Assessment of Air Quality of Karachi on Real-Time Rainfall Data through GIS Analysis

Anila Kausar[1*], Owais Iqbal Khan[2], Fizza Ejaz[1], Altaf Hussain Lahori[3], Romana Ambreen[4], Mehdi Hassan[1]

[1] Department of Geography, University of Karachi
[2] Institute of Environmental Sciences, University of Karachi
[3] Department of Environmental Sciences, Sindh Madressatul Islam University, Karachi 74000, Pakistan
[4] Department of Geography University of Balochistan, Quetta

* Corresponding author e-mail: anilak@uok.edu.pk (A.K)

Received: 9 July 2024 / Accepted: 18 September 2024

Abstract. Karachi is a metropolitan city lying on the coastline of the Arabian Sea facing the effects of climate change. Weather patterns are changing and in a transition stage as the world is facing weather variability issues, due to climate change. The existing study was performed based on the real-time rainfall in Karachi held on January 29, 30, February 2, 3, and 4th, 2024. January and February are the month of winter in Pakistan and, in the winter, such continuous rainfall spells have never been witnessed by Karachiites for a long time specifically in February rainfall has never been witnessed on such a large scale. Due to such a long dry and cold season, Karachiites used to face health problems related to Air Quality in winter. Such heavy rain changes the environmental conditions in the winter consequently people feel fresh due to clean air. Pollutants i.e., AQI, PM2.5, and SO^2 have been monitored on selected days of 36 locations in Karachi. Interpolation techniques have been used in mapping. Results revealed that before the rain, in the air, all observed pollutants existed in large quantities i.e., AQI, PM2.5, and, SO_2 ranged from 158.1-310.5, 70.1-260.5 µg/m³, and 113.5-246.9 ppbV respectively declines dramatically i.e., 69.05- 111.9, 48.3-136.8 5 µg/m³, and 50.04-99.9 ppbV after the rain. Results are analyzed through GIS analysis and further tested through Anova statistical analysis. Tree plantation and enhancing green cover can somehow reduce the contamination level of air. Therefore, instead of waiting for rain which does not usually happen in winter. Karachiites should participate in tree plantation activities/green infrastructure to clean the environment and reduce of health issues of Karachiites.

Keywords: rainfall, pollutants, Sulphur Dioxide, PM2.5, Air Quality Index, monitoring, mapping.

1. Introduction

Karachi is a metropolitan city lying on the coastline of the Arabian Sea facing the effects of climate change (Nazeer et al., 2020; Kausar et al., 2024). Weather patterns are changing and in a transition stage (Asante et al., 2017). Above the industrial baseline, the year 2023 is marked as the highest-ever temperature in the world, with a margin of uncertainty of ± 0.12 °C, and global near-surface temperatures rise at 1.45°C, therefore, it is confirmed that 2023 is the warmest year by the World Metrological Organization (Reiners et al., 2021). In daily life, rain plays an important role in terms of its rate of occurrence, where high leads to floods and where low it leads to drought conditions, decades earlier, it was realized rainfall (averagely) increased because of global warming (Zhang et al., 2021). Because of greenhouse gases and global warming unparalleled precipitation or torrent extremes, heat incantations and storms strengthened and augmented (Kumar et. al., 2022).

Karachi-Pakistan winters are mostly dry except for post-monsoon rain which is mostly witnessed in December i.e., the beginning of the winter season (Qureshi et al., 2023). Winters are dry and continental winds blow in Karachi (Alam et al., 2012). Due to Climate change weather and climate variability have increased globally (Thornton et al., 2014). Based on time, space, and scale variability in terms of the ranges of storms to ranges of droughts have been charted (Ault, 2020). Pollutants in the environment are always a threat to all living things (Chattopadhyay et al., 2020). Air-contained pollutants are the utmost threat (Ajmal, et al., 2016), and are vital to public health (Craig et al., 2008). The ultimate environmental peril to health is air pollution and countries can reduce health-related diseases such as “stroke”, “heart disease”, “lung cancer” etc. by reducing air pollution (Crowley et al., 2022). The Air Quality Index (AQI) in Karachi is usually unhealthy. Urban air quality has inhospitably worsened through hasty urbanization and industrialization over the aforementioned few decades (Sachdeva et al., 2023). In areas of the metropolitan, the AQI examined results have reached up to 315 at Jinnah International Airport, falling in the category of Hazardous (Kausar et al., 2023), 267 at Gulshan-e-Iqbal, falling at the category of very unhealthy (Kausar et al. 2024), 180 at Korangi (Kausar et al. 2024), falling at the category of Unhealthy (Stieb et al., 2008). An existing study has been conducted to examine the effects of rain on the atmosphere and reduce AQI in Karachi. Air Pollution can generally be reduced by Rain (Yaqub et al., 2019). The impact of PM2.5 is great on human beings as well as on economies (Fang et al., 2009). According to Wang et al. (2023), air quality will improve because of rainfall due to the dissolution of particulate matter/ pollutants. The impact of weather indicators (“wind”, “temperature”, “sunshine”, “humidity” and, “rain”) on air pollution exists (Beecher et al., 2016).

Recently, Kausar et al. (2024) stated that wind velocity plays a role in the spread of pollutants in the environment of a Megacity i.e., Karachi. Pollutants such as PM2.5 declined during lockdown when not only Karachi but the whole world was on pause meaning no transportation activities happened, during the lockdown 53.55% decline was recorded in mean PM2.5 (Ali et al., 2024). Therefore, it is clear that transportation activities are also the main cause of spreading pollutants in the atmosphere. Fossil fuel burning by power plants and industrial uses is the largest source of SO_2 in the atmosphere (Wondyfraw, 2014). Existing research seeks to examine air quality assessment in real-time rainfall data in one of the largest metropolitan cities i.e., Karachi. AQI, PM 2.5, and SO_2 have been monitored. The hypothesis of the research is rain lowers the urban air pollution level. No such study has been conducted on real-time rainfall data for Karachi to date therefore existing research is unique as no study in Pakistan has been conducted i.e., 36 locations have been selected on unusual rainfall events and their impact on the urban environment specifically Karachi's environment which is the largest urban region of the country where the industries are functioning as well as an active port city with major commercialization regions and active transportation activities which cause the region highly vulnerable air conditions. The real-time data integrated with the statistical analysis provides a response dynamics between pollution and variable and unusual weather activity. This study will give profound insight into the environmental issues and provide a solution in the form of mitigation strategies that will be useful for Karachi's environment. The main objectives of the study are 1) To collect pollutant ($PM_{2.5}$, AQI, and SO_2) Data from 36 locations (before, during, and after rain). 2) To develop a base map. 3) To collect metalogical data. 4) To develop spatial interpolation maps using ArcGIS 5) To analyze the hotspots through GIS and Statistical Analysis. O_3, PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, and VOCs; are the seven pollutants indicate urban air quality (Airqoon, 2024). The quality of urban air is indicated by the number of certain pollutants in the air, like Ozone (O_3), Particulate Matter (PM_{10}, $PM_{2.5}$), Sulfur Oxides (SO_x), Nitrogen Oxides (NO_x), Carbon monoxide (CO) and Volatile Organic Compounds (VOCs). Ozone is the gas; found in the stratosphere and the lower atmosphere on clear days when UV lights reach the ground (Department for Environment & Rural Affairs 2024). In the perpetual cover of clouds, discussion on this pollutant is invaluable, therefore O_3 is recorded in the existing study. Similarly, PM_{10} is particulate matter found in dust and smoke washed away during large-scale rain (Department of Climate Change, Energy, the Environment and Water 2024). NO2 is emitted from cars mostly, and during rain, there is less mobility on roads.   CO is also associated with vehicular activity, VOCs associated with automobiles, materials used in home decor and making, etc. All such activities have stopped or slowed down during rainy periods already. Therefore, the selection of AQI, PM2.5, and SO2 is the deliberate attempt of pollutants for the existing research.

1.1.Objectives and Tasks of Study

The wide-ranging objective of the study is to verify the air quality of Karachi has been improved by rainfall in the winter for the year 2024. The following are specific objectives

- **i.** To collect pollutant ($PM_{2.5}$, AQI, and SO_2) Data from 36 locations (before, during, and after rain).
- **ii.** To develop a base map.
- **iii.** To collect metalogical data.
- **iv.** To develop spatial interpolation maps using ArcGIS.
- **v.** To analyze the hotspots through GIS and Statistical Analysis.

2. Materials and Methods

2.1. Study area

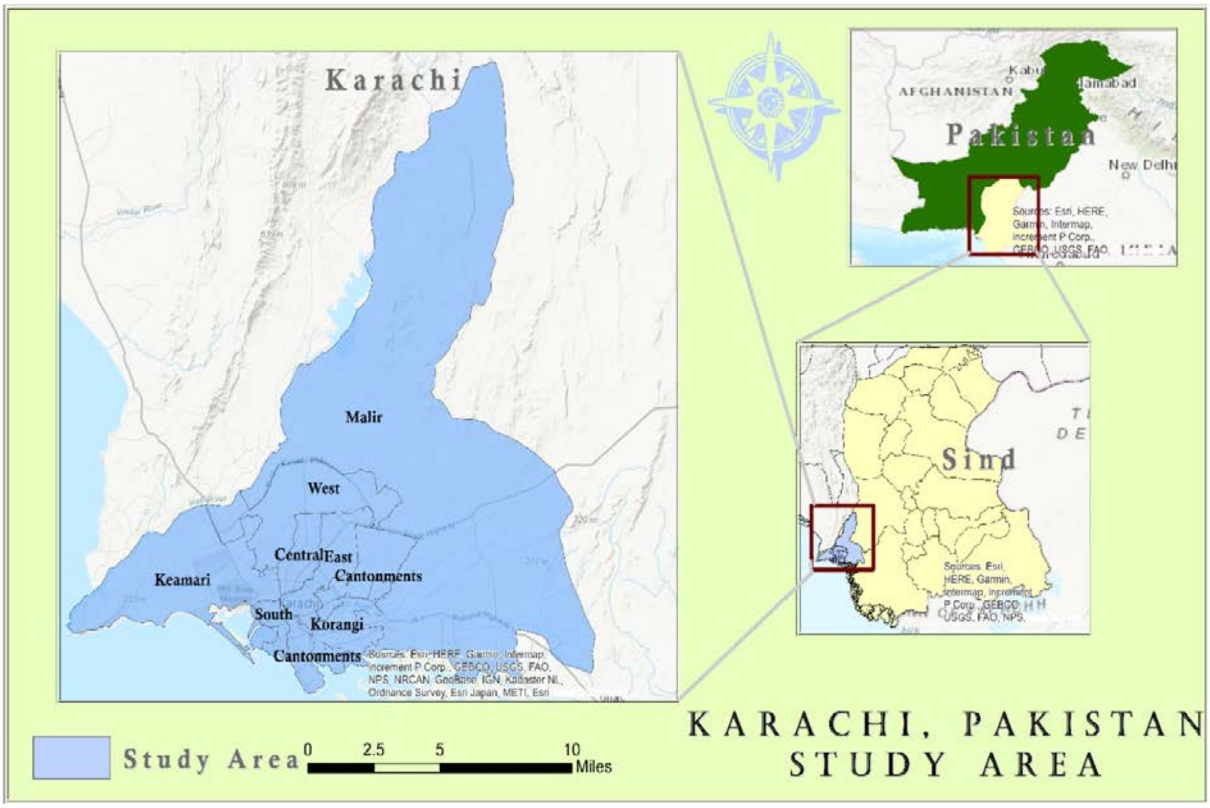
Karachi (Fig. 1) has been selected as a study Area for existing research. Karachi; 3530 km^2 (Kausar et. al., 2022) comprises 79.9% of mountain/barren land with a coastal environment (Kausar et al., 2024), where most of the population resides densely (Kausar, et al., 2024) in the metropolitan area. The existing study is based on real-time rainfall in Karachi held on January 29, 30, February 2, 3, and 4^{th}, 2024. In the winter such continuous rainfall spells have never been witnessed by Karachiites for a long time. In February rainfall has never been witnessed on such a large scale It was reported by the Karachi Met Office Karachi has received more than 50mm of rain 44 years previously it happened in 1979 (NEWS,2024).

Figure 1. Study Area

2.2. Study plan

2.2.1. Data Collection

Pollutant data have been collected from 36 locations in Karachi before and after rain for the dates of January 27 and 28 (before rain) and from January 29 to February 4th 2024 (during and



after rain). Data on the following pollutants have been collected:

i. PM 2.5 (($\mu g/m^3$)

ii. AQI

iii. SO_2 (ppbV)

(conversion calculator for ppbV https://www.rapidtables.com/convert/number/ppb-to-ppm.html).

Table 1. Average Presence of Pollutants in the Air.

Average Presence of Pollutants in the Air (before)*, (during & after)** Rain

s.no.	January 27-28	January 29-February 4	January 27-28	January 29-February 4	January 27-28	January 29-February 4
	PM 2.5 (μg/m³)	PM 2.5 (μg/m³)	AQI	AQI	SO_2 (ppbV)	SO_2 (ppbV)
1	76	69	162	76	143	56
2	172	52	222	109	227	93
3	77	76	162	69	193	50
4	70	93	158	112	138	100
5	125	92	187	74	246	54
6	150	68	200	107	148	90
7	172	52	222	111	120	99
8	155	58	205	84	175	62
9	188	51	238	85	188	63
10	127	69	188	106	124	87
11	195	89	245	89	244	66
12	221	87	271	85	172	63
13	182	48	232	75	135	55
14	207	61	257	76	156	56
15	86	63	167	106	113	87
16	231	71	281	96	147	72
17	119	58	184	112	217	100
18	175	71	225	108	161	91
19	262	133	312	106	150	87
20	229	84	279	102	247	78
21	247	93	297	85	198	63
22	147	123	198	103	211	81
23	170	60	220	102	247	78
24	193	137	243	105	152	86
25	162	87	212	105	217	85
26	221	108	271	74	180	54
27	216	95	266	112	242	100
28	122	90	185	1050	127	86
29	226	69	276	69	160	50
30	165	107	215	94	189	70
31	70	135	158	82	122	61
32	200	52	250	87	171	65
33	91	70	169	105	220	84
34	193	89	243	82	130	61
35	83	57	165	102	224	79
36	71	69	159	95	214	71

*January 27 & 28, 2024 (BR)
**January 29 to February 4, 2024 (ADR)

2.2.3. Base Map Development

Data that have been collected from different locations in Karachi need a base map to show not only the distribution of rainfall for an observed period but also the results of pollutants that were observed during a selected period. Thirty-six locations (Table 2) were marked on the base map of Karachi for data analysis. The ground control, points (GCPs) of surveyed locations are indicated in (Fig. 2).

Table 2. Study area selected for observation.

S.No.	Area	S.No.	Area
1	Korangi	19	Nazimabad
2	Fasial Base	20	Karachi Airport
3	Burns Road	21	Quaidabad
4	Malir Jinnah Square	22	Gulshan E Hadeed
5	Port Qasim	23	North Nazimabad

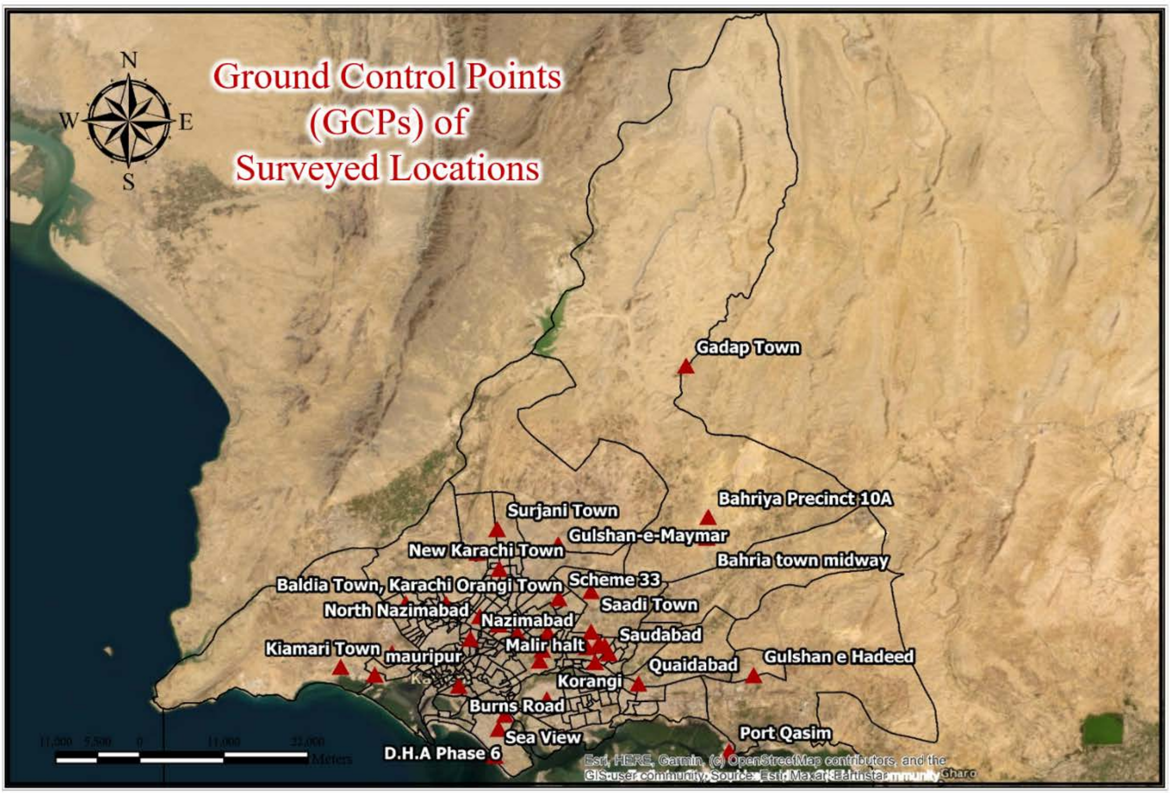


Figure 2. Ground Control Points of Surveyed Area (From Where Observation Collected)

2.3. Data Acquisition

2.3.1. Meteorological Data

Rainfall data obtained from the Pakistan Meteorological Department (PMD) is a reliable source. In this data rainfall amounts are included in millimeters for different weather stations within Karachi. The data is in a format of ArcGIS, such as a CSV file with coordinates (latitude/longitude) of stations and rainfall values correspondingly.

2.4. Research Methodology and Data Analysis

2.4.1. Spatial Interpolation Technique Analyses

The inverse Distance Weighting (IDW) method utilized the Spatial Analyst extension in ArcGIS to assign the better consequence to rainfall values. By putting the point layers to input rainfall data and as an extension use the base map of Karachi and mark the Karachi shape file through GIS (polygon). Run the IDW tool to generate the surface of the raster and the estimation of the spatial distribution of rainfall across Karachi for January 27 & 28, 2024, and January 29 to February 4, 2024. The methodological framework (Fig. 3) comprises the following steps:

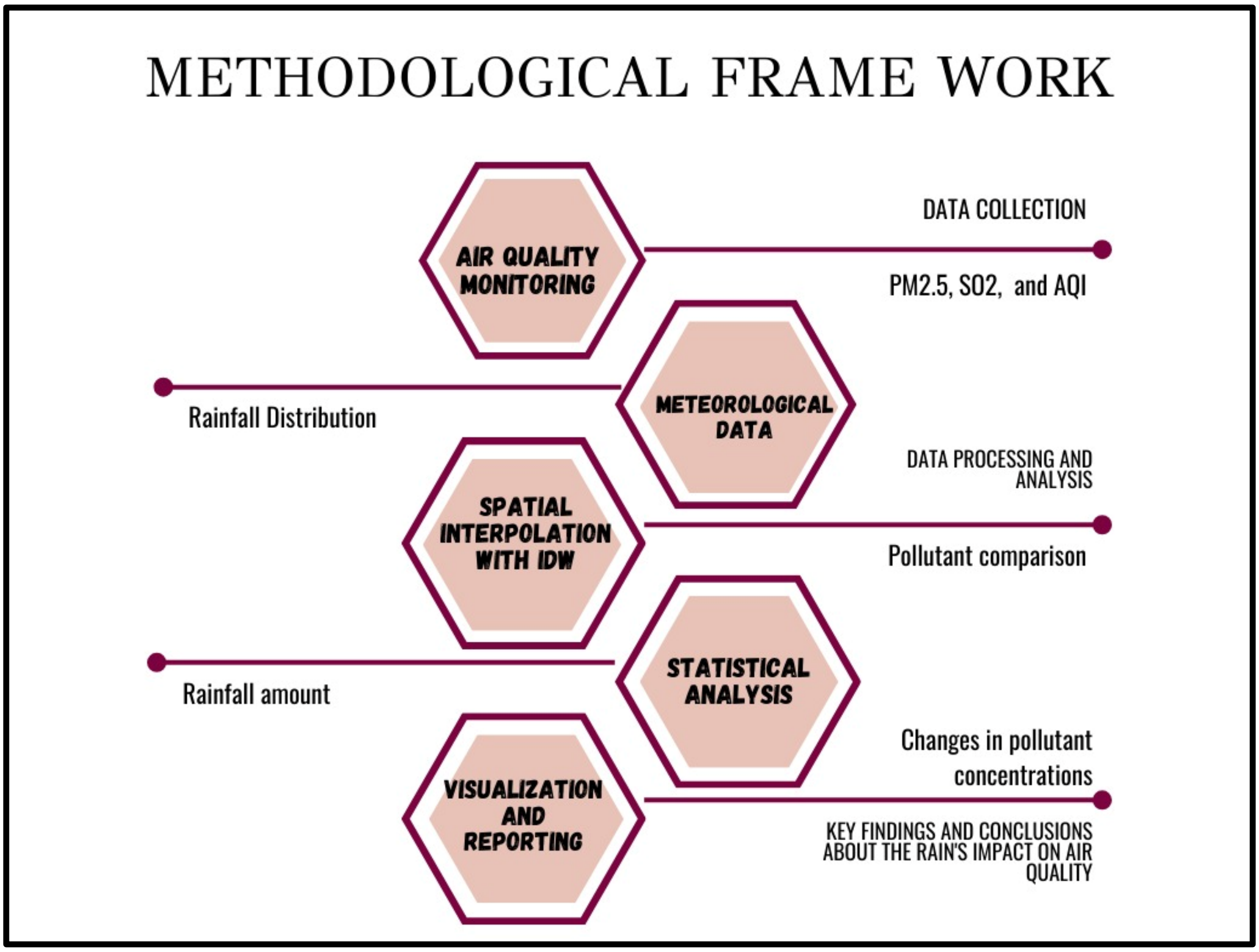


Figure 3. Methodological Framework

i. Air Quality Monitoring,
ii. Exclamation of Metrological Data,
iii. Geo-Spatial Assessment through ArcGIS,

iv. Statistical Analysis,
v. Visualization and Reporting.

2.4.2. ANOVA Test

ANOVA has been used through the Minitab statistical software for analyzing the data. The following steps have been conducted to run the ANOVA test:

i. Import Excell Worksheet into Minitab Software;
ii. In Stat tab navigate ANOVA;
iii. One-way has been employed to test the results;
iv. In One-Way Analysis Variance the Response and Factor have been selected to generate results.

3. Results and Discussion

The rainfall distribution of Karachi from January 29th to 30th 2024 has been mentioned in Figure 4. Different areas of Karachi have received different amounts of rainfall i.e., 0.207 mm to 35.3 mm. The highest rainfall has been recorded at Bahria Town and its surrounding areas. Followed by most of the Gadap-agricultural region received. The metropolitan area received rainfall ranges of 0.207-3.4mm. Model colony, Karachi Air Port, and Korangi also received rainfall ranges of 3.41-6.59 mm.

Figure 4. Rainfall Distribution of Karachi January 29-30, 2024

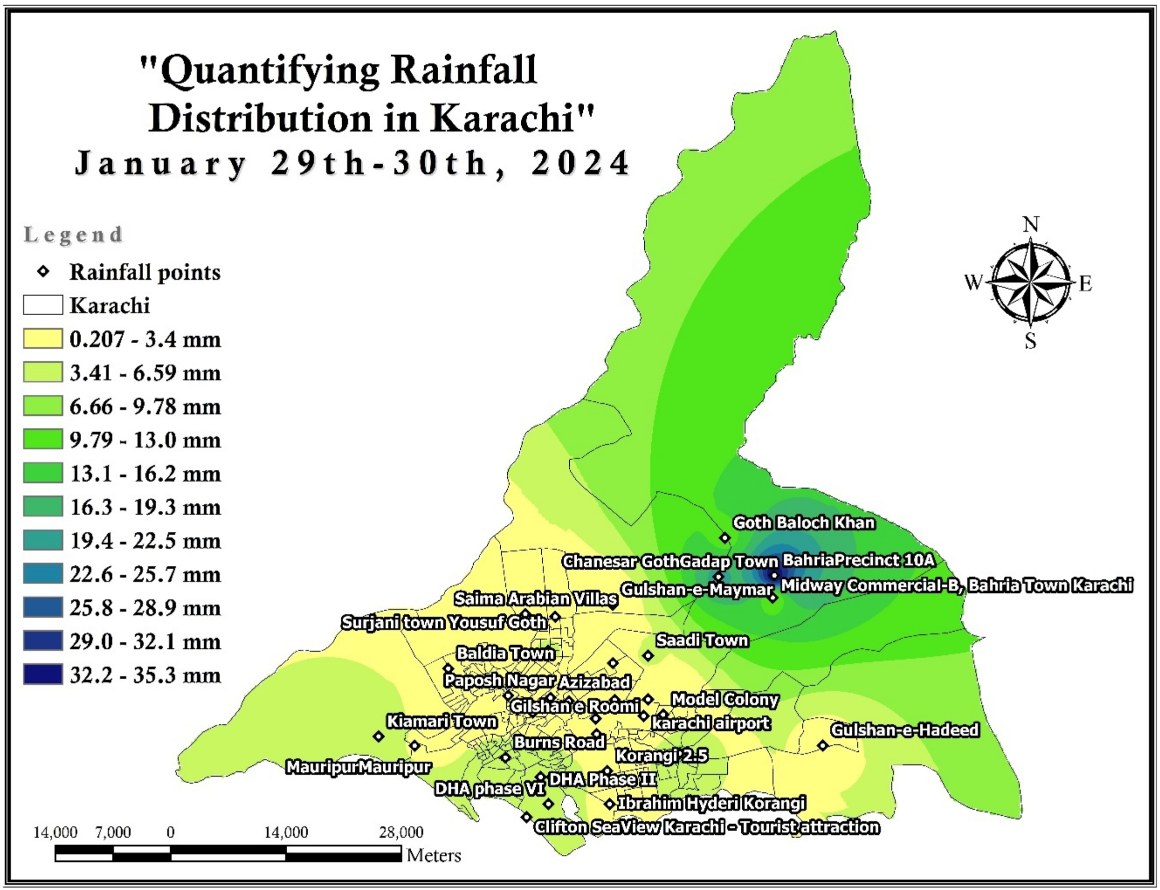


Figure 5 shows more than 90% of rainfall has been received at Bahria Town followed by Chanesar Goth at 40% (approx.), Goth Baloch Khan 35% (approx.). The remaining areas received rainfall of less than 20%. The minimum amount of rainfall has been received at Gulishtan-e-Johar. Lisboa et al. (2024) examine the performance of six methods for dimensioning rainwater pools present in Brazilian standards, as a result found that the reservoir volumes calculated will be the lowermost in locations with a higher annual rainfall rate for the exact Rio state cities case.

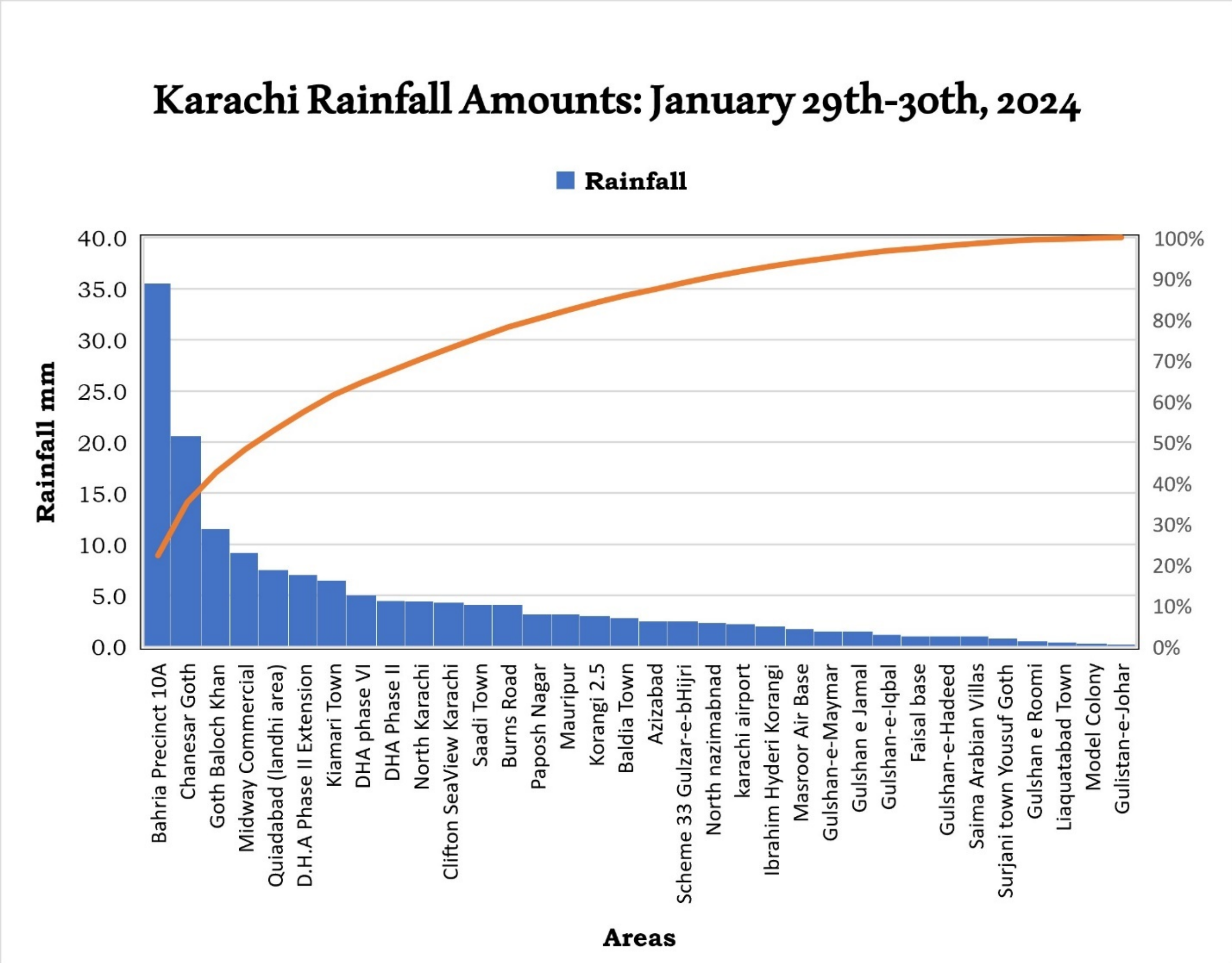


Figure 5. Karachi Rainfall data January 29-30, 2024

The rainfall distribution of Karachi from February 2nd to 4th 2024 has been mentioned in Figure 6. Again, the highest rainfall has been received at Gadap Town but the amount of rainfall is far higher than the January rainfall statistics i.e., the highest value reached up to 106mm. complete rainfall ranges from 24.8 to 106mm. such amount of rainfall was record-breaking. Most of the metropolitan received rainfall ranging from 33-65.4 mm. The coastal belt received a little higher than the continental part i.e. 73.6 to 81.6 mm. In comparison to what would be predicted by stationary time series, this rise has resulted in 12% more record-breaking rainfall events worldwide between 1981 and 2010 Lehmann et al. (2015).

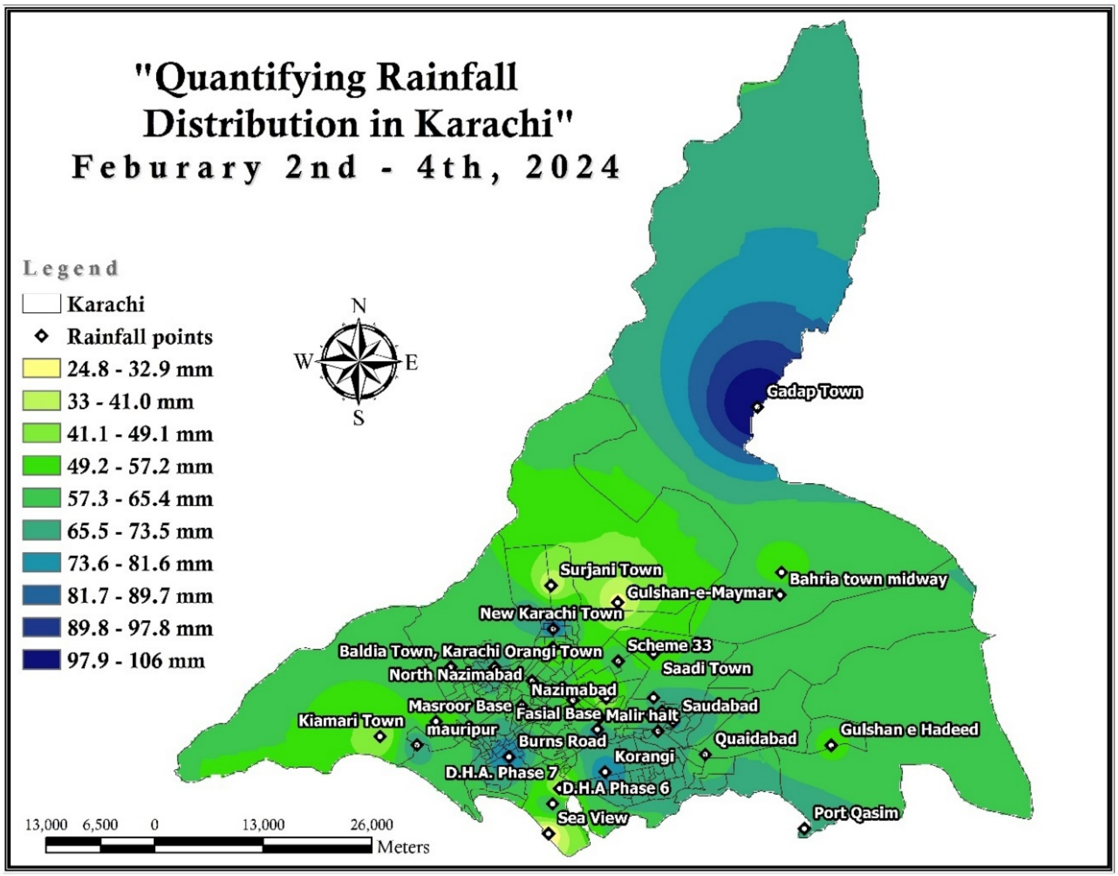


Figure 6. Rainfall Distribution February 2-4, 2024

Figure 7 shows more than 90% of rainfall has been received at Gadap Town followed by New-Karachi, Burns Road, Korangi, etc. Gadap is an open land area containing mountainous belts, agricultural lands, and a wilderness environment. On the Northwestern side of Behria town mountainous belt exists. Figure c represents rain belts with the highest fall in Gadap town it reflects highest rain has been received on the windward sides of mountains due to orographically uplifting.

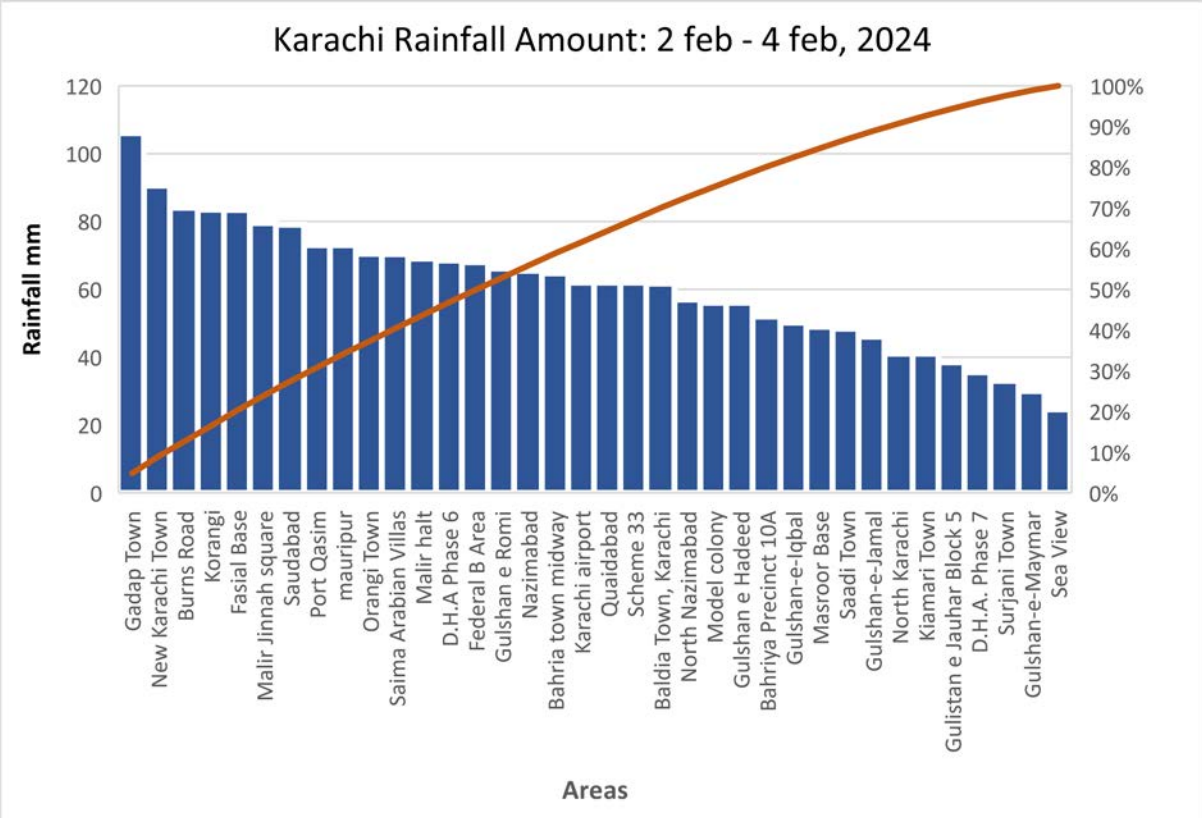


Figure 7. Karachi Rainfall Distribution February 2-4, 2024

Figure 8 depicts a remarkable difference in AQI between before and after rain. Though Gadap is an agricultural area without heavy infrastructure even the Minimum AQI for the area falls in the range of 158.1-183, this AQI is considered unhealthy and not good for everyone according to the cautionary statement (Kausar et al. 2023; EPA, 2022). The Maximum value reached up to 310.5 before the rain and it is hazardous (Kausar et al. 2023; EPA, 2022). After the rain AQI dropdown up to 69 approximately which is considered moderate but still a cautionary measure applied on sensitive people. The maximum value of AQI hits up to 111.9 which is far better than the air quality situation before the rain. Though before and after rain comparison depicts the decline in the AQI in Karachi the central part where most of the population resides in Karachi still has high AQI values followed by the Site area where the industrial region exists.

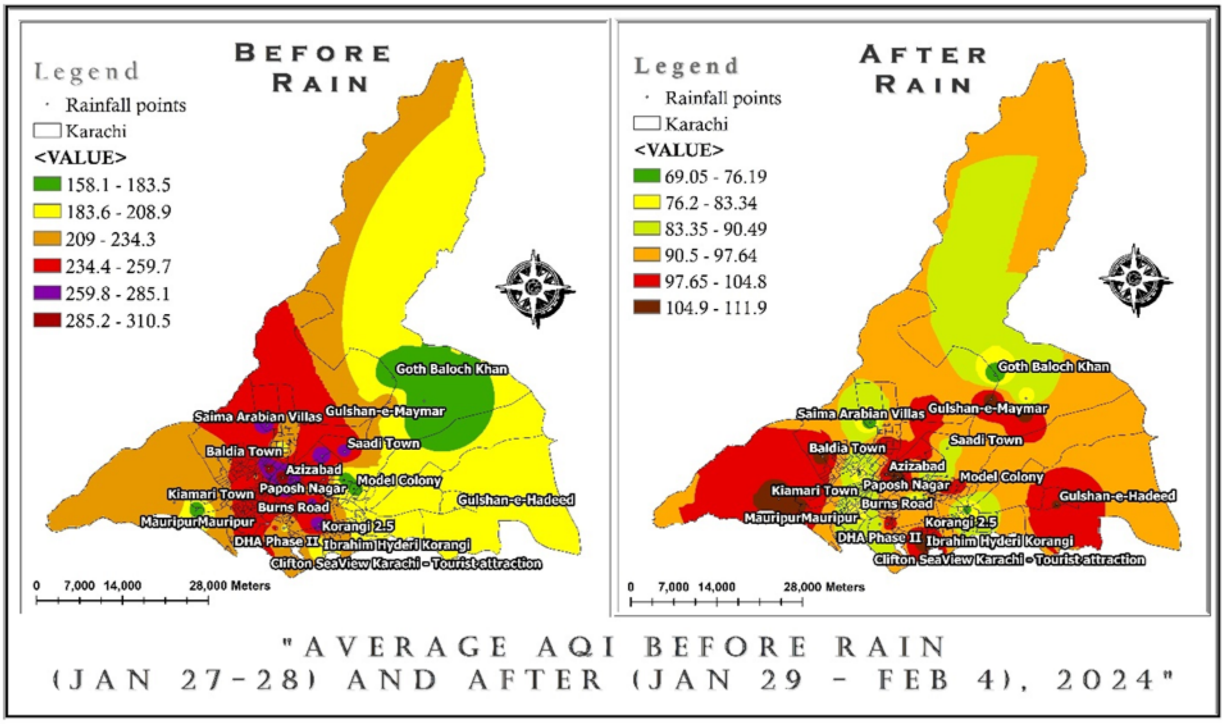


Figure 8. Average AQI before and after rain- January 29-February 4, 2024

Figure 9 depicts a remarkable difference in SO_2 between before and after rain. SO_2 results are apparent at the Karachi Airport, North Nazimabad, Port Qasim, industrial sites like Korangi, Site, Central locations of metropolitan Gulshan-e-Iqbal, Gulishtan-e-Johar as well as dairy farming regions of Gadap where the readings reached up to 224.7-246.9ppbV. The presence of SO_2 gas is harmful to human respiratory activity and can be a cause of acid rain ((EPA, 2024). After and during the rain results and dramatic, even the highest recorded reading is below 100 ppbV. It reflects most of SO_2 which was suspended in air is washed away. After the rain highest contamination was found at Gulshan-e-Iqbal, Gulshan-e-Romi, and Malir Jinnah Square i.e. 100ppbV (Fig. 9 and Table 1).

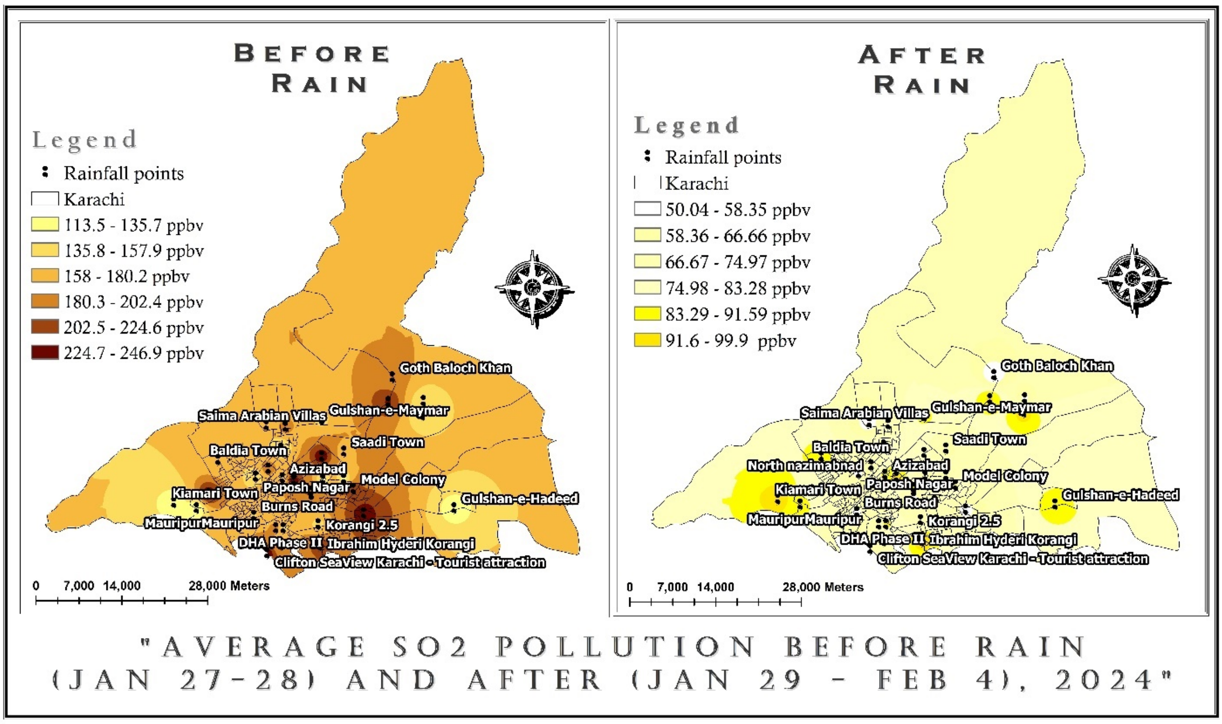


Figure 9. Average SO_2 pollution before and after rain- January 29-February 4, 2024

Figure 10 depicts the contamination level of pollutants i.e. particulate matter having a diameter of 2.5 micro-meters(mm), before rainfall reached up to 260.5 µg/m³ and the areas are Nazimabad, Quaidabad, Karachi Air Port, etc. Through the interpolation (Fig. 10), it is observable that this inland region of Karachi is subject to the concentration of pollutant levels, and there is a huge contiguous region of polluted air zone. After the rain overall air quality of Karachi normalized but the regions such as open areas like Gadap and Bahria Town and areas along the coastline presented cleaner and clearer air i.e. less than 50 µg/m³. Khaniabadi et al. (2017) revealed that 1.7% of total, 3.4% of cardiac, and 2% of breathing death were recognized to SO_2, respectively.

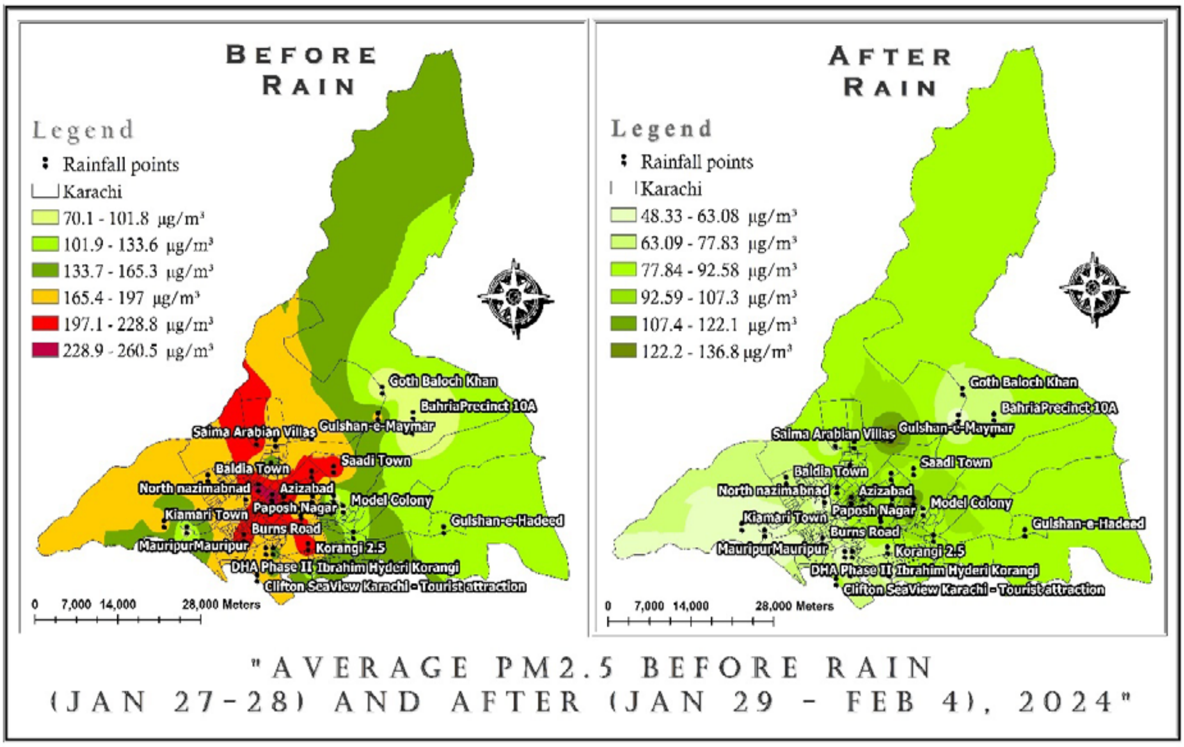


Figure 10. Average PM2.5 before and after rain- January 29-February 4, 2024

The comparative graphical representation (Fig. 11) depicts all studied pollutants i.e., AQI, PM2.5, and SO_2 declined after the rain. The air was previously polluted enough that termed hazardous, but the coastal environment in the South and range lands in the North of Karachi transformed the environment to clean and clear rapidly. Wu et al. (2024) examined an important positive suggestion among AQI and occurrence of AD with a clear dose-response association.

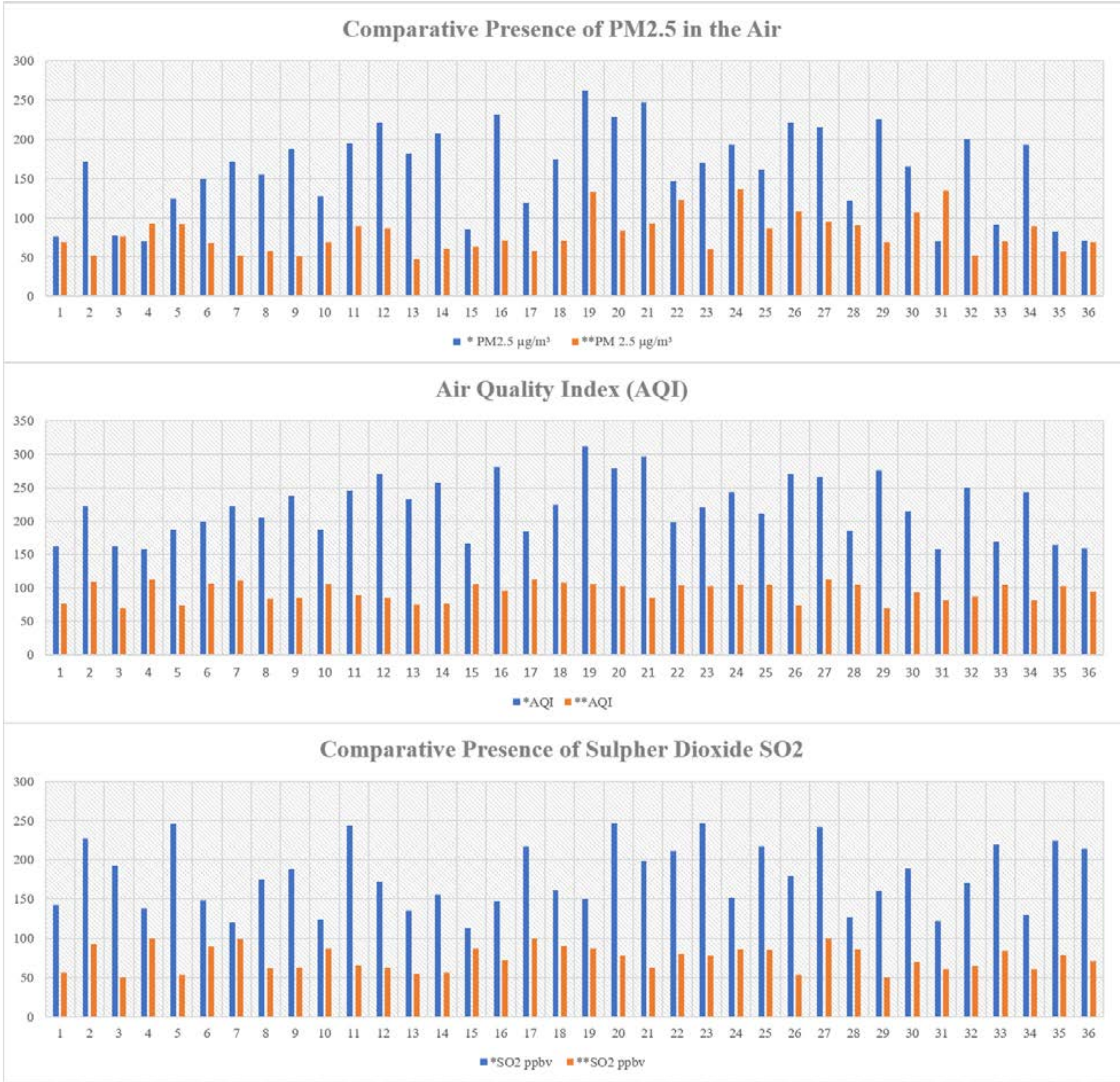


Figure 11. Comparative graphs of Pollutants before and after rain- January 29-February 4, 2024

3.1. Anova Test for Pollutants (variables/Factors)

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05
Rows unused	12

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	6	PM2.5 µg/m³(BR), PM 2.5 µg/m³(ADR), AQI (BR), AQI (ADR), SO_2 ppbV (BR), SO_2 ppbV (ADR)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	654668	130934	98.14	0.000
Error	210	280163	1334		
Total	215	934830			

3.2. One-way ANOVA

PM2.5 µg/m³(BR), PM 2.5 µg/m³(ADR), AQI (BR), AQI (ADR), SO_2 ppbV (BR), SO_2 ppbV (ADR) (Table 3).

3.2.1. Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
36.5254	70.03%	69.32%	68.29%

S= Standard Deviation

R-sq = Percentage of Variance (it should be in between 0-100

R-sq(adj) = R-sq adjusted

R-sq(Pred) = R-sq Predicted

Table 3. Means.

Factor	N	Mean	StDev	95% CI
PM2.5 µg/m³(BR)	36	161.00	56.51	(149.00, 173.00)
PM 2.5 µg/m³(ADR)	36	80.17	24.61	(68.17, 92.17)
AQI (BR)	36	220.11	44.37	(208.11, 232.11)
AQI (ADR)	36	94.31	13.94	(82.30, 106.31)
SO_2 ppbV (BR)	36	179.11	42.37	(167.11, 191.11)
SO_2 ppbV (ADR)	36	74.53	15.72	(62.53, 86.53)

Pooled StDev = 36.5254

The mean value for PM2.5 before rain (BR) was calculated at 161 µg/m³ in 36 observed areas compared to 80.17 µg/m³ in similar areas after and during rain (ADR) and these 36 locations with 95% CI (class interval) (Figure 12) fall in the category of 149-173 µg/m³before rain and

68.17-92.17 µg/m³ after and during rain. The mean value of AQI (BR) was calculated at 220.11 in 36 observed areas compared to 94.31 AQI (ADR) with 95% CI fall in the category of 208.11-232.11 (BR) compared to 82.30-106.31 (ADR). The mean value for the SO_2 BR was calculated at 179.11ppbV for 36 locations compared to 74.53 after and during rain with a 95% CI value of 167.11-191.11 BR compared to 62.53-86.53 ADR. Tsai et al. (2020) assessed the relationships among PM2.5 and hydro-meteorological variables, as a result, pollutant roses that are generated from the rebuilt wind directions expose the sources of PM2.5 on dissimilar scales. PM2.5 was found to be connected to land wind at the daytime scale and to winter monsoons at the yearly scale. The scale-dependent wind track that donates to the enhancement of PM2.5 is well-known. Oh et al. (2024) proposed that the ratio of the mass release rate of PM2.5 to the fresh air delivery rate of air cleansers is a significant value in influencing the effect of aeration.

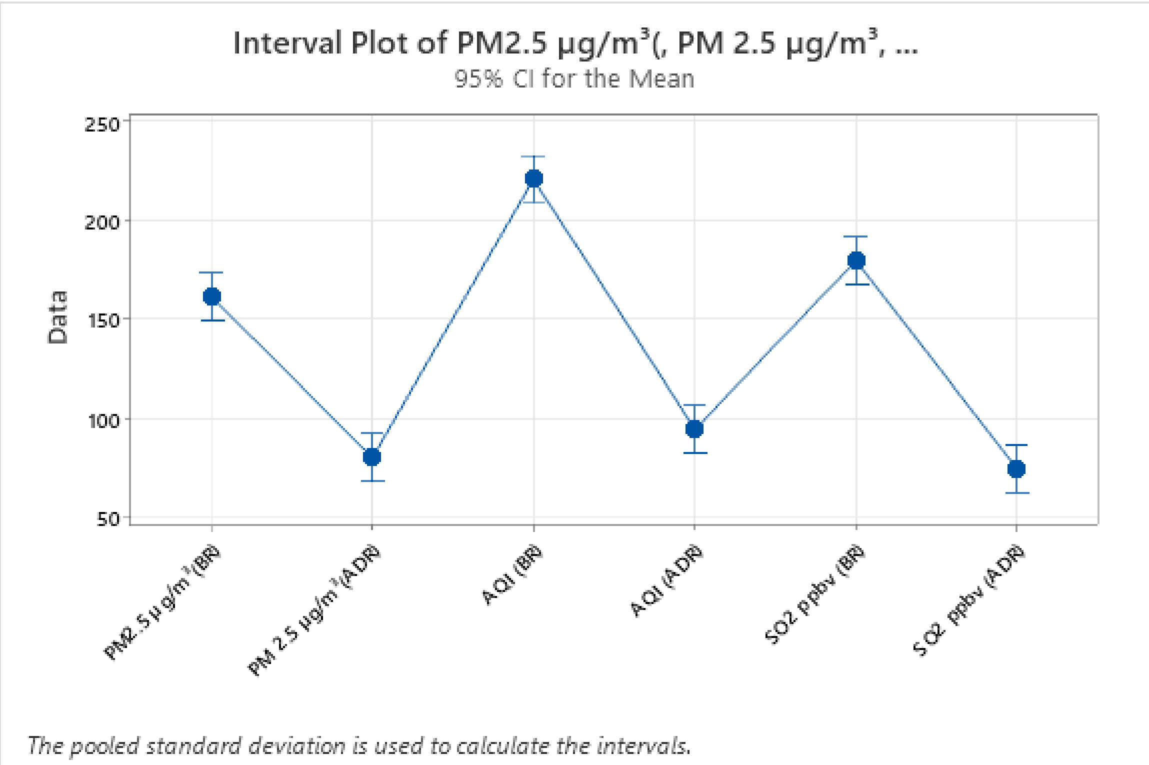


Figure 12. The Pooled Standard Deviation of Variables

4. Conclusion

Karachi received heavy rainfall at the end of January and the beginning of February. Before the rain, pollutants are present in the air in large quantities. In the existing study, three pollutants have been observed AQI, SO_2, and PM2.5. AQI before the rain (BR) was recorded at 310.5 falling in the category of hazardous. It is dropdown up to 69 (approx.) falls in the category of moderate during and after rain (ADR). The presence of SO_2 shows a remarkable difference between BR and ADR rain. SO_2 presents up to 246.9 ppbV before the rain dropdown up to 50.04 and even the maximum reading could not touch 100 ppbV during and after the rain. PM2.5 level was 260.5 µg/m BR and ADR, it dropped up to 50 µg/m³. After conducting Anova test following results have been computed. The mean value for PM2.5 before rain (BR) was calculated at 161 µg/m³ in 36 observed areas compared to 80.17 µg/m³ in similar areas after and during rain (ADR) and these 36 locations with 95% CI (class interval) fall in the category of 149-173 µg/m³before rain and 68.17-92.17 µg/m³ after and during rain. The mean value of AQI (BR) was calculated at 220.11 in 36 observed areas compared to 94.31 AQI (ADR) with 95% CI fall in the category of 208.11-232.11 (BR) compared to 82.30-106.31 (ADR). The mean value for the SO_2 BR was calculated at 179.11ppbV for 36 locations compared to 74.53 after and during rain with a 95% CI value of 167.11-191.11 BR compared to 62.53-86.53 ADR. The obtained results indicate there is a strong correlation between air quality and rain. When it rains the pollution level goes down dramatically.

Suggestions and recommendations

Karachiites face air quality issues especially in winter when there is no rainfall recorded. Tree plantation/Green cover can somehow reduce the contamination level of air. Therefore, instead of waiting for rain which does not usually happen in winter. Karachiites should participate in tree plantation activities/green infrastructure. Karachiites; especially with sensitive health should wear masks in winter. Indoor plants those helpful in maintaining Air Quality, e.g. elephant ear philodendron and aloe vera, etc. should be used in homes/offices/educational institutions where mass assembly of people mostly happens. The government should take action regarding industries and transportation activities to bind them with some rules of burning fossil fuels etc.

References

Airqoon, 2024, Urban Air Pollution: Sources and Pollutants. https://airqoon.com/resources/urban-air-pollution-sources-and-pollutants/#:~:text=Air%20Pollutants,Volatile%20Organic%20Compounds%20(VOCs) [Accessed 11/09/2024].

Ajmal M., Tarar M. A., Arshad,M. I., Gulshan,A. B., Iqbal,M. A. & Tanvir, F., 2016. Air Pollution and Its Effect on Human Health: A Case Study in Dera Ghazi Khan Urban Areas, Pakistan. Journal of Environment and Earth Science 6(9): 87–93.

Alam K., Trautmann T., Blaschke T. & Majid H., 2012. Aerosol optical and radiative properties during summer and winter seasons over Lahore and Karachi. Atmospheric Environment 50: 234–245.

Ali N., Kausar A., Vambol S., Kozub P. & Kozub S., 2024. Environmental retrieval during COVID-19 lockdown in the megacity Karachi, Pakistan. Ecological Questions 35(3): 1–16. https://doi.org/10.12775/EQ.2024.032

Asante W.A., Acheampong E., Kyereh E. & Kyereh B., 2017, Farmers' perspectives on climate change manifestations in smallholder cocoa farms and shifts in cropping systems in the forest-savannah transitional zone of Ghana. Land Use Policy 66: 374–381.

Ault T.R., 2020, On the essentials of drought in a changing climate. Science 368(6488): 256–260.

Beecher M.E., Eggett D., Erekson D., Rees L.B., Bingham J., Klundt J., Bailey R.J., Ripplinger C., Kirchhoefer J., Gibson R. & Griner D., 2016. Sunshine on my shoulders: Weather, pollution, and emotional distress. Journal of Affective Disorders 205: 234–238.

Chattopadhyay P., Chattopadhyay P. & Palit D., 2020, Effect of environmental pollution on health and its prevention: an overview. Environmental and sustainable development through forestry and other resources, p. 229–266.

Craig L., Brook J.R., Chiotti Q., Croes B., Gower S., Hedley A., Krewski D., Krupnick A., Krzyzanowski M., Moran M.D. & Pennell W., 2008, Air pollution and public health: a guidance document for risk managers. Journal of Toxicology and Environmental Health, Part A, 71(9-10): 588–698.

Crowley R., Mathew S., Hilden D. & Health and Public Policy Committee of the American College of Physicians, 2022, Environmental health: a position paper from the American College of Physicians. Annals of Internal Medicine 175(11): 1591–1593.

Department for Environment & Rural Affairs, 2024, What is Stratospheric Ozone?. https://uk-air.defra.gov.uk/research/ozone-uv/ozone-concerns#:~:text=The%20lower%20down%20in%20the,concentrations%20tend%20to%20be%20lower [Accessed 11/09/2024].

Department of Climate Change, Energy, the Environment and Water, 2024, https://www.dcceew.gov.au/environment/protection/npi/substances/fact-sheets/particulate-matter-pm10-and-pm25 [Accessed 11/09/2024].

EPA, 2022, Criteria Air Pollutant. https://www.epa.gov/ criteria-air-pollutants

EPA, 2024, Sulpher Dioxide (SO_2) Pollution. Retrieved from EPA United Nations Environmental Protection Agency. https://www.epa.gov/so2-pollution/sulfur-dioxide-basics

Fang M., Chan C.K. & Yao X., 2009, Managing air quality in a rapidly developing nation: China. Atmospheric Environment. 43: 79–86. http://doi.org/10.1016/j.atmosenv.2008.09.064

Kausar A., Afsar S., Wazir Z., Lahori A.H., Afzal A., Arif J., Sydorenko V., Pruskyi A. & Tyshchenko V., 2022, Land Use Analysis of Central Business District (CBD) of Metropolis Saddar Karachi through SRS/GIS Techniques. Ecological Questions 33(1): 91–101.

Kausar A., Afzal A., Khan O. I., Maqsoom A., Saeed G., Vambol S., Trush O., Murasov R. & Mykhailov V., 2024, Impact of Surrounding Infrastructure on Urban Environment: A Case Study of Karachi Metropolitan. Ecological Questions 35(2):1–19. https://doi.org/10.12775/EQ.2024.018

Kausar A., Afzal A., Khan O.I., Maqsoom A., Saeed G., Vambol S., Trush O., Murasov R. & Mykhailov, V., 2024. Impact of Surrounding Infrastructure on Urban Environment: A Case Study of Karachi Metropolitan. Ecological Questions 35(2): 1–19.

Kausar A., Afzal A., Saeed G., Maqsoom A., Khan O. I., Afsar S., Anis Y., Zehra S.M., Vambol V., Vambol S. & Kravchenko Y., 2023, Land-Use/Land Cover Analysis Through Object Based Technique: A Case Study of Shahrah-e-Faisal. Ecological Questions 34(2): 117–125. https://doi.org/10.12775/EQ.2023.024

Kausar A., Zubair S., Sohail H., Anwar M.M., Aziz A., Vambol S., Vambol V., Khan N.A., Poteriaiko S., Tyshchenko V., Murasov R., Ejaz F. & Khan O.I., 2024, Evaluating the challenges and impacts of mixed-use neighborhoods on urban planning: an empirical study of a megacity, Karachi, Pakistan. Discover Sustainability 5(1): 5–25. https://doi.org/10.1007/s43621-024-00195-5

Khaniabadi Y.O., Polosa R., Chuturkova R.Z., Daryanoosh M., Goudarzi G., Borgini A., Tittarelli A., Basiri H., Armin H., Nourmoradi H. & Babaei A.A., 2017, Human health risk assessment due to ambient PM10 and SO_2 by an air quality modeling technique. Process Safety and Environmental Protection 111: 346–354.

Kumar S., Thakural L.N., Gurrapu S. & Patra J.P., 2022, Extreme Rainfall Trends and their Statistical Significance, p. 295–304. https://doi.org/10.1007/978-3-031-13119-6_17

Lehmann J., Coumou D. & Frieler K., 2015, Increased record-breaking precipitation events under global warming. Climatic Change 132: 501–515.

Lisboa A.E.A., Fazzioni P.F.P.C., Chinelli C.K., Faisca R.G. & Soares, C.A.P., 2024, Influence of the accumulated precipitation and the spatial distribution of rainfall on the results of reservoir sizing methodologies. International Journal of Environmental Science and Technology 21(5): 5149–5164.

Nazeer M., Waqas M., Shahzad M.I., Zia I. & Wu W., 2020, Coastline vulnerability assessment through landsat and cubesats in a coastal mega city. Remote Sensing 12(5), 749.

NEWS., 2024, Urban Flooding Threat: Did Karachi just get record-breaking rain? Karachi, Sindh, Pakistan.

Oh S., Chang J., Jeong J., Yang D.S., Ham D.J., Kwon H.J., Choi H., Kim M., Ha J., Heo H.S. & Vervoort R., 2024, Effects of air purifiers and ventilation on particulate matter concentration at semi-outdoor space. Journal of Cleaner Production 434, 139903.

Qureshi H.U., Hussain Shah S.M. & Fang Y.T., 2023, Spatio-temporal assessment of changing annual and seasonal climate patterns over the major climatic zones of Pakistan. Journal of Sustainable Civil Engineering & Technology (JSCET) 2(1): 61–84.

RapidTable, 2024, ppb to ppm conversion. https://www.rapidtables.com/convert/number/ppb-to-ppm.html [Accessed 1/09/2024].

Reiners P., Asam S., Frey C., Holzwarth S., Bachmann M., Sobrino J., Göttsche F.M., Bendix J. & Kuenzer C., 2021, Validation of AVHRR Land Surface Temperature with MODIS and in situ LST—A timeline thematic processor. Remote Sensing 13(17), 3473.

Sachdeva Shelly & Kaur R. & Kimmi & Singh, H. & Aggarwal, K. & Kharb S., 2023, Meteorological AQI and pollutants concentration-based AQI predictor. International Journal of Environmental Science and Technology 21. https://doi.org/10.1007/s13762-023-05307-8 [Accessed 11/09/2024].

Stieb D.M., Burnett R.T., Smith-Doiron M., Brion O., Shin H.H. & Economou V., 2008, A new multipollutant, no-threshold air quality health index based on short-term associations observed in daily time-series analyses. Journal of the Air & Waste Management Association 58(3), 435–450.

Thornton P.K., Ericksen P.J., Herrero M. & Challinor A.J., 2014, Climate variability and vulnerability to climate change: a review. Global Change Biology 20(11): 3313–3328.

Tsai C.W., Hsiao Y.R., Lin M.L. & Hsu Y., 2020, Development of a noise-assisted multivariate empirical mode decomposition framework for characterizing PM 2.5 air pollution in Taiwan and its relation to hydro-meteorological factors. Environment International 139, 105669.

Wang R., Cui K., Sheu H.L., Wang L.C. & Liu X., 2023, Effects of precipitation on the air quality index, PM2. 5 levels and on the dry deposition of PCDD/fs in the ambient air. Aerosol and Air Quality Research 23(4), 220417.

Wondyfraw M., 2014, Mechanisms and effects of acid rain on environment. Journal of Earth Science & Climatic Change 5(6): 1–3.

Wu C.Y., Wu C.Y., Li M.C., Ho H.J. & Ao C.K., 2024, Association of air quality index (AQI) with incidence of atopic dermatitis in Taiwan: A nationwide population-based cohort study. Journal of the American Academy of Dermatology 90(6): 1218–1225.

Yaqub G., Hamid A. & Asghar S., 2019, Rain water quality assessment as air quality indicator in Pakistan. Bangladesh Journal of Scientific and Industrial Research 54: 161–168.

Zhang W., Furtado K., Wu P., Zhou T., Chadwick R., Marzin C., Rostron J. & Sexton D., 2021, Increasing precipitation variability on daily-to-multiyear time scales in a warmer world. Science Advances 7(31), eabf8021.