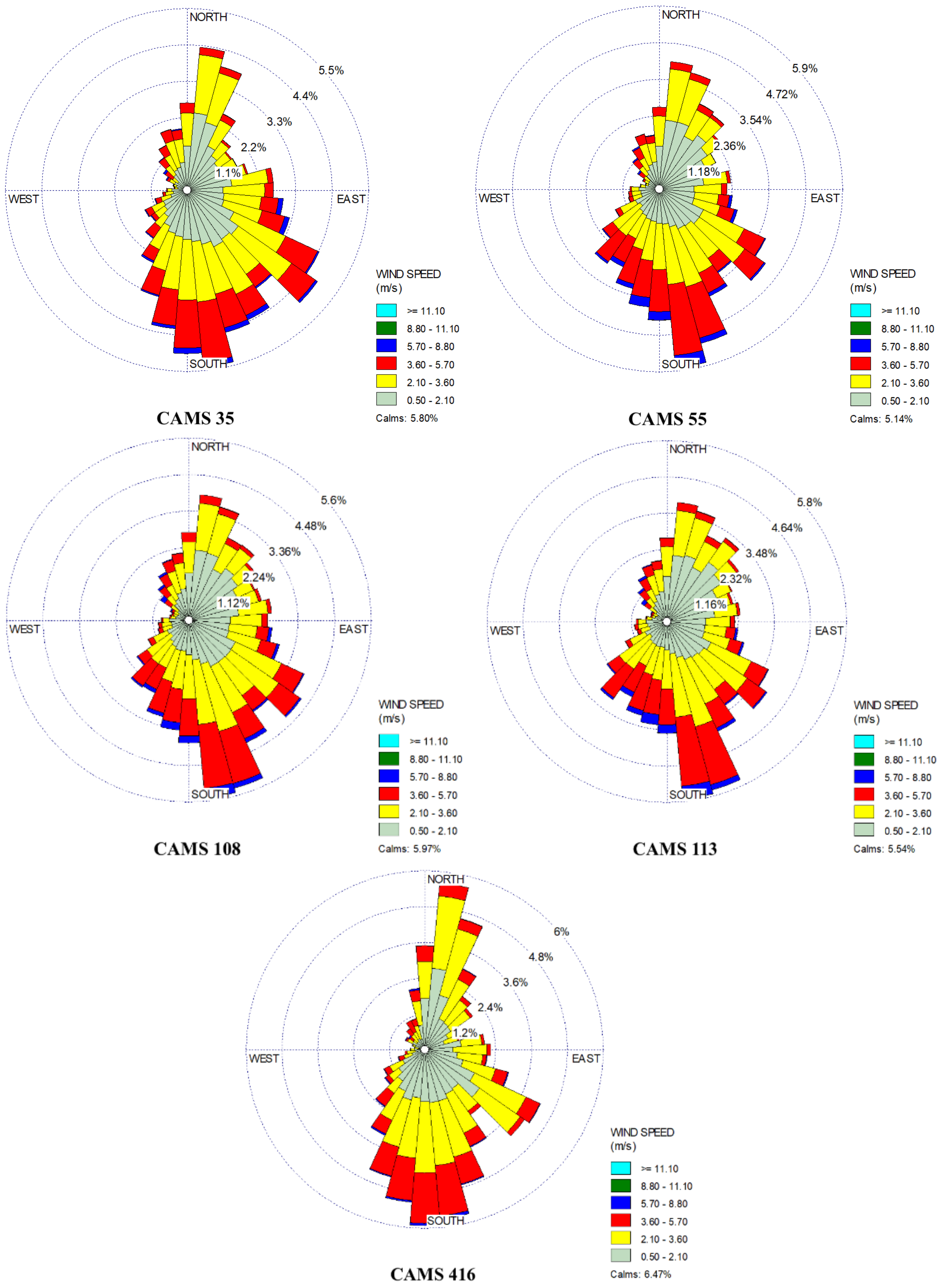

Figure 3. Wind roses for the Houston TCEQ CAMS sites for the study period.

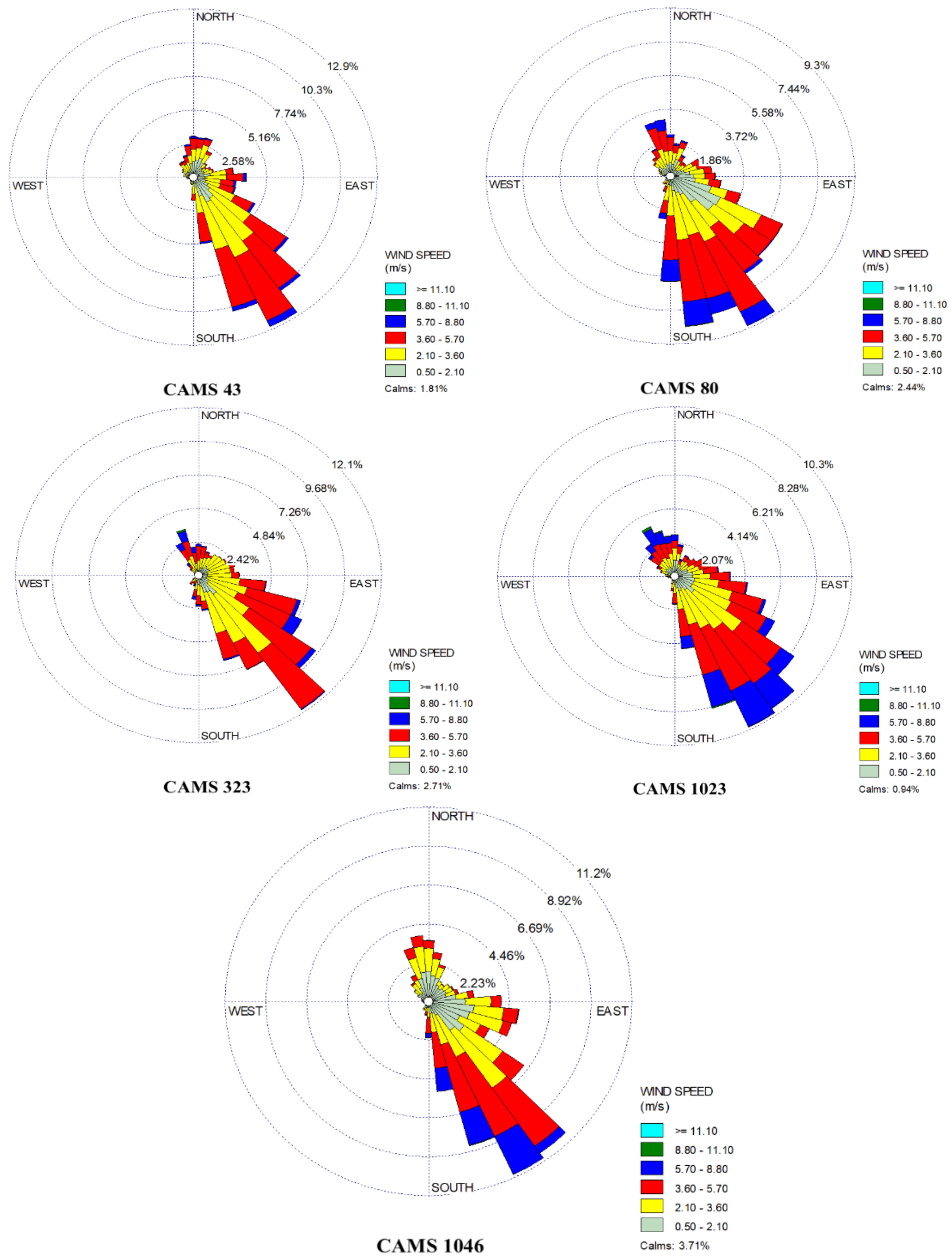

Figure 4. Wind roses for the Rio Grande Valley TCEQ CAMS sites for the study period.

analyses for the various pollutant data. Pollutant time-series and boxplots were plotted to illustrate pollutant concentrations. R Statistical Software (v.4.0.1; R Core Team 2020) was used to design wind roses that would offer a graphical snapshot of the meteorological levels. Spatiotemporal correlations between Houston and RGV sites were conducted to indicate inter-pollutant and intra-pollutant correlations. Coefficient of Divergence (COD) analyses help identify the differences in the levels of pollutant across the CAMS sites in the two regions. COD offers uniformity amongst the concentrations of pollutants at the sites. COD is defined as

$$\mathrm{COD}_{j,k} = \sqrt{\frac{1}{p}\sum_{i-1}^{p}\left[\frac{x_{ij} - x_{i,k}}{x_{ij} + x_{i,k}}\right]^2}$$

where, x_{ij} is the i^{th} concentration measured at site j over a 24-hr sampling period, j and k are two different sites, and p is the number of observations [6] [9]. COD values of unity signify vast differences between the concentrations at the sites. COD values < 0.20 specifies similar concentrations between sites whereas, values > 0.20 identify a significant difference in the concentrations between sites.

3. Results and Discussion

3.1. 24-hr Concentration Analyses

The time series in **Figure 5** illustrates descriptive statistic for 2016 monthly average data of $PM_{2.5}$, PM_{10}, & $PM_{10-2.5}$ during local conditions at CAMS site C35. C35 is one of the Houston region's CAMS sites, and the only site to log the majority of air pollutants focused for this study (the PM species). C35 is located near a neighborhood park and indicates exposure to the components of $PM_{2.5}$ from combustion particles, organic compounds, and metals and PM_{10} from sources such as dust pollen and mold. Therefore, the time series displays the contribution

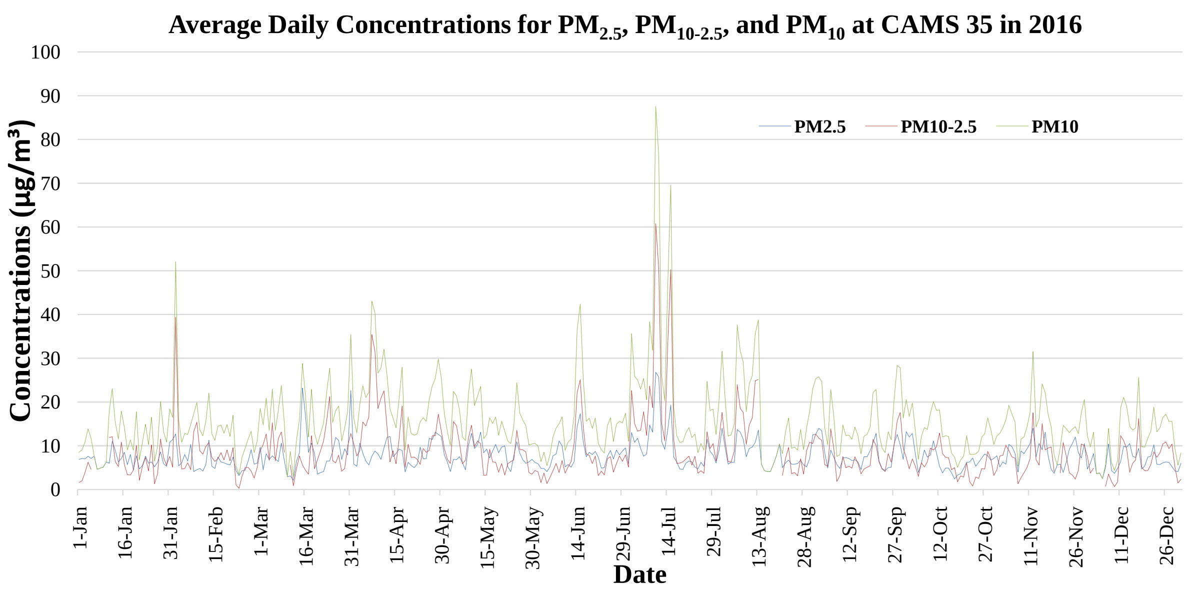

Figure 5. Time series of $PM_{2.5}$, PM_{10}, & $PM_{10-2.5}$ at CAMS 35 for 2016.

of pollutants for a single CAMS with the comparison between the PM species. PM_{10} logged higher contribution in approximately 90% of the month of July. Throughout the year of 2016, the comparison PM_{10} recorded the maximum contribution value than the other mentioned pollutants.

Boxplot variations of 24-hr average concentrations in meteorological and air pollutant averages at the RGV and Houston regions are shown in **Figure 6** and **Figure 7**, respectively. 24-hr meteorological averages at RGV CAMS sites include solar radiation in (l pm) and outdoor temperature in (˚F); with pollutant averages involving PM in local conditions and O_3 (ppb). While in the Houston CAMS sites meteorological averages include relative humidity (%) and outdoor temperature (˚F). Pollutant averages comprise of O_3 (ppb), CO (ppm), NO_2 (ppb), and PM in local conditions.

3.2. Coefficient of Divergence (COD) Analyses

Spatial variation in the pollutant concentrations at the CAMS sites at the Houston and RGV regions during the year of 2016 are represented as Coefficient of Divergence (COD) values in **Table 3** & **Table 4**, respectively. In the Houston area the highest COD value was 0.49 for $PM_{2.5}$ concentration between C55-C416; C416-C113; and C35-C416. The highest COD value for O_3 was between CAMS C35-C416 with a value of 0.21. As for NO_2, the highest value is

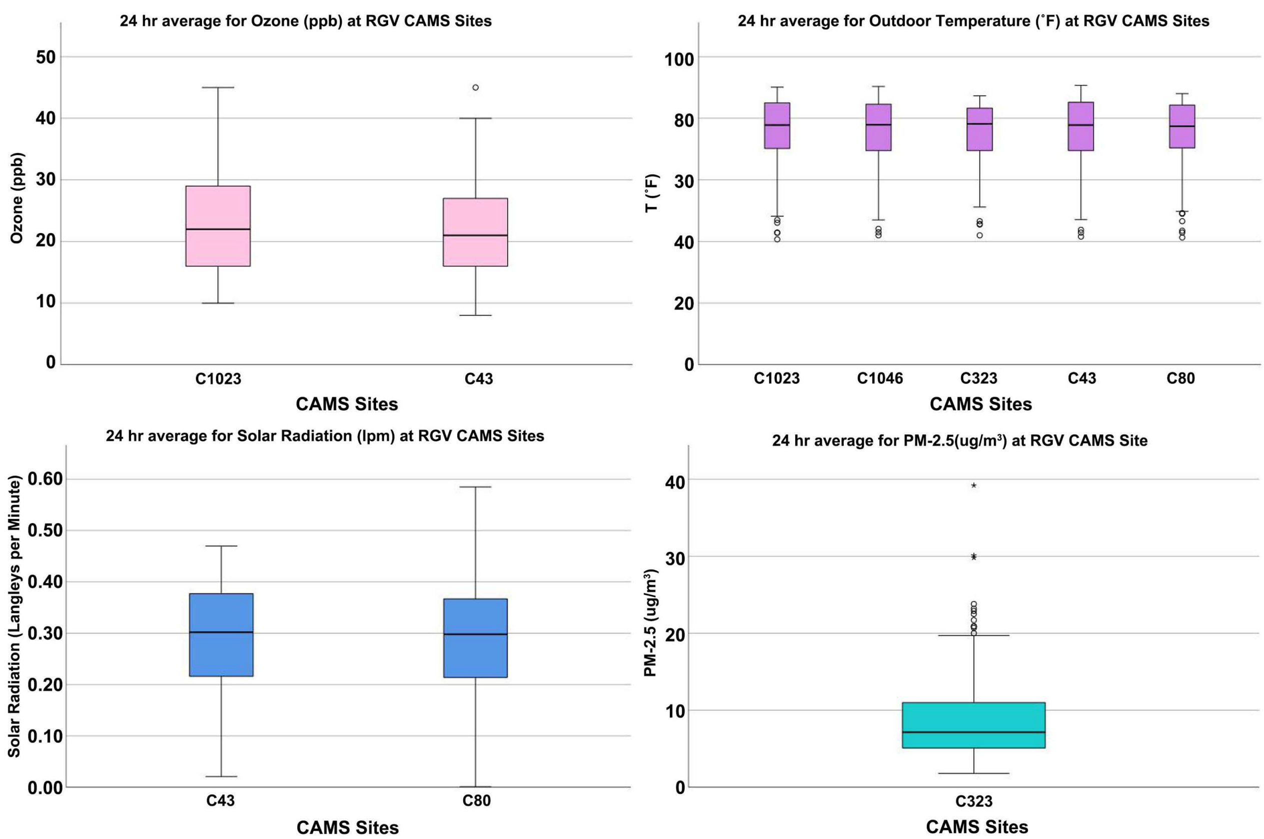

Figure 6. Boxplot variations of 24-hour average concentrations of CO (ppm), NO_2 (ppb), Ozone (ppb), and PM in RGV TCEQ CAMS sites.

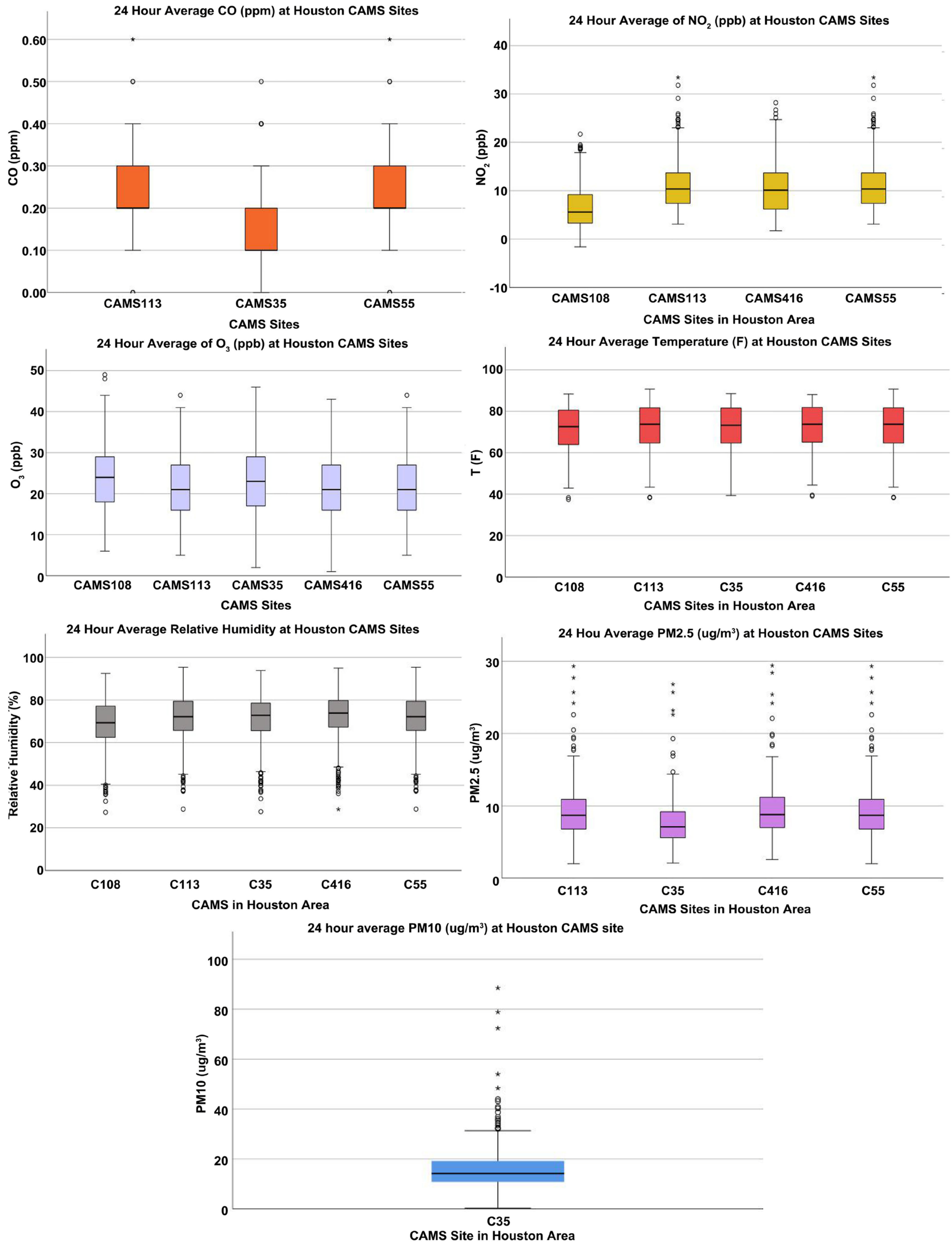

Figure 7. Boxplot variations of 24-hour average concentrations of CO (ppm), NO_2 (ppb), Ozone (ppb), and PM in Houston TCEQ CAMS sites.

Table 3. COD values for TCEQ CAMS in the RGV Region.

Pollutant	C43				C80			C323		C1023
	C1023	C80	C323	C1046	C323	C1023	C1046	C1023	C1046	C1046
O_3	0.1									
T	0.01	0.12	0.06	0.01	0.13	0.12	0.06	0.06	0.06	0.01
W		0.18								

Table 4. COD values for TCEQ CAMS in the Houston Region.

Pollutant	C35				C55		C108		C416	C55
	C55	C113	C108	C416	C108	C416	C113	C416	C113	C416
CO	0.32	0.32								
NO_2					0.42	0.27	0.42	0.43	0.27	
O_3	0.18	0.18	0.18	0.21	0.15		0.15	0.17	0.17	0.17
T	0.09	0.09	0.01	0.12	0.09	0.12	0.09	0.12	0.15	
RH	0.09	0.09	0.03	0.12	0.1	0.12	0.1	0.12	0.15	
$PM_{2.5}$	0.14	0.14		0.49		0.49			0.49	

0.43 from C108-C416 with CAMS C55-C108 and C108-C113 having a close COD value of 0.42. Within the RGV region O_3 represents the COD value of 0.1 between C43-C1023. The following COD values are generated from meteorological data (temperature, wind, relative humidity).

Overall, the results confirm that the Houston region exhibits significant pollutant variations between the various sites, as highlighted by COD analyses. This emphasizes the difference between intra and interurban heterogeneity in air pollutants. Available TCEQ central sites in Houston are located within and between the major city of Houston, therefore; it is a quintessential example of an intra and inter urban study area. COD analyses for 24-hour PM concentrations between four CAMS sites (C35, C55, C113, C416) in Houston are all greater than 0.2, so there is indication of intra-urban heterogeneity within these sites. The available TCEQ central sites are spread throughout the RGV region, in between and in the main city (see Figure 2). The COD value in the RGV CAMS site C43 and C1023 is 0.1, indicating spatial uniformity since the value is below 0.2.

3.3. Correlation Coefficient Analyses

Spearman's correlations within the two regions are represented in Table 5 (RGV region) & Table 6 (Houston region), respectively. Correlation coefficients with ** are significant at the 0.01 level (2-tailed), whereas correlation values with * are significant at the 0.05 level (2-tailed). Resulting coefficients range between −1 and +1, indicating either a positive or negative relationship. Values near −1 or +1 demonstrate a stronger relationship, either negatively or positively. O_3 and NO_2 are relatively correlated between the numerous CAMS sites in the Houston region. In the RGV region, the correlation is strong with the pollutant O_3 within

Table 5. Spearman's correlation for the various meteorological parameters and pollutants at the Rio Grande Valley Region TCEQ CAMS sites.

RGV		O_3		T					W		$PM_{2.5}$
		C43	C1023	C43	C80	C323	C1023	C1046	C43	C80	C323
O_3	C43	1									
	C102	0.907**	1								
T	C43	−0.386**	−0.537**	1							
	C80	−0.408**	−0.549**	0.984**	1						
	C323	−0.369**	−0.534**	0.935**	0.949**	1					
	C1023	−0.416**	−0.554**	0.992**	0.992**	0.938**	1				
	C1046	−0.392**	−0.538**	0.997**	0.987**	0.935**	0.994**	1			
W	C43	−0.101	−0.185**	0.710**	0.674**	0.613**	0.677**	0.696**	1		
	C80	−0.078	−0.127*	0.644**	0.632**	0.581**	0.632**	0.635**	0.864**	1	
$PM_{2.5}$	C323	−0.123*	−0.133*	0.346**	0.367**	0.176**	0.367**	0.356**	0.166**	0.122**	1

Table 6. Spearman's correlation for the various meteorological parameters and pollutants at the Houston Region TCEQ CAMS sites.

Spearman's Rho Correlations		CO			SO_2				NO_2				O_3				
		C35	C55	C113	C35	C55	C113	C416	C55	C108	C113	C416	C35	C55	C108	C113	C416
CO	C35	1															
	C55	0.564**	1														
	C113	0.564**	1	1													
SO_2	C35	0.516**	0.475**	0.475**	1												
	C55	0.302**	0.252**	0.252**	0.263**	1											
	C113	0.302**	0.252**	0.252**	0.263**	1	1										
	C416	0.254**	0.175**	0.175**	0.383**	0.329**	0.329**	1									
NO_2	C55	0.451**	0.594**	0.594**	0.303**	0.337**	0.337**	−0.061	1								
	C108	0.527**	0.596**	0.596**	0.337**	0.265**	0.265**	−0.011	0.779**	1							
	C113	0.451**	0.594**	0.594**	0.303**	0.337**	0.337**	−0.061	1	0.779**	1						
	C416	0.673**	0.695**	0.695**	0.620**	0.383**	0.383**	0.314**	0.682**	0.720**	0.682**	1					
O_3	C35	0.118*	0.028	0.028	0.075	0.296**	0.296**	0.045	0.178**	0.064	0.178**	0.158**	1				
	C55	0.089	−0.038	−0.038	0.042	0.252**	0.252**	0.058	−0.006	−0.006	−0.006	0.089	0.912**	1			
	C108	0.002	−0.103*	−0.103*	−0.040	0.234**	0.234**	−0.003	0.057	−0.111*	0.057	−0.032	0.836**	0.851**	1		
	C113	0.089	−0.038	−0.038	0.042	0.252**	0.252**	0.058	−0.006	−0.006	−0.006	0.089	0.912**	1	0.851**	1	
	C416	0.010	−0.088	−0.088	−0.044	0.188**	0.188**	0.003	0.030	−0.058	0.030	−0.022	0.894**	0.931**	0.851**	0.931**	1

the CAMS C43 and C1023. Typically, O_3 is strongly correlated amongst all the CAMS sites thereby suggesting that at the intra-urban level ground-level ozone pollutant concentrations do not vary considerably. According to the results, relationship between the pollutants in Houston CAMS sites vary. Correlations between $PM_{2.5}$ and NO_2 in CAMS sites C55, C113, C416 were positive, indicating the pollutant variable concentrations fluctuate at the same rate temporally. In the Rio Grande Valley region, $PM_{2.5}$ is negatively correlated with O_3 ($r = -0.123$, $p < 0.05$ level) suggesting that both these pollutants have different emission sources. In the Houston area, the correlation coefficients between NO_2 and CO exhibit strong and statistically significant relationships in the positive direction across all the CAMS sites ($0.451 < r < 0.695$, $p < 0.01$ level). This suggests that both these pollutants have a common emission source *i.e.*, traffic emissions in this region, and they vary temporally in tandem with each other.

Correlations coefficients as shown in this research work demonstrate their overall effectiveness at understanding the temporal relationship between the various pollutants at the TCEQ CAMS sites. Furthermore, the various site locations allow the analyses of spatial heterogeneity for intra urban areas. Different meteorological and pollutant concentrations vary in an urban airshed.

4. Conclusions and Recommendations

This research work addresses the issue of urban air pollution in two regions of Texas state (Houston area and the Rio Grande Valley region) in the United States of America. The Houston area exhibits a varying pollutant concentration gradient for NO_2, SO_2, and CO across the various CAMS sites. O_3 concentration patterns across these same sites are typically similar suggesting that at the intra-urban levels this pollutant does not vary considerably. In contrast, the pollutant patterns at the Rio Grande Valley sites are typically similar. In this study, the difference between intra and inter-city is demonstrated as the pollutants in the intra-area to be greater than the inter-area. This research work adds to the existing body of literature in that spatial and temporal heterogeneity of the various pollutants provide a snapshot of the exposure burden of the local populations. Findings from such studies are assessed to model the air pollution burden to human health from day-to-day exposure to concentrations.

Further research with inter and intra-urban air pollutants for these chosen regions (Houston and the RGV) will need to be undertaken to surmise air pollution in urban settings. Future recommendations for similar studies, are to expand the study area throughout western and eastern Texas. With an extended study area, there will be an increase in availability of TCEQ CAMS sites. The results of pollution levels in additional sites throughout the state will further accentuate relationships and trends while providing a better understanding of urban air pollution.

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Conflicts of Interest

The authors declare no conflict of interest in this research work.

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