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Monitoring and Data Analysis of Indoor Air Quality to Improve Ventilation

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Abstract

This study conducts a thorough analysis of indoor air quality in Al-Baha Region, Saudi Arabia, utilizing data collected from seventy-two diverse locations. The investigation focuses on annual average key pollutants including CO_2, PM2.5, PM10, TVOC, and HCOH. The study emphasizes the significance of understanding the spatial dynamics of indoor air quality for informed decision-making in public health and environmental management. The data analysis contributes valuable insights for researchers, policymakers, and the public, serving as a comprehensive resource for assessing and addressing potential health risks associated with indoor air pollutants. The results underscore the importance of implementing targeted strategies to improve ventilation, reduce pollutant sources, and enhance the overall quality of indoor environments in Al-Baha Region. The concentrations of CO_2 ranged from 390 to 609 parts per million, PM2.5 varied between 3 and 26 micrograms per cubic meter, PM10 showed fluctuations within the range of 3 to 32 micrograms per cubic meter, TVOC exhibited values spanning from 0.04 to 0.8 per milligrams per cubic meter, and HCOH concentrations fluctuated between 0.009 and 0.1 milligrams per cubic meter. According to the standards, these observed values fall within the acceptable range. This study forms a solid foundation for future research initiatives and policy developments aimed at fostering healthier living conditions in the region. It highlights the need for proactive measures to create sustainable and optimal indoor environments that positively impact the well-being of residents in Al-Baha Region and similar geographic contexts.

Subject Areas

Mechanical Engineering

Keywords

Air Quality, Air Pollution, Formaldehyde Concentration, TVOC

1. Introduction

Air pollution is a global crisis with limited solutions due to the presence of compounds in the atmosphere that affect the well-being of habitats or pose a threat to the ecosystem or objects [1]. Indoor air pollution is the third largest cause of air pollution worldwide after coal and photochemical smog [2]-[4]. Air pollution refers to changes in the composition of the air due to natural phenomena or human activities. The World Health Organization (WHO) reported that air pollution is a major health problem for citizens in developing countries [5] [6]. Increasing urbanization requires effective and reliable techniques for monitoring and controlling air quality [7]. The nature of the reported air has significant impacts on the environment and human health. Therefore, details of ambient emissions need to be estimated to incorporate prior knowledge in safety reporting of their environmental concentrations. Most urban areas were particularly quickly affected by air quality and energy shortage problems [8]. Air pollution continues to be a major public health problem worldwide. It has been linked to millions of deaths worldwide [9], three times more than other infectious diseases such as malaria, tuberculosis and AIDS. In general, air pollution is a complex mixture of gases and particles of different sizes [10]. It is known that particulate matter, particularly PM2.5 (diameter 2.5 micrometers or less), is responsible for the development of cardiovascular and respiratory diseases [11]. In addition, it has been found that higher exposure to PM2.5 leads to a significantly higher mortality rate [12]. As air quality deteriorates, it directly and indirectly impacts communities, economic growth and social well-being [13]. Therefore, it is important to gain a deeper and more accurate understanding of air pollution at the local level [14] [15]. Air quality analysis has become crucial to understanding the impact of air pollution on the environment and public health. As global concerns about air quality and its impacts continue to grow, comprehensive assessments of air quality data in specific regions have attracted significant attention. Over the years, the concept of smart and environmentally sustainable cities has become a hot topic [16]. The concept of smartness has become multidimensional and is not limited to the use of technology to manage urban systems. Adding the social and economic dimensions to smart cities helps researchers understand how policies can be made more citizen-centered [17] to create socially sustainable cities. Community participation in scientific research, also known as citizen science, is widely used in environmental monitoring [18]. In many recent studies, citizens have been increasingly involved in the scientific process due to several factors such as the easy availability of sensing devices and the emphasis on research for community benefit [19]. When it comes to air quality monitoring, most citizen science activities rely on participatory sensor research methods that use low-cost sensors to solve problems at the local level [20]-[22]. In recent years, several studies have conducted citizen science activities to improve people's understanding of issues such as air quality, noise, etc. The citizen weather station data obtained from the weather stations set up by people in the United Kingdom was analyzed and it was observed that instrument biases affected the data [23]. Surveys are used to understand how communities and experts think about environmental issues and sensor data [24]. Another work conducted noise monitoring and highlighted the fact that noise monitoring conducted by citizens had similar accuracy to standard noise monitoring [25]. Al-Baha region is located in the southwest of the Kingdom of Saudi Arabia, as shown in **Figure 1**. It is known for its unique natural beauty and environmental diversity, but is no exception to the challenges posed by air pollution. This paper aims to analyze indoor air quality data in the Al-Baha region of Saudi Arabia by measuring and analyzing PM2.5, PM10, CO_2, HCOH and TVOC concentrations at various seventy-two locations. Finally, the paper presents new diagrams for values and contours of these concentrations in Al-Baha region in Saudi Arabia.

Figure 1. Location of Al-Baha Region in Saudi Arabia.

2. Research Area Overview and Data

The research area overview for the analysis of indoor air quality in Al-Baha Region, Saudi Arabia is a critical investigation into a matter of significant importance. The indoor air quality in any region directly impacts the health and well-being of its residents, making this an issue of paramount concern. In the case of Al-Baha Region, a comprehensive understanding of the state of indoor air quality is not only essential for improving the living conditions of the local population but also for implementing effective policies and interventions. The data collected for this analysis serves as a valuable resource, providing insights into the various factors influencing indoor air quality, including pollutants, climate, building structures, and human activities. Moreover, this research delves into the specifics of data analysis, shedding light on the methodologies and techniques employed to process and interpret the collected information. The findings of this study will not only contribute to our knowledge of indoor air quality in the region but also pave the way for informed decision-making and initiatives aimed at enhancing the overall quality of life for the residents of Al-Baha. The significance of this research is amplified by its potential to serve as a model for addressing indoor air quality concerns in similar regions, both in Saudi Arabia and around the world. This research is particularly relevant in the context of Saudi Arabia, given the varying climatic conditions and the rapid urbanization witnessed in recent years. Al-Baha Region, characterized by its unique topography and climate, presents a distinctive case study, offering valuable insights into the challenges and opportunities for improving indoor air quality in arid, mountainous environments. Data collection for this research involved gathering information from seventy-two distinct locations situated across Al-Baha Region in Saudi Arabia, as outlined in **Table 1** and visually represented in **Figure 2**. The meticulous selection of these diverse locations ensures a comprehensive representation of the region's indoor air quality landscape. The data collected from these sites encompasses a range of environmental factors, including concentrations of CO_2, PM2.5, PM10, TVOCs, and formaldehyde (HCOH).

Table 1. Latitude and longitude of different measuring locations.

No.	Latitude	Longitude	No.	Latitude	Longitude
1	20.061	41.361	37	19.745	41.446
2	20.011	41.462	38	19.783	41.442
3	20.021	41.431	39	19.81	41.442
4	20.022	41.432	40	19.573	41.295
5	20.02	41.423	41	19.554	41.175
6	20.022	41.414	42	19.551	41.203
7	20.012	41.459	43	19.703	41.391
8	20.011	41.464	44	19.802	41.359
9	20.045	41.499	45	19.731	41.377
10	20.025	41.475	46	19.802	41.431
11	20.012	41.464	47	20.076	41.448
12	19.995	41.459	48	20.026	41.449
13	20.061	41.442	49	20.066	41.346
14	20.022	41.452	50	20.052	41.351
15	20.014	41.452	51	20.066	41.347
16	20.023	41.434	52	19.843	41.753
17	20.007	41.452	53	19.999	41.466
18	19.997	41.528	54	20.069	41.346
19	20.018	41.454	55	20.067	41.345
20	20.063	41.462	56	20.17	41.283
21	20.071	41.455	57	20.159	41.283
22	20.064	41.459	58	20.172	41.281
23	20.069	41.455	59	20.142	41.292

Continued

24	20.068	41.465	60	20.174	41.282
25	20	41	61	20.158	41.292
26	20.053	41.503	62	20.192	41.277
27	20.057	41.505	63	20.171	41.273
28	20.044	41.489	64	20.191	41.288
29	20.036	41.486	65	20.162	41.277
30	19.999	41.453	66	20.456	41.436
31	20.011	41.449	67	20.478	41.625
32	20.02	41.433	68	20.492	41.832
33	20.053	41.502	69	20.421	41.635
34	20.039	41.502	70	19.2	40.8
35	19.707	41.388	71	20.8	42.2
36	19.704	41.383	72	19.745	41.446

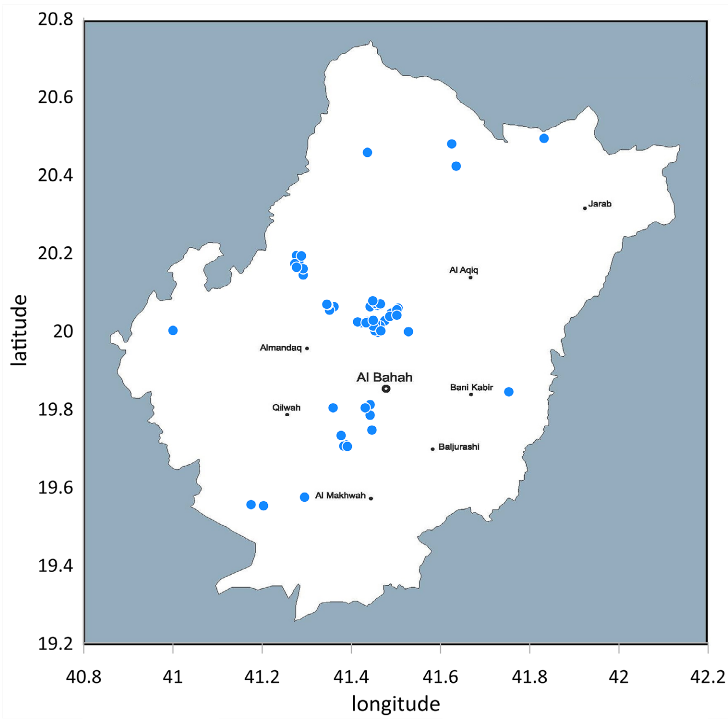

Figure 2. Different locations of measurement in Al-Baha Region.

The strategic distribution of measuring points facilitates a thorough examination of the spatial variability of indoor air pollutants, providing valuable insights into potential sources and contributing factors. This extensive dataset serves as the foundation for the subsequent data analysis, enabling a detailed exploration of indoor air quality conditions and informing targeted strategies for improvement within the Al-Baha Region. Tables 2-6 present a comprehensive breakdown of the indoor air quality parameters, including CO_2, PM2.5, PM10, TVOC, and HCOH concentrations, along with their respective indications [26]-[30].

Table 2. Concentration of CO_2 and its indications in indoor air quality.

CO_2 (ppm)	Air Quality
Less than 600	Excellent
600 - 800	Good
800 - 1000	Fair
1000 - 1500	Mediocre Contaminated indoor air Ventilation recommended
More than 1500	Bad Heavy contaminated indoor air Ventilation required

Table 3. Concentration of PM2.5 and its indications in indoor air quality.

PM2.5 ($\mu g/m^3$)	Air Quality
0 - 12	Good
12 - 35	Moderate
35 - 55	Unhealthy for sensitive group
55 - 150	Unhealthy
150 - 250	Very unhealthy
More than 250	Hazardous

Table 4. Concentration of PM10 and its indications in indoor air quality.

PM10 ($\mu g/m^3$)	Air Quality
0 - 55	Good
55 - 155	Moderate
155 - 255	Unhealthy for sensitive group
255 - 355	Unhealthy
355 - 425	Very unhealthy
More than 425	Hazardous

Table 5. Concentration of TVOC and its indications in indoor air quality.

TVOC (mg/m^3)	Air Quality
Less than 0.3	Excellent
0.3 - 1	Good
1 - 3	Medium
3 - 10	Poor
More than 10	Bad

Table 6. Concentration of HCOH and its indications in indoor air quality.

HCOH (mg/m^3)	Air Quality
Less than 0.3	Good
0.3 - 0.5	Medium
More than o.5	Bad

Figure 3 presents the DM73B TUYA WIFI multifunctional gas detector, a sophisticated device designed to monitor and assess various environmental parameters, offering a comprehensive 7-in-1 solution for indoor air quality. The inclusion of sensors for formaldehyde (HCHO), total volatile organic compounds (TVOC), particulate matter (PM2.5/PM10), carbon dioxide (CO_2), temperature, and humidity is noteworthy. The LCD display provides a user-friendly interface for real-time data visualization, allowing users to easily track and interpret air quality metrics. This multifunctional gas detector serves as a valuable tool for both professionals and individuals concerned about the quality of the air they breathe indoors. The inclusion of WIFI connectivity enhances the device's accessibility, enabling users to remotely monitor air quality and receive timely alerts. This feature is particularly beneficial for proactive measures and ensuring a prompt response to any fluctuations in the monitored parameters. The device's ability to measure a diverse range of pollutants and environmental factors reflects a commitment to providing a holistic understanding of indoor air quality. This information is crucial for creating healthier indoor environments, especially considering the potential impact of pollutants on human health.

Figure 3. DM73B TUYA WIFI multifunctional gas detector.

3. Results and Discussion

In this section, the outcomes of investigation into indoor air quality in Al-Baha Region, Saudi Arabia. Through a comprehensive examination of key pollutants CO_2, PM2.5, PM10, TVOC, and HCOH across seventy-two diverse locations are discussed. Figure 4 provides a clear and concise representation of the interplay between temperature and humidity across various locations in Al-Baha Region depending on the present measurement. The direct-fit lines for both temperatures, ranging from 17 to 32 degrees Celsius, and humidity, fluctuating between

51% and 68%, highlight a compelling relationship. The positive correlation between temperature and humidity is apparent from the upward trend of both fitted lines. As temperatures rise, there is a corresponding increase in humidity levels, and vice versa. This direct-fit underscores the dynamic balance between these two critical climatic factors in Al-Baha Region. This figure not only captures the quantitative aspects of temperature and humidity changes but also provides a visual tool *for easily identifying trends and potential outliers in different locations. Further investigations into the specific mechanisms influencing this relationship would contribute to a more nuanced understanding of the local climate dynamics in Al-Baha Region.

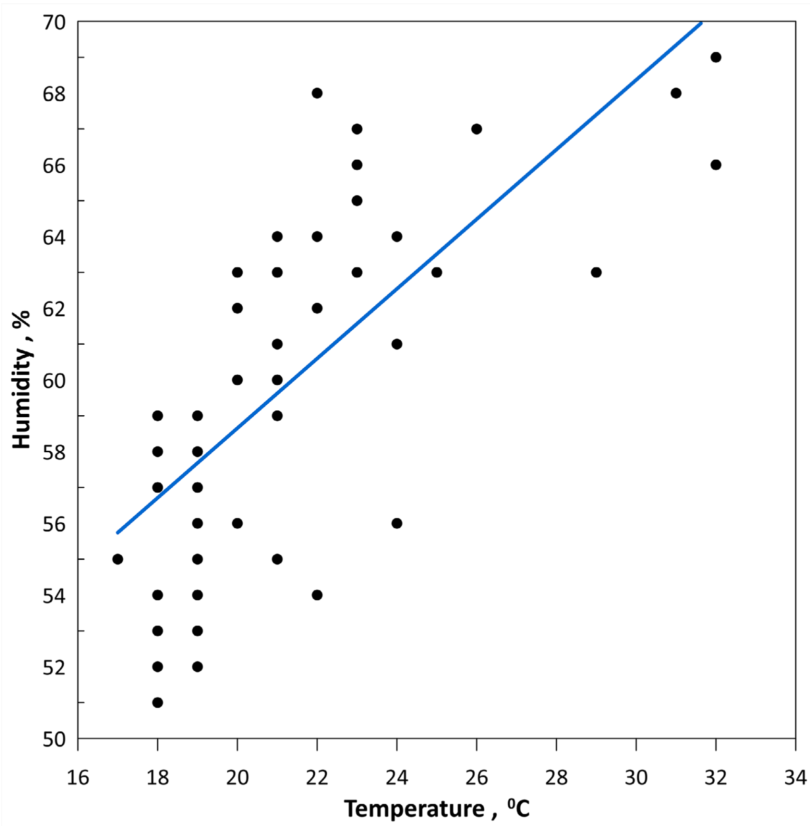

Figure 4. Relation between temperature and humidity across various locations in Al-Baha Region for present work.

Figure 5 provides a valuable snapshot of indoor CO_2 concentrations across 72 locations within the Al-Baha region through present work measurement. The depicted range from 390 to 609 parts per million (ppm) underscores the diversity in indoor air quality, highlighting variations that may be influenced by factors such as building design, ventilation, and human activities. The spatial distribution of indoor CO_2 concentrations is a key insight for understanding the quality of the air in various settings, including homes, offices, and public spaces. The range observed suggests a spectrum of indoor environments, with some locations maintaining lower CO_2 levels indicative of effective ventilation, while others experience higher concentrations possibly due to limited airflow or increased occupancy. The seventy-two locations coverage ensures a comprehensive assessment, capturing the nuances of indoor air quality across different types of buildings and land uses. This information is crucial for identifying areas where indoor air quality may need improvement and implementing targeted interventions to enhance ventilation and reduce CO_2 levels. The figure serves as a valuable tool for both researchers and policymakers, providing a visual representation of the indoor CO_2 landscape in the Al-Baha region. It prompts considerations for sustainable building practices, ventilation strategies, and public health interventions aimed at optimizing indoor air quality. In conclusion, the figure effectively communicates the variability in indoor CO_2 concentrations, offering insights into the factors influencing air quality within diverse indoor environments. This understanding is instrumental for promoting healthier living and working conditions in Al-Baha region and can inform strategies for sustainable building design and indoor air quality management.

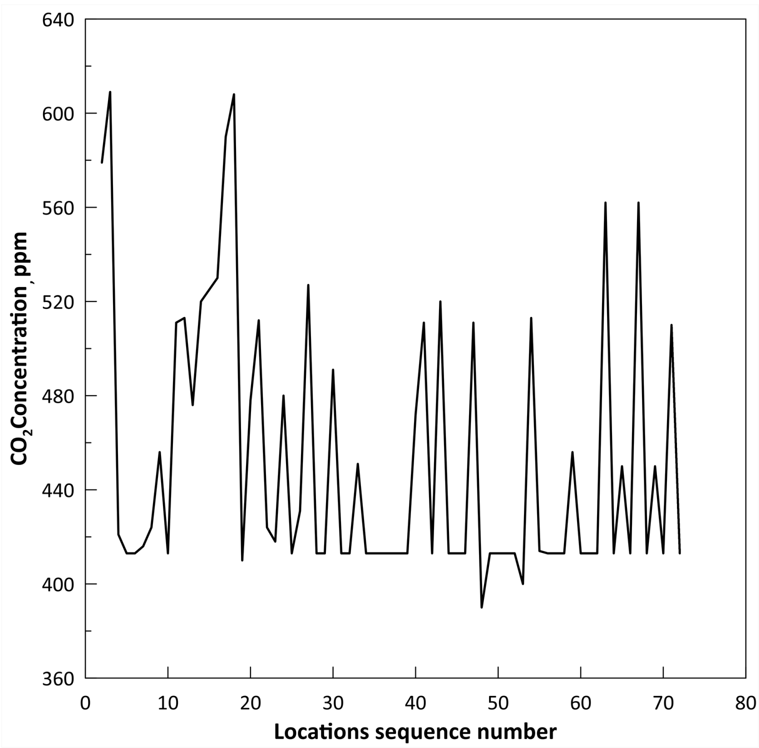

Figure 5. CO_2 concentration in different locations for present work locations.

The contours of indoor CO_2 concentrations in Al-Baha region are presented in **Figure 6**, offering a dynamic and insightful portrayal of the spatial distribution. The use of contours adds a layer of detail, allowing for a quick and comprehensive understanding of CO_2 levels in various indoor environments.

The diverse range of contours captures the nuanced patterns of CO_2 concentrations, highlighting areas with both lower and higher levels. This information is instrumental in identifying potential areas for improvement in indoor air quality and aids in the formulation of targeted strategies for ventilation and environmental management. The use of contours not only enhances visual clarity but also facilitates the identification of hotspots or areas requiring specific attention for mitigating elevated CO_2 levels. This figure significantly contributes to our understanding of indoor air quality dynamics in Al-Baha region, utilizing contours to convey a spatial perspective on CO_2 concentrations. It serves as an essential tool for informed decision-making and interventions aimed at fostering healthier indoor environments.

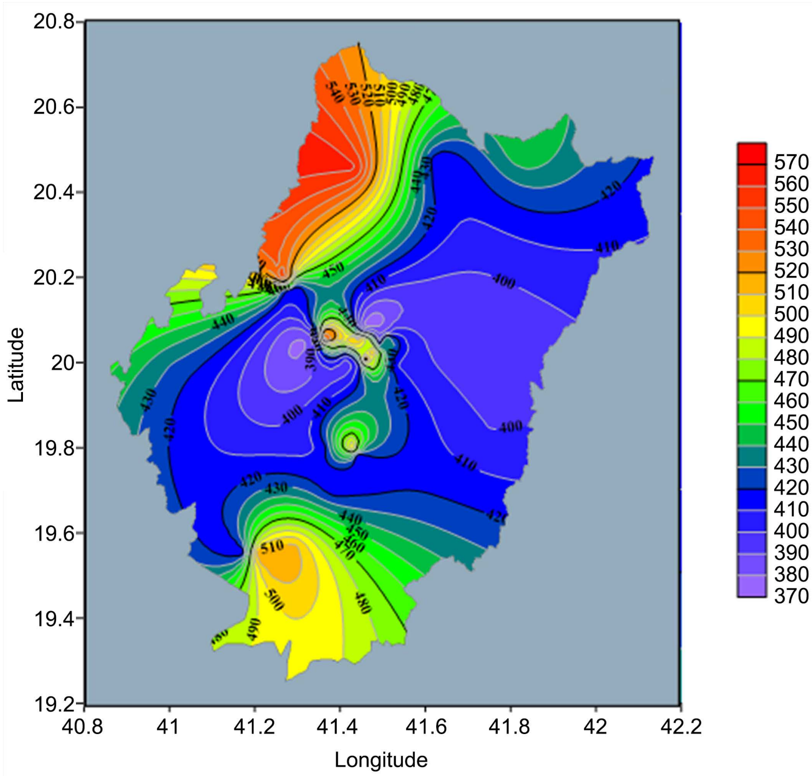

Figure 6. CO_2 contours in different locations for present work locations.

A comprehensive overview of indoor PM2.5 concentrations across seventy-two locations in Al-Baha region is provided in **Figure 7**, revealing a range from 3 to 26 micrograms per cubic meter (μg/m^3). This detailed representation offers valuable insights into the spatial distribution of fine particulate matter, a critical component of indoor air quality. The depicted range underscores the diversity in indoor environments, with some locations exhibiting lower PM2.5 concentrations indicative of effective air filtration and ventilation, while others experience higher levels possibly due to various indoor sources such as cooking, smoking, or insufficient ventilation. Indoor PM2.5 concentrations are of significant concern due to their association with respiratory and cardiovascular health issues. This figure provides insight into areas where indoor air quality needs improvement and guides efforts to improve ventilation, air filtration, and overall indoor environmental quality.

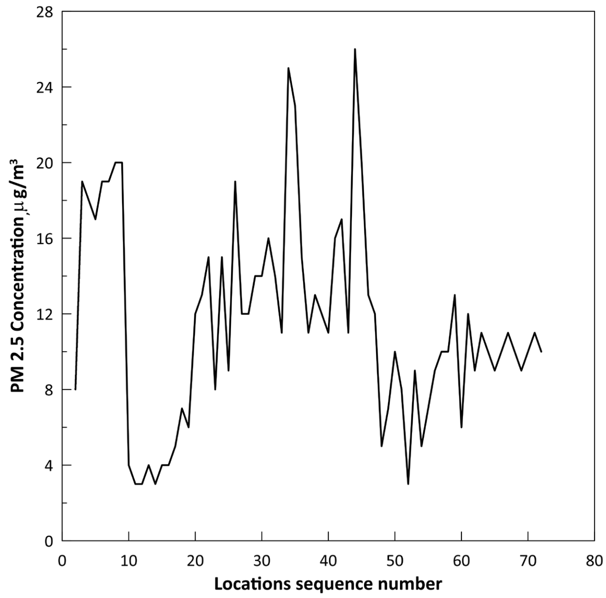

Figure 7. PM2.5 concentration in different locations for present work locations.

Figure 8 presents a compelling visualization of indoor PM2.5 concentration contours in Al-Baha region, offering a nuanced and spatially informed perspective on air quality. The use of contours provides a clear representation of PM2.5 distribution, revealing areas with varying levels of fine particulate matter within indoor environments. The contours highlight the diversity in PM2.5 concentrations across different locations, allowing for quick identification of areas with both lower and higher levels. This information is pivotal for understanding indoor air quality dynamics and tailoring strategies to mitigate particulate matter exposure. This figure significantly contributes to our understanding of indoor PM2.5 distribution, utilizing contours to provide a spatially rich depiction.

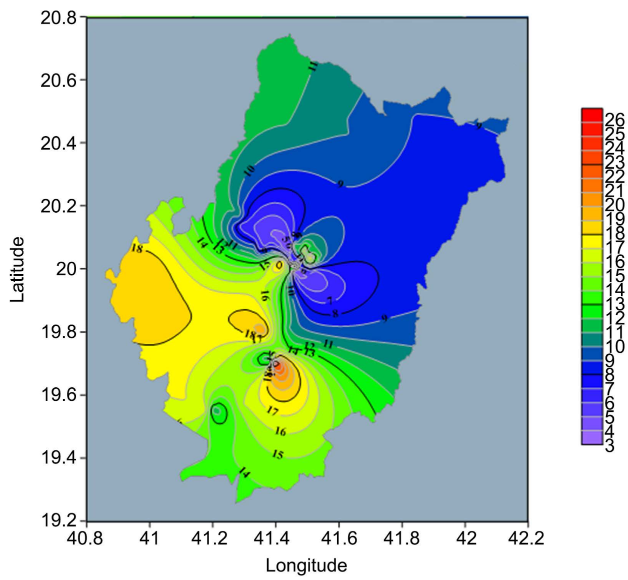

Figure 8. PM2.5 contours in different locations for present work locations.

In **Figure 9**, a comprehensive depiction of indoor PM10 concentrations across present work locations in Al-Baha region is presented, showcasing a concentration range from 3 to 32 micrograms per cubic meter (μg/m³). This detailed representation provides valuable insight into the spatial distribution of inhalable particulate matter, contributing to a nuanced understanding of indoor air quality. The observed range underscores the diversity of indoor environments, with some locations exhibiting lower PM10 concentrations indicative of effective air quality management, while others experience higher levels potentially influenced by various indoor sources such as dust, pollutants from combustion, or inadequate ventilation.

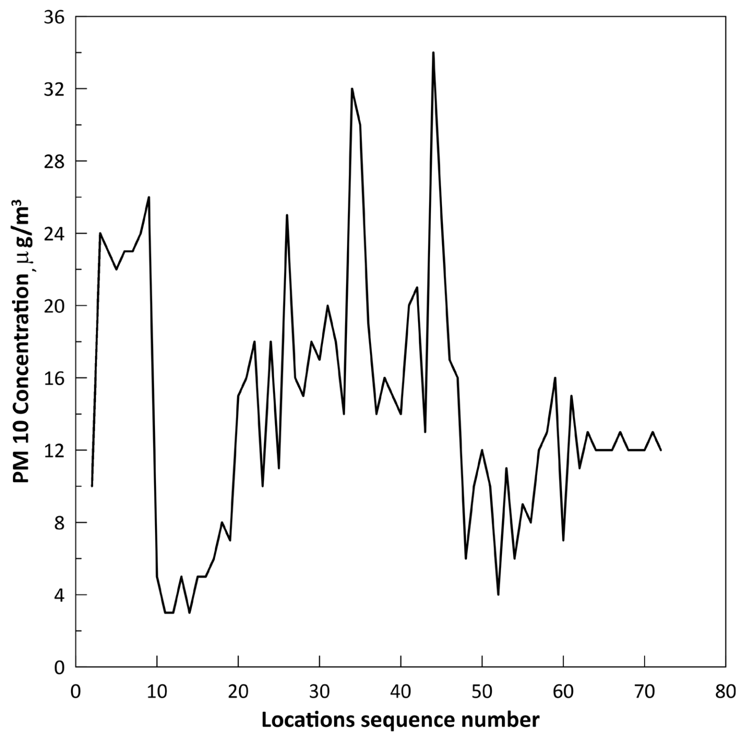

Figure 9. PM10 concentration in different locations for present work locations.

Figure 10 elegantly illustrates indoor PM10 concentration contours in Al-Baha region, providing a visually compelling representation of spatial variations in particulate matter. The use of contours enhances the clarity of the figure, allowing for a quick and insightful interpretation of PM10 distribution within indoor environments.

Figure 11 offers a comprehensive view of indoor Total Volatile Organic Compound (TVOC) concentrations across current locations in Al-Baha region, showcasing a concentration range from 0.04 to 0.8 milligrams per cubic meter (mg/m³). This detailed representation provides valuable insights into the spatial distribution of TVOCs, contributing to a nuanced understanding of indoor air quality. According to **Table 5**, these values are in an acceptable range of good air quality.

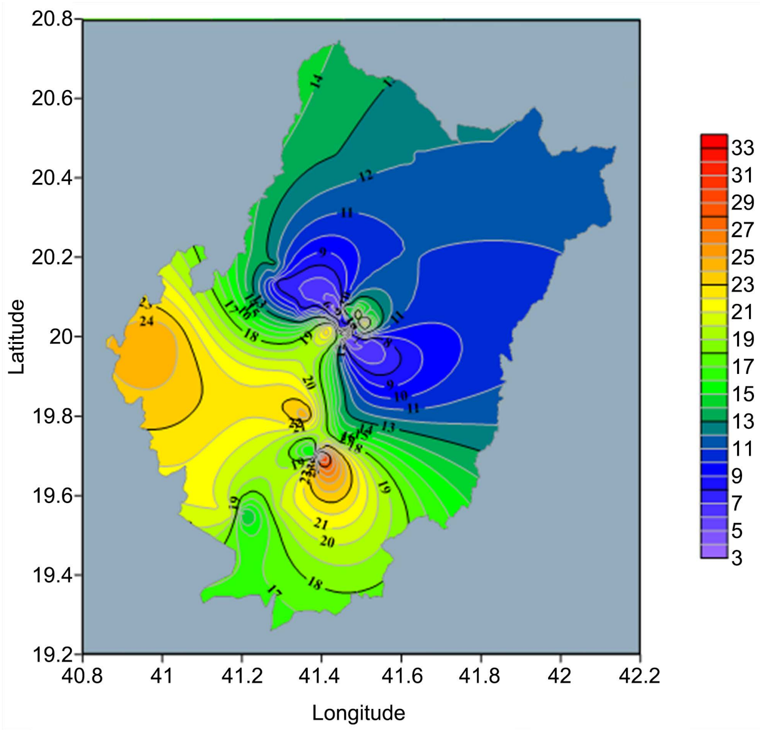

Figure 10. PM10 contours in different locations for present work locations.

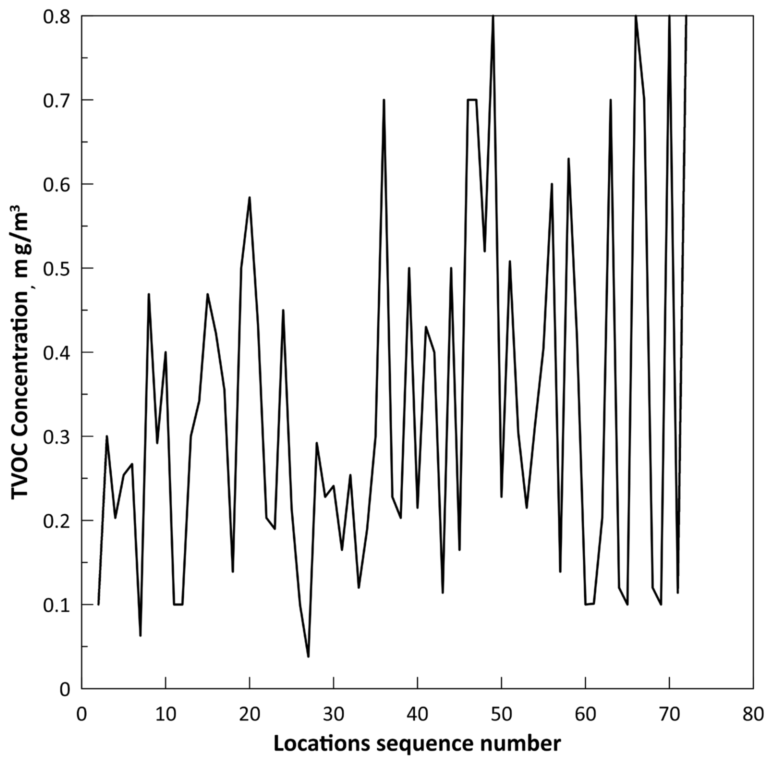

Figure 11. TVOC concentration in different locations for present work locations.

A captivating visualization of indoor Total Volatile Organic Compound (TVOC) concentration contours in Al-Baha region is shown in Figure 12, offering a spatially nuanced perspective on indoor air quality. The contours provide a clear and insightful portrayal of the distribution of TVOCs, revealing areas with varying levels within indoor environments. The use of contours adds depth to the figure, facilitating the identification of regions with both lower and higher TVOC concentrations. This information is crucial for understanding indoor air quality dynamics and tailoring strategies to mitigate the presence of volatile organic compounds.

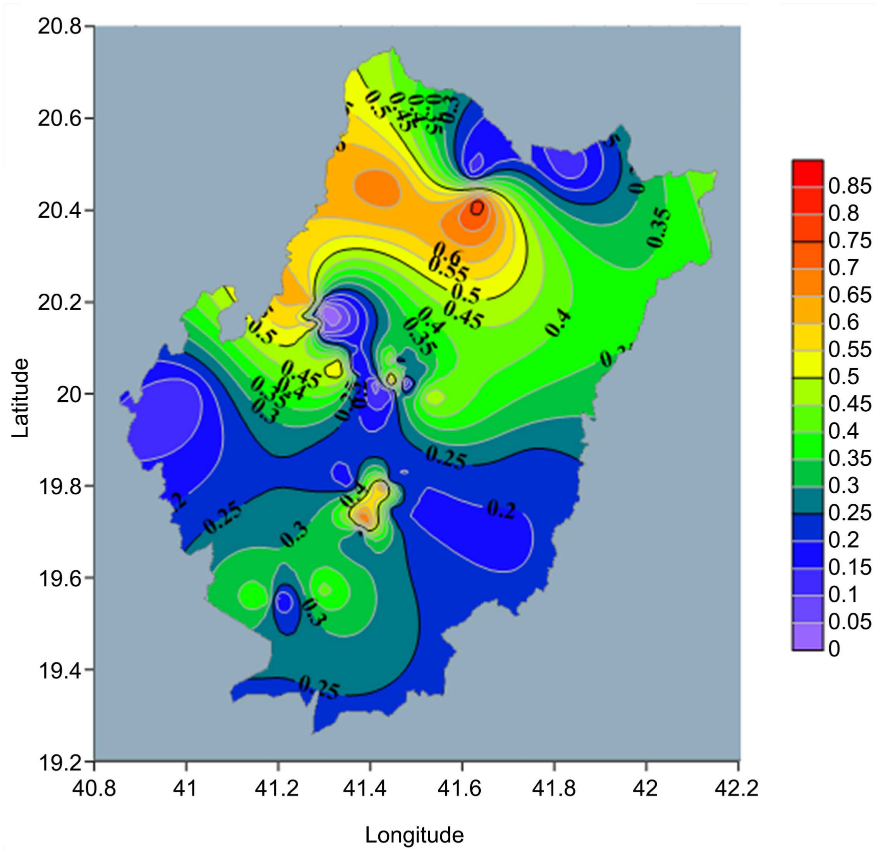

Figure 12. TVOC contours in different locations for present work locations.

Figure 13 provides a comprehensive overview of indoor formaldehyde (HCOH) concentrations across 72 locations in Al-Baha region, showcasing a concentration range from 0.009 to 0.1 milligrams per cubic meter (mg/m^3). This detailed representation offers valuable insights into the spatial distribution of formaldehyde, contributing to a nuanced understanding of indoor air quality promoting healthier indoor environments and safeguarding the well-being of individuals in diverse indoor settings.

Figure 14 presents a visually compelling representation of indoor formaldehyde (HCOH) concentration contours in Al-Baha region, providing a nuanced insight into spatial variations of this volatile organic compound within indoor environments. The contours enhance the clarity of the figure, allowing for a quick and informed interpretation of formaldehyde distribution.

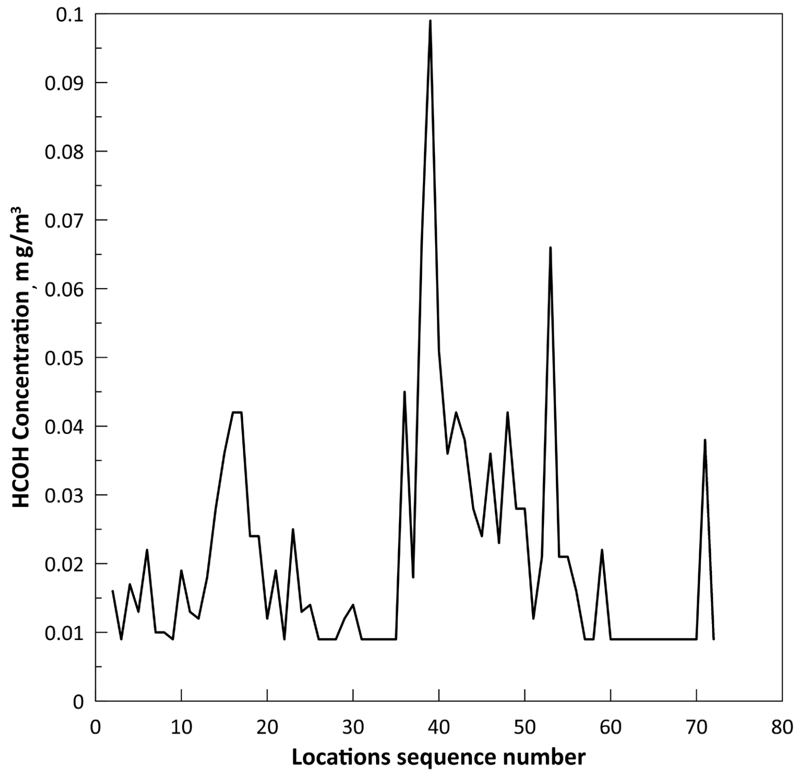

Figure 13. HCOH concentration in different locations for present work locations.

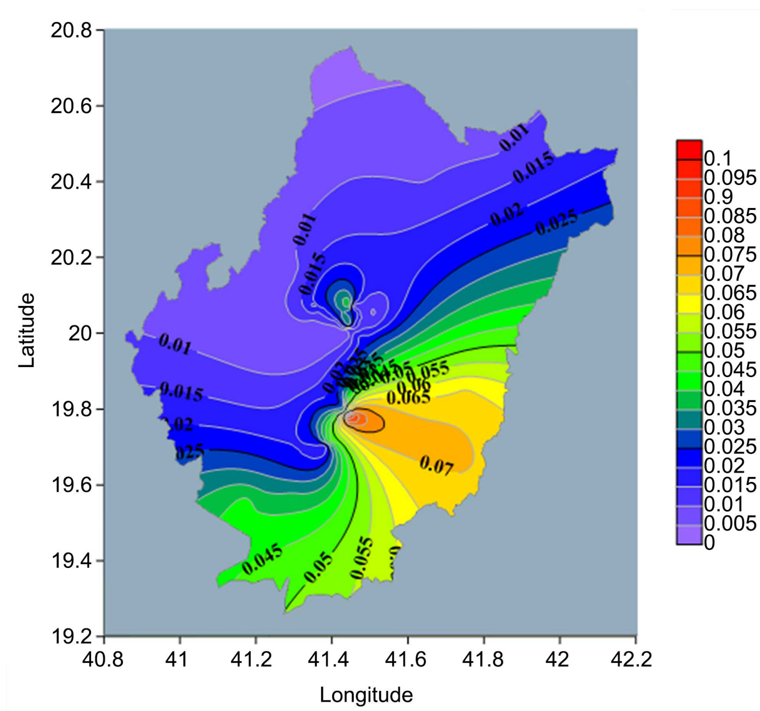

Figure 14. HCOH contours in different locations for present work locations.

4. Conclusion

The concentrations of CO_2 ranged from 390 to 609 parts per million, PM2.5

varied between 3 and 26 micrograms per cubic meter, PM10 showed fluctuations within the range of 3 to 32 micrograms per cubic meter, TVOC exhibited values spanning from 0.04 to 0.8 per milligrams per cubic meter, and HCOH concentrations fluctuated between 0.009 and 0.1 milligrams per cubic meter. According to the standards outlined in **Tables 2-6**, these observed values fall within the acceptable range. The compliance of these measurements with established standards underscores the adherence to recognized benchmarks for indoor air quality, providing reassurance regarding the environmental conditions in the studied locations in conclusion, the data analysis of indoor air quality in Al-Baha Region, Saudi Arabia, has provided valuable insights into the spatial dynamics of various pollutants, including CO_2, PM2.5, PM10, TVOCs, and formaldehyde. The comprehensive examination of seventy-two locations has allowed for a thorough assessment, revealing a diverse range of indoor air quality conditions. The findings highlight the significance of such studies in understanding the factors influencing indoor air quality, with the data serving as a crucial resource for researchers, policymakers, and the public. The use of contours in visual representations has enhanced our ability to grasp the spatial patterns of pollutant concentrations, enabling informed decision-making for interventions aimed at creating healthier indoor environments. This analysis contributes to the ongoing efforts to promote sustainable living conditions and underscores the importance of proactive measures in addressing potential health risks associated with indoor air pollutants. The data obtained fosters a deeper understanding of the nuances in air quality within Al-Baha Region, paving the way for targeted strategies to enhance ventilation, reduce pollutant sources, and ultimately improve the overall well-being of residents. As we move forward, this comprehensive analysis forms a solid foundation for future research endeavors and policy initiatives aimed at fostering a healthier and more sustainable indoor living environment in the Al-Baha Region and beyond.

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Conflicts of Interest

The authors declare no conflicts of interest.

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