Al-Mukhtar Journal of Basic Sciences 23 (3): 198-207, 2025
Doi: https://doi.org/10.54172/1h6kpy80

Research Article **Open Access**

Air Pollution Impact on Rainwater Quality in Tripoli City-Libya

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Received:
17 November 2025

Accepted:
25 December 2025

Publish online:
31 December 2025

Abstract

This paper is concerned with the evaluation of the air pollution impacts on rainwater quality in the city of Tripoli during the rainy season extended from December 2023 to May 2024. A total of 167 samples were collected from seven selected locations, including two urban sites (Tripoli Center and Ras-Hassan area), in addition to five other sites representing the suburban areas which is (Souq Al-Jumaa, Al-Sabaa, Ain-Zara, Al-Khalla, and Al-Hadba Al-Mashrou). Samples were analyzed for pH, electrical conductivity (EC), nitrate (NO_3^-), nitrite (NO_2^-), sulfate (SO_4^{2-}), chloride (Cl^-), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and total dissolved solids (TDS).
The results showed that the levels of air pollutants containing acids and salts in the city rainwater were low and within the normal range according to the Libyan Water Quality Standards (2015) and the World Health Organization (2017). It was also found that, the highest levels of pollution were in dense urban areas, while they were low in suburban areas. Looking at the chronology, pollution rates peaked during April followed by May, reflecting the seasonal effects of weather factors, and the pollution during the spring is higher than in winter, due to the decrease in the number of rainfall and consequently the lower rates of wet sedimentation, rising temperatures, in addition to increasing the chances of exposure to windborne dust, which contains mineral, calcareous and salt particles, and a decrease in the rate of diffusion of marine salts. However, the city's rainwater remains within safe limits for various uses in drinking, agriculture and industry.

Keywords: Air pollution, water Quality, rainfall, Acid rain.

INTRODUCTION

The effects of air pollution are more pronounced in urban areas compared to rural regions, posing an increasing environmental threat to cities and necessitating the monitoring of air quality, concentration, and dispersion to assess its impact on ecosystems and the feasibility of mitigation programs (Chen et al., 2025). The type and location of pollution sources influence the quantity and nature of pollutants, their horizontal and vertical dispersion, and their response to continuously changing atmospheric factors such as wind, temperature, and humidity (Habeebullah, 2013). This underscores the importance of studying, assessing, and monitoring pollutants and their multiple effects.

The accumulation of acidic oxides and fine particulate matter in the atmosphere, such as SO_2, NO_x, CO, PM_{10}, and $PM_{2.5}$, leads to chemical reactions that produce acid rain, which affects soil, water, vegetation, and infrastructure through wet deposition (Latif, 2011; Cheng et al., 2007; Ge et al., 2016; Rennenberg et al., 2001). These pollutants also reflect the type and level of air pollution, particularly in urban areas with heavy traffic and diverse human activities (Cheng et al., 2007; Drever, 1997; Harrison et al., 1998).

Analyzing rainfall physical and chemical properties, such as pH, electrical conductivity (EC), and total dissolved solids (TDS), provides key information on acidity, ionic strength, salinity, and water quality, and serves as a reliable tool for assessing pollution levels, sedimentation, and environmental risks (Hem, 1985; Seinfeld et al., 2016). Previous studies in various locations in Libya indicate that rainfall quality generally falls within safe limits, occasionally requiring minor treatment for different uses (Almdny, 2008; Awad et al., 2024; Eiblou et al., 2024). In the context of the study area, coastal geography, marine salts, and human activities clearly influence rainwater chemistry.

Studies conducted in other coastal cities have highlighted the significant role of atmospheric emissions, particularly anthropogenic emissions, in controlling ion concentrations and acidity over time; however, knowledge gaps remain regarding temporal and spatial variations, especially in rapidly growing major coastal cities (Huang et al., 2024; Zeng et al., 2024). Within this context, the present study aims to evaluate the impact of atmospheric air pollution on rainfall characteristics and to estimate the contributions of both continental emissions and marine salts to water and air quality.

THE STUDY AREA

The city of Tripoli is located in the northwestern part of Libya and is the largest coastal city in the country along the Mediterranean Sea, covering an area estimated at about 400 square kilometers, rising to about 17 meters above sea level, and its population in 2025 is estimated at about 1,800,000 people in addition to more than 738,000 migrants, (BSC, 2020; IOM, 2024). The city is experiencing rapid urban growth and expansion with high traffic density with a steady increase in diverse industrial, commercial and agricultural activities, creating environmental and urban limitations represented by poor air and water quality, infrastructure pressures, loss of agricultural land, and water scarcity (Farag, I., Algeblawi, et al. 2022).

Climatically, the climate of the city is belongs to the Mediterranean climate and relatively moderate like other cities in the coast, compared to the center and south of the country, which has hot and dry air in summer affected by desert conditions, which causes a large disparity in the degrees of temperature between day and night, and it is mild and rainy in winter, The rainy period extends from September to May and records annual rainfall ranging from 265-550 mm, (Sen, Z., & Eljadid, A. G. 1999), relative humidity ranges between 49-66%, and the average wind speed is 11.2. Km/h, (Ghazali, A. M., et al. 2012; Zekry, 2005).

MATERIALS AND METHODS

In this study, seven sites were selected to collect rainwater samples in the city and we took into account what reflects the urban center and the suburbs, where each of the sites (City center and Ras-Hassan) represent the dense urban areas and the rest of the other five sites represent the suburbs which are the areas of (Souq Al-Jumaa, Al-Sabaa, Al-Hadba Elmashrou, Al-Khalla, and Ain-Zara). A total of 167 rain samples were collected in 5-liter plastic containers placed at a height of 4 meters above the ground during the rainy season from December 2023 to May 2024, in which the actual rainfall days were recorded at 27 days. Coinciding with the main rainy season in northern Libya, (Eljadid, A. G. 2007). Once the rainstorm is over, samples are collected from different locations and transferred for analysis at the laboratories of the University of Tripoli, the Environment Center, the Ministry of Local Administration and the Al-Sadim Laboratory for Environmental Analysis.

In the study, the acidity and alkalinity analyses followed the scientific protocols in accordance with the Libyan Water Standards (LWS, 2015) and the World Health Organization guidelines (WHO, 2017), Table 1. Each time samples were analyzed for pH using a pH meter and a digital electro-chemical meter, which is an electronic instrument used to determine the acidity or alkalinity of a given liquid. Electrical conductivity (EC) and dissolved salts (TDS) were measured using a conductivity meter and a digital electrochemistry meter. Chloride ions (Cl^-) were determined using a spectrophotometer and a Hydro Test HT1000 analyzer. Carbonates (CO_3^{2-}) and bicarbonates were determined by titration with diluted sulfuric acid using phenolphthalein and methyl orange indicators, while bicarbonates (HCO_3^-) were titrated with a sulfuric acid solution. Nitrates (NO_3^-) and nitrites (NO_2^-) were measured using a spectrophotometer. Sulfates (SO_4^{2-}) were also determined spectrophotometrically. All samples were subjected to standardized analytical procedures using appropriate calibrated instruments.

Table:(1). Normal range of the elements in the rainwater according to (LWS and WHO) standard**.**

Elements	Formula	Normal range LWS	Normal range WHO	Unit
Hydrogen ion concentration /hydrogen number	PH	6.5 -8.5	6.5 -8.5	/
Electrical Conductivity	EC	50-750	50 – 400	µS/cm
Chlorides	Cl^-	250	200-600	mg/l
Carbonates	CO_3^{2-}	50	45	mg/l
Bicarbonates	HCO_3^-	200	500	mg/l
Nitrates	NO_3^-	45	45	mg/l
Nitrites	NO_2^-	3	3.3	mg/l
Sulphates	SO_4^{2-}	250	250	mg/l
Total Dissolved Solids	T.D.S	1000	600	mg/l

RESULTS AND DISCUSSION

Analysis of rainfall samples revealed that all the elements analyzed are within the normal limits of rainwater in accordance with (LWS) and (WHO) guidelines, reflecting the relatively high air quality in the city and low rainwater acid levels as an indicator of low emission rates at all study sites Table 2.

Table:(2). Total averages of the elements Concentration in the Study Area

Measurement in study area	Elements								
	PH	EC	NO_3^-	NO_2^-	SO_4^{2-}	CL^-	HCO_3^-	CO_3^{2-}	TDS
Total Average	6.85	301.61	5.51	0.0135	16.15	23.31	30.36	0.0	173.43
LWS	Acceptable								
WHO	Acceptable								

The analyses also showed spatial variation in rainwater properties in pH, electrical conductivity, nitrate (NO_3^-), nitrite (NO_2^-), sulfate (SO_4^{2-}) and chloride (Cl^-), Table 3. It was also noted that the highest average pH was at the Souq Al-Jumma location and the lowest level in Al-Sabaa site. This variation is attributed to the lower acidity of the coastal sites of the city than to the locations farther from the coast, where there are marine alkaline ions carried by wind and aerosols near the sea (Na^+, HCO_3^-, CO_3^{2-}, Cl^-) which have the ability to neutralize acidity, and also to the relatively low levels of air pollution in the city in general, which allow natural neutralization mechanisms to work effectively, (Maauf, N., Mansour, et al. 2024).

Table:(3). Mean Monthly Concentration of pH, EC, NO^{3-}, NO^{-2}, SO_4^{2-}, CL^- in the Rainfall samples (mg/l).

Measurement Site	Measurements Period						average
	SYMBLE	Dec.	Jan.	Feb.	Apr.	May	
Souq Al-Juma	PH	6.84	6.74	6.8	7.23	6.92	6.91
	EC	178.54	164.5	268.2	387.9	182.6	236.25
	NO_3^-	4.24	4.67	4.52	6.08	4.45	4.79
	NO2-	0.007	0.006	0.009	0.014	0.015	0.0102
	SO42-	6.65	1.10	10.43	42.00	6.00	13.24
	CL-	14.04	12.04	19.05	31.05	13.41	17.92
Al-Sabaa	PH	6.61	6.63	6.98	7.04	6.88	6.828
	EC	106.38	131.5	132.05	368.0	182.3	184.05
	NO_3^-	3.05	3.1	4.24	6.00	4.43	4.16
	NO2-	0.005	0.006	0.005	0.006	0.015	0.0074
	SO42-	2.00	1.87	1.93	45.3	4.5	11.12
	CL-	6.06	10.43	9.63	28.09	13.38	13.51
Ras-Hassan	PH	6.73	6.85	6.7	6.99	6.89	6.83
	EC	345.09	301.8	196.44	563.4	626	406.56
	NO_3^-	6.18	4.63	5.41	8.88	9.62	6.944
	NO2-	0.008	0.013	0.007	0.015	0.033	0.0152
	SO42-	30.26	7.30	3.18	53.5	5.23	19.894
	CL-	27.73	22.41	13.10	51.20	48.93	32.674
Center Tripoli	PH	6.71	6.78	6.73	6.71	6.83	6.75
	EC	355.87	308.3	199.42	607.5	632	420.63
	NO_3^-	6.44	5.11	5.68	9.30	9.07	7.12
	NO2-	0.009	0.016	0.007	0.016	0.038	0.0172
	SO42-	31.61	7.78	3.4	56	5.43	20.84
	CL-	28.77	23.42	13.7	54.58	49.4	33.97
Mashrou Alhadba	PH	6.91	6.77	6.68	7.16	6.92	6.89
	EC	123.24	185.5	273.65	470.8	144.8	239.61
	NO_3^-	3.23	5.70	4.79	9.93	4.39	5.40
	NO2-	0.005	0.005	0.019	0.024	0.013	0.0132
	SO42-	7.2	4.37	6.88	41.57	5.57	13.118
	CL-	9.64	13.86	21.67	35.97	11.8	18.588
Al-Kalla	PH	6.88	6.84	6.83	6.91	6.87	6.87
	EC	118.78	180.0	272.21	468.3	150.7	238.01
	NO_3^-	3.09	5.29	4.58	9.53	4.20	5.338
	NO2-	0.005	0.005	0.015	0.017	0.013	0.011
	SO42-	6.9	3.38	6.4	39.67	5.27	12.324
	CL-	9.32	12.31	20.14	35.85	11.03	17.73
Ain Zara	PH	6.69	6.66	6.75	7.16	7.07	6.87
	EC	161.26	369.8	278.38	571.06	549.67	386.04
	NO_3^-	3.15	3.60	3.93	9.00	4.43	4.822
	NO2-	0.006	0.005	0.031	0.030	0.030	0.0204
	SO42-	11.5	12.0	27.25	55.0	7.67	22.684
	CL-	10.87	19.26	24.63	46.70	42.27	28.746
Averages	PH	6.77	6.75	6.78	7.03	6.91	6.85
	EC	198.45	234.5	231.48	491.00	352.58	301.61
	NO_3^-	4.20	4.59	4.74	8.39	6.03	5.59
	NO2-	0.0643	0.008	0.0133	0.0174	0.02243	0.025
	SO42-	13.73	5.40	8.50	47.58	5.67	16.01
	CL-	15.20	16.25	17.42	40.49	27.17	23.31

The rates of electrical conductivity also varied between the sites, recording the highest averages within the urban areas at city center and Ras Hassan regions and the lowest value was recorded at Al-Sabaa site, indicating a decrease in suburban air pollution. The highest values of nitrate were recorded at Al-Hadba Al-Mashrou location followed by Al-Kalla site, which was attributed to the agricultural activities in it and the accompanying use of organic fertilizers, the absence of central drainage systems, the spread of black wells. Nitrite concentrations were also generally low, reflecting limited sources of nitrite-containing emissions. These results indicate to limited local contamination, and nitrate and nitrite levels in the samples are low and consistent with previous studies in northwestern Libya and similar to the coastal cities, (Mas-Pla, J., & Menció, A. 2019).

Sulfate and chloride concentrations were within normal limits, and the highest values were in the city center and in Ain-Zara site, while the site of Al-Sabaa recorded the lowest values, reflecting low rates of air pollution and limited environmental impact. Carbonates have generally recorded rare rates in all rainwater samples, which is normal as they convert to bicarbonate in the presence of acidity or disappear completely when the pH drops below 4.8 (Huo, M., et al. (2012); Murillo, R., et al (2023). This is a strong indicator of the limitation of carbon dioxide gas that converts in water to carbonic acid (H_2CO_3), which in turn converts to bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}), especially in areas near calcareous soils or deserts due to metallic molecules that are diffused by the wind in the air. Without neglecting that salt ion levels also indicate the contributions of marine salts to increased alkalinity. Bicarbonate recorded a low concentration in all regions and the highest was at the Ain-Zara site, while carbonate was completely absent in all regions, reflecting very low carbon emissions at all sites.

The dissolved salts also recorded moderate rates and were within the normal limits in all sites, and the highest was at the city center site, which indicates the efficiency of atmospheric air quality and the levels of naturally acidic pollution, as well as the low rates of dissolved substances such as compounds, Na, K, Mg, and Ca.

Seasonal changes were observed in all the elements, where the lowest concentrations were recorded in the winter season, especially during the months of December and January, Figure 1 to 8, due to the frequency of rainfall in winter and sedimentation processes and decreases in the rate of various emissions, and the decrease in temperatures, which limits the air lifting operations and the spread of pollutants vertically, in addition to the high wind speeds which promote horizontal dispersion and dilution processes in parallel with increasing the chances of marine salts. On the other hand, the spring season has seen a rise in the concentration of all elements, peaking during the months of April and May, highlighting the seasonal dynamics in the distribution of pollutants and in atmospheric interactions and their correlation with the important change that occurs for different weather factor.

These results are consistent with the fact that rainwater chemistry is strongly influenced by meteorological and near-coastal conditions, not to mention the nature of various human activities and their outputs. Rainwater composition is also directly affected by local environmental factors in the study area. The coastal location plays a key role in enhancing the influence of marine salts transported by prevailing winds on rainwater chemistry, while wind patterns, temperature, and humidity control the mechanisms of pollutant transport and deposition. Additionally, traffic density and urban and industrial activities significantly contribute to the concentrations of gaseous and particulate pollutants, which participate in chemical reactions in the atmosphere and subsequently affect the characteristics of rainwater. These findings are in agreement with previous studies conducted in other coastal cities, (Liu, Y., et al., 2015; Murillo, R., et al. 2023).

Table:(4). Mean Monthly Concentration of HCO^{3-}, CO_3^{-2} and TDS in the Rainfall samples (mg/l)

Measurement Site	Measurements Period						average
	SYMBLE	Dec.	Jan.	Feb.	Apr.	May	
Souq Al-Juma	HCO3-	16.03	26.42	34.81	53.23	25.6	31.22
	CO32-	0.000	0.000	0.000	0.000	0.000	0.00
	TDS	103.27	88.09	147.56	213.35	103.53	131.16
Al-Sabaa	HCO3-	7.61	19.55	23.42	53.45	25.63	25.93
	CO32-	0.0	0.0	0.0	0.0	0.0	0.00
	TDS	46.97	72.33	72.63	202.43	103.53	99.58
Ras-Hassan	HCO3-	26.22	30.6	25.55	38	37.33	31.54
	CO32-	0.000	0.000	0.000	0.000	0.000	0.00
	TDS	211.5	166.2	105.58	372.32	367.3	244.59
Center Tripoli	HCO3-	27.46	32.17	26.6	40.82	39.6	33.33
	CO32-	0.000	0.000	0.000	0.000	0.000	0.00
	TDS	216.73	169.9	107.21	389.13	376.47	251.90
Mashrou Alhad-ba	HCO3-	10.38	19.51	27.82	51.36	22.02	26.22
	CO32-	0.000	0.000	0.000	0.000	0.000	0.00
	TDS	65.7	102.0	150.54	258.97	88.3	133.11
Al-Kalla	HCO3-	9.78	18.32	25.97	52.33	22.07	25.69
	CO32-	0.000	0.000	0.000	0.000	0.000	0.00
	TDS	62.55	99.05	149.73	257.53	86.9	131.15
Ain Zara	HCO3-	11.75	22.82	41.41	54.18	62.95	38.62
	CO32-	0.000	0.000	0.000	0.000	0.000	0.00
	TDS	88.2	203.4	153	348	319.93	222.51
	HCO3-	15.60	24.20	29.37	49.05	33.60	30.36
Averages	CO32-	0.000	0.000	0.000	0.000	0.000	0.00
	TDS	113.56	128.7	126.61	126.61	206.57	173.43

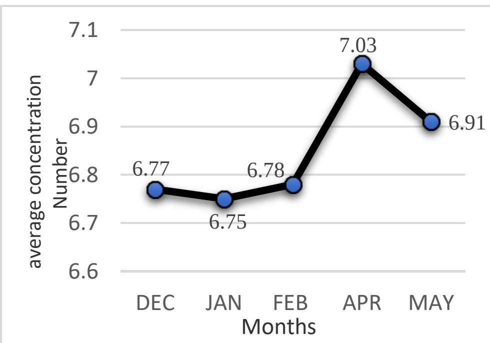

Figure:(1). Monthly Variation of PH

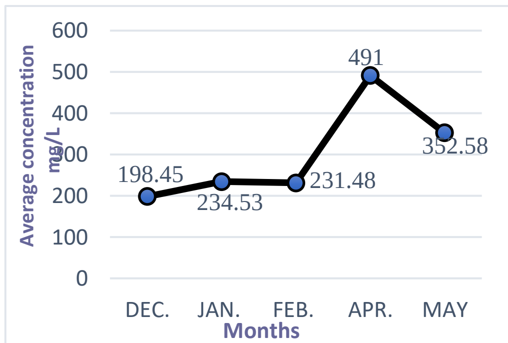

Figure:(2). Monthly Variation of EC

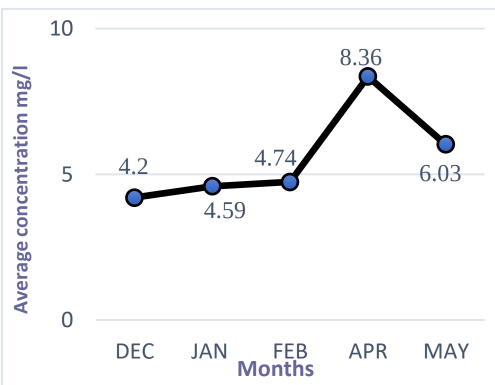

Figure:(3). Monthly Variation of NO^3

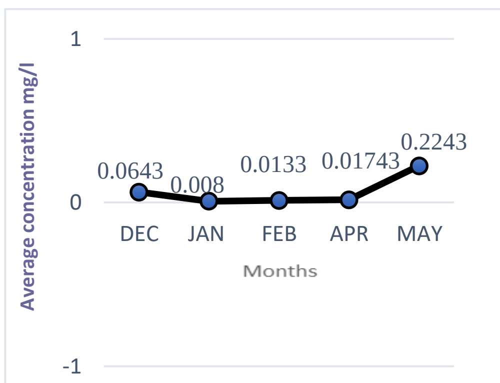

Figure:(4). Monthly Variation of NO^2

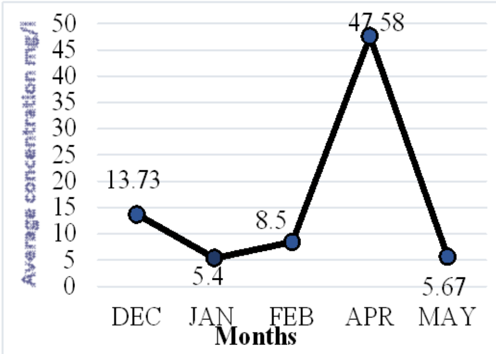

Figure:(5). Monthly Variation of SO^4

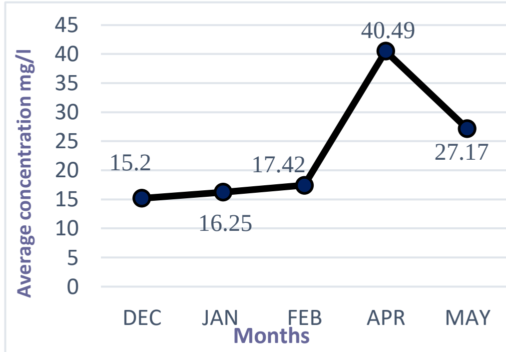

Figure:(6). Monthly Variation of CL^-

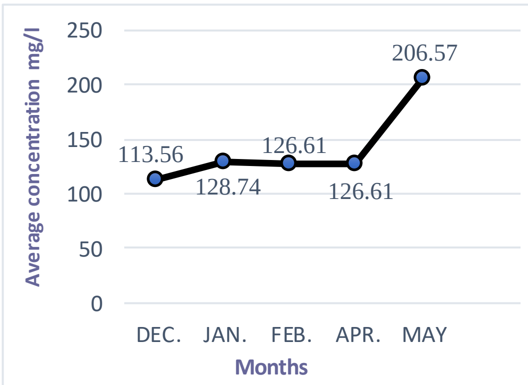

Figure:(7). Monthly Variation of $H\ CO^3$

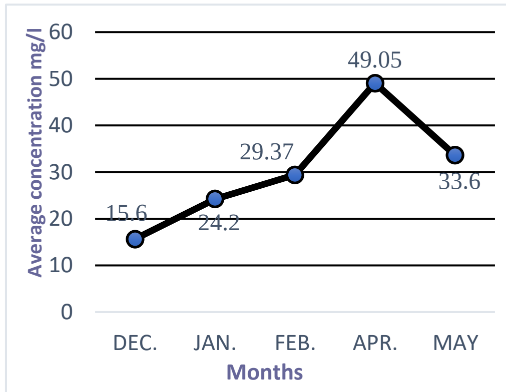

Figure:(8). Monthly Variation of TDS

CONCLUSION

The Results shows that, the air in Tripoli center and its surrounding areas is free from pollutants, and that the city rainwater is natural and non-acidic. All analyzed elements were found to fall within the limits of pristine natural water, in accordance with Libyan Standards (2015) and World Health Organization guidelines (2017), reflecting low levels of atmospheric pollution across the city. Densely populated urban areas, particularly the City Center and Ras Hassan site, recorded the highest element concentrations compared to suburban areas around the city; nevertheless, their levels remain within safe limits, indicating a limited impact of population density and various human activities throughout the city, including industrial operations, transportation, and other activities.

Regarding temporal variations, the results revealed a clear seasonal pattern, with peak emissions occurring during the spring, particularly in April and May, while the lowest values were recorded during the winter months of December and January. These variations reflect different meteorological influences, especially those related to changes in solar radiation, temperature, precipitation frequency, wind speed and direction, and relative humidity. The study concluded that the city is free from air pollution and that its rainwater is natural and suitable for various municipal, agricultural, and industrial uses.

RECOMMENDATION

The study recommends systematic and continuous monitoring of rainwater chemistry, assessment of the effects of atmospheric air pollution, enhancing public awareness of the negative effects of pollution and the extent of the risks it poses to all environmental systems, and continuous work to ensure the control of sources of air and water pollution and reducing potential future risks.

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