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Evaluation of Acid Rain Impacts Using Geostatistical Analysis and Remotely Sensed Data in Kirkuk City, Iraq

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Acid rain is linked to the process of urbanization and industrialization and harms buildings. This study aims to evaluate acid rain in Kirkuk city using GIS-based spatial analysis, mathematical statistical modeling, and laboratory tests and examine the harmful effects on the city buildings and human health. Precipitation ranges were determined based on Theisen's polygon techniques. The methodology is based on two types of laboratory measurements of specific rainfall samples within the city for the period of January 2021 to March 2022. Geographical Information Systems GISs were used to verify the spatial distribution and quantity of precipitation data in the study area. Remote sensing RS was also used for mapping rainfall rates during the study period. According to spatial distribution maps, the acidity level of rain was classified as (least acidic) ranging between (5.5 and 5.6). Specifically in the southern and south-eastern parts of the study area. Besides, spatial distributions have been presented with high accuracy with 95% and 83% accuracy ratings in 2021 and 2022, respectively. Thus, we attempt to offer some useful guidelines for conserving buildings so that they are preserved for a long time. RS and GIS techniques are best suited for estimating and modeling rainfall data characteristics.

Keywords; Acid rain, geostatistical analysis, GIS, Kirkuk city, spatial distributions.

Introduction

Acid rain has become a main environmental concern (Butnariu and Samfira, 2013). Due to its wide-ranging and dangerous effects on ecosystems and its transboundary nature, acid rain received extensive scientific and public attention (Grennfelt et al., 2020). Some factors affect the precipitation chemical composition such as weather conditions, and emission transferring (Zhang et al., 2024)

Acid rains can be referred to as any rain at a more acidic rate than uncontaminated rain whereas, any precipitate with a pH < 5.6 is defined as acidic (Butnariu and Samfira, 2013). This term was first used by Robert Smith in 1872 to describe the rain-acidic nature of Manchester city an industrial city in the United Kingdom, but, researchers often call it "acid deposition" as a more precise term for acidic rain (Singh and Agrawal, 2007). It is formed by natural and human sources such as volcanic eruptions and industrial emissions (Mehta, 2010). The acidity of acid rain depends on a mix of components that react with SO2 and NO2 in the air, it's a complex process that happens through some chemical reactions forms of sulphuric and nitric acids (Butnariu and Samfira, 2013). Acid is deposited in two forms; wet deposition (Zhang et al., 2024) such as acid rain, fog, snow, and sleet, or dry deposition as fine particles even less than 2.5 microns (Sivaramanan, 2015; Altae, 2022).

Acid deposition is one of the most serious environmental problems that affects every component of the ecosystem, it also damages man-made materials and structures (Bhargava and Bhargava, 2013). Acid rains that correlate with urbanization and the industrialization process harm some types of buildings (Omar and Rindam, 2011; Guo et al., 2024). Construction materials will degrade over time due to environmental factors, acid rain affects by accelerating the degradation (Yates, 1988). The spatial variance and distributions are determined by a geostatistical approach according to the spatial scale of the study area, the spatial pattern of the model, and the distance of the samples (Sulyman et al., 2020).

Respiratory problems are one of the severe concerns of acid rain on people (Butnariu and Samfira, 2013). The deposition of particles of less than 2.5 microns can reach the bloodstream via the lungs and can cause lung cancer (Sivaramanan, 2015). Sulfates, ozone, nitrates, and hydrocarbon compounds are some of the constituents of acid pollution, they form fog, which affects vision (Brown et al., 2012). Acid depositions on buildings cause corrosion. Limestone and marble were converted to a crumbly material named gypsum. The road industry is required to spend more money on repairing damages resulting from acid rain (Butnariu and Samfira, 2013).

Remote sensing and GIS-based evaluations offer the best solutions and effective information interpretation with spatial data visualization (Hadi et al., 2022; Jamal Jumaah et al., 2023; Ahmad et al., 2024). This study aims to evaluate acid rain ranges in Kirkuk city using

GIS-based spatial interpolation mapping, mathematical statistical analysis, and laboratory tests.

Precipitation ranges were determined based on statistical analysis and Theisen's polygon techniques. The study was based on field measurements, manual laboratory tests, and remotely sensed data. Accuracy ratings also have been applied in the study. The study highlights the variability of rain acidity in Kirkuk city and the harmful effects of acid rain on the city buildings and human health. Moreover, it describes the problems that acid deposits cause for buildings and other materials. Furthermore, rating the acidity of precipitation over specific locations within the study area Kirkuk city, Iraq. We relied on rainfall samples data, laboratory measurements data, and ArcGIS geostatistical analysis and spatial distribution.

Material and Methods

Study Area and Samplings

Kirkuk city is located north of Iraq and about 250 km away from Baghdad the capital of Iraq (Buraihi and Shariff, 2015).

The weather in Kirkuk is characterized as a dry warm summer and cold rainy winter, with low annual precipitation concentration (Al-Shamarti, 2016). The annual rainfall average is about (250 - 320) mm. Based on the Kirkuk metropolis, Kirkuk is divided into three areas: residential areas with high population, few population areas, and industrial areas. It is estimated that the population of Kirkuk increased from 1,050,000 in 2008 to 1,445,556 in 2020 (Awaz, 2015). Figure 1 represents rainfall samples in the study area (Kirkuk).

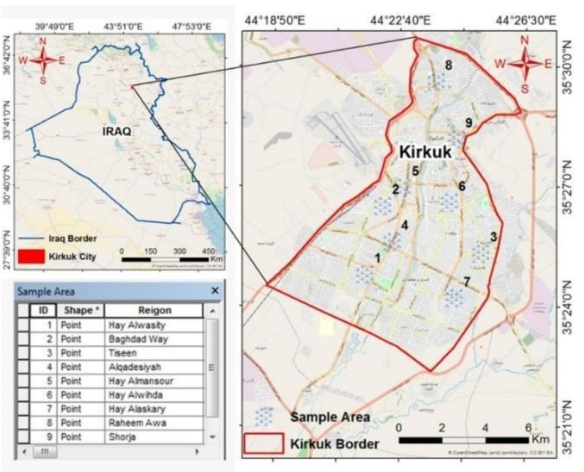


Fig. 1 Rainfall samples in the study area (Kirkuk).

We conducted fieldwork over two years at several sites in Kirkuk city. Nine sites were identified to collect rainfall samples from some regions in Kirkuk city. The samples covered the geographical areas which are (Hay Alwasity, Baghdad Way, Tiseen, Alqadesiyah, Hay Almansour, Hay Alwihda, Hay Alaskary, Raheem Awa, and Shorja). The samples were collected during rainy months from the study area at different times. The study period involved the two years 2021 and 2022. Furthermore, rainfall samples were collected and saved by the area name and then transferred to the laboratory to conduct laboratory tests. coordinates of sample areas have been determined using GPS. The study included laboratory analysis of the pH of each sample using two methods.

Furthermore, the quantity of precipitation per hour in each sample area has been collected via the RET-Screen Expert program. The recorded values represented the average monthly precipitation in each position. In addition, precipitation per hour from satellite images has been determined for the same period of study. In order to represent maps GIS-based techniques were adopted. Two methods have been used; Interpolation and Thiessen polygons.

Laboratory Measurements

Two types of measurements were used in order to measure the pH of rainfall water; a pH meter was used to measure the acidity and alkalinity of each sample and a wide range of pH test paper was used to detect the pH scale based on colors within thirty seconds of each sample (Figure 2). In order to compare acidity results we relied on Figure 3, pH scale (Butnariu and Samfira, 2013).

(a) (b)

Fig. 2 Laboratory tests using; (a) a pH meter, and (b) a wide range of pH test paper.

The pH scale is divided into 14 scales each scale represents a measure of acidity or alkalinity where 7 is neutral. A pH measure of less than 7 refers to acidity, whereas a pH of more than 7 refers to alkalinity. Normal rain has a pH measure of (5.0 - 5.5) (Butnariu and Samfira, 2013). However, typical acidic rain has a pH measure of 4.

GIS-Based Analysis

Geographical statistical interpolation was applied using ArcGIS and the method included all nine sites across all prediction sites. In this case, the precipitation sample data are determined using pH values as the input observation, where the goal is to predict the pH data for each site in the study area.

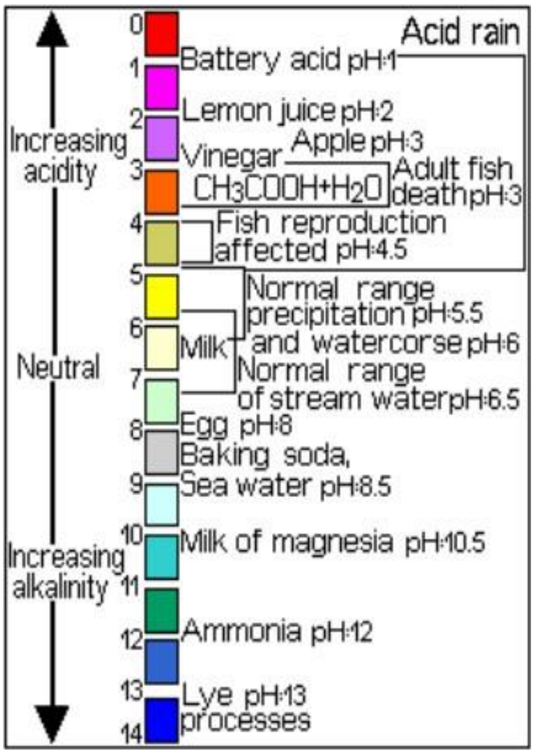


Fig. 3 pH scale (Butnariu and Samfira, 2013).

Inverse Distance Weighted IDW was used for the interpolation method and spatial distribution maps. The equation of IDW can be stated as;

$$\hat{z}(s_0)\frac{\sum_{i=1}^{n}(s_i)d_{i0}^{-2}}{\sum_{i=1}^{n}d_{i0}^{-2}} \qquad (1)$$

Where $\hat{z}(s_0)$ is the predicted point by IDW, $z(s_i)$ are the measurements at $i = 1, 2, \ldots, n$, locations. An inverse squared distance with an exponent -2 is applied to get weights. d_{i0} is the detached distance between s_0 and the s_i (Jumaah et al., 2019; Jumaah et al., 2023a).

For calculating average precipitation we used Thiessen polygons. Thiessen has come up with the first technique for calculating or estimating the average precipitation. The hypothesis of the technique is a set of polygons, each polygon encoded by the nominal value of each station. It is based on the point measurement of gage in a specific area. which defines the closer area to the gage then the assumption of the best estimation of rainfall in that region is determined by that point (Naoum and Tsanis, 2004). From the Thiessen polygons, we can attain the quantity and the kind of feature, which are the effecting factors in selecting a suitable and significant location, besides getting detailed data (Widaningrum, 2015). The average Precipitation can be calculated by the equation below;

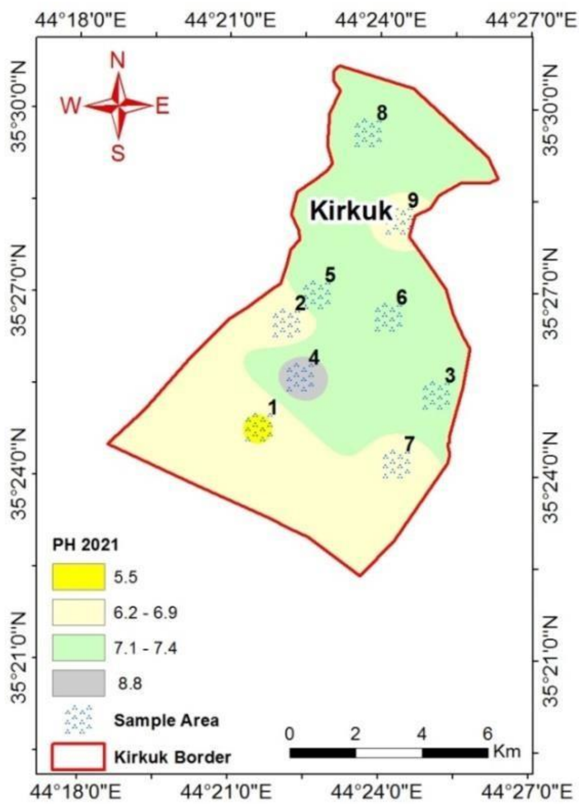
$$P = \sum_{i=1}^{n} \left(\frac{pi*ai}{Ta}\right) \qquad (2)$$

where, P is the precipitation rate by Thiessen's polygons, pi is the monthly precipitation data at i place, i is the gage station, ai is the area of polygon around the station, and Ta is the total area of the region (Davie and Quinn, 2019).

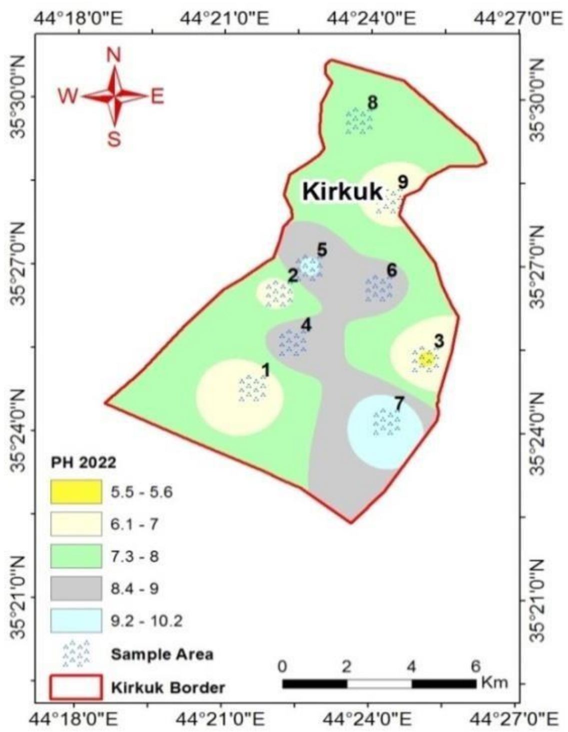
We also mapped the maximum rainy days in the study period based on remotely sensed images. The analysis involved downloading satellite images from NASA's EOSDIS an open-source code application. 30m resolution images in the tiff extension were processed using ArcGIS 10.3. The analysis involved converting from raster to polygon and interpolating the data to get the rainfall rates.
Integrated Multi-satellite Retrieval of Global rainfall (IMERG) displays rain rate in millimeters per hour. It is predicted for the Global Precipitation Measurement GPM/IMERG algorithm. This algorithm uses passive-microwave and infrared data. The NASA Precipitation Processing System (PPS) provides early predictions, and the high-quality final predictions are built 4 months after the calibration dataset became accessible like monthly rain-measure analyses.

Results and Discussion

Figure 4, represents rainfall pH data of Kirkuk city in; (a) 2021, and (b) 2022. While rainfall pH distribution accuracy ratings are represented in Figure 5.

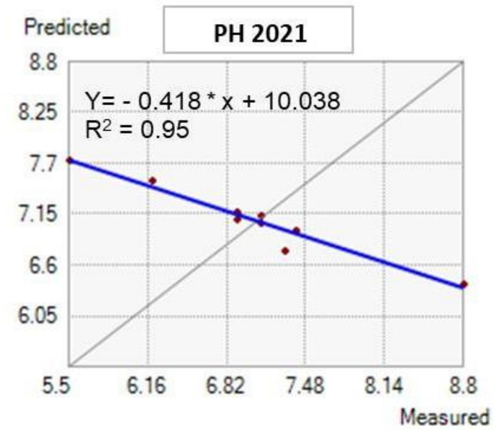


(a)

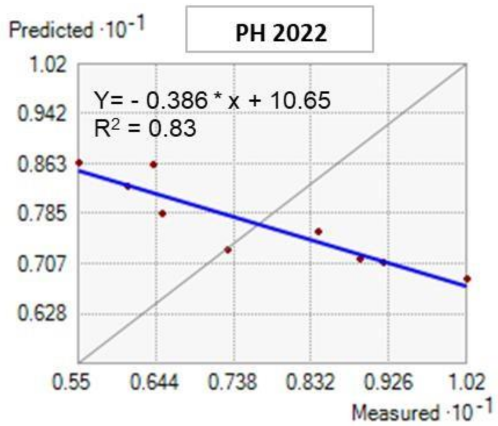


(b)

Fig. 4 Rainfall pH data of Kirkuk city in; (a) 2021, and (b) 2022.



(a)



(b)

Fig. 5. Rainfall pH distribution accuracy ratings of; (a) 2021, and (b) 2022.

The data of pH spatial distribution maps ranged between (5.5 to 8.8) and (5.5 to 10.2) for 2021, and 2022 prospectively. Some insignificant variation in pH measures of the rainfall in areas in Kirkuk was found. Some areas in the southern and south-eastern parts of the city showed the least acidity, other parts were within high values of pH more than 6 which refers to the alkalinity of rainfall water. In addition, the accuracy ratings obtained by spatial modeling from the ArcGIS environment were in high values (95% and 83%) for 2021, and 2022 models respectively.

Figure 6 represents Thiessen polygons of rainfall data. Based on Thiessen polygons, it's divided the study area into 9 areas based on sampling points. Each area is affected by the value of the sampling point. Based on equation (2), the estimated average precipitation data by Thiessen polygons were (282.6, and 394.2) mm in the years 2021 and 2022 respectively which represent lower values in comparison to previous years.

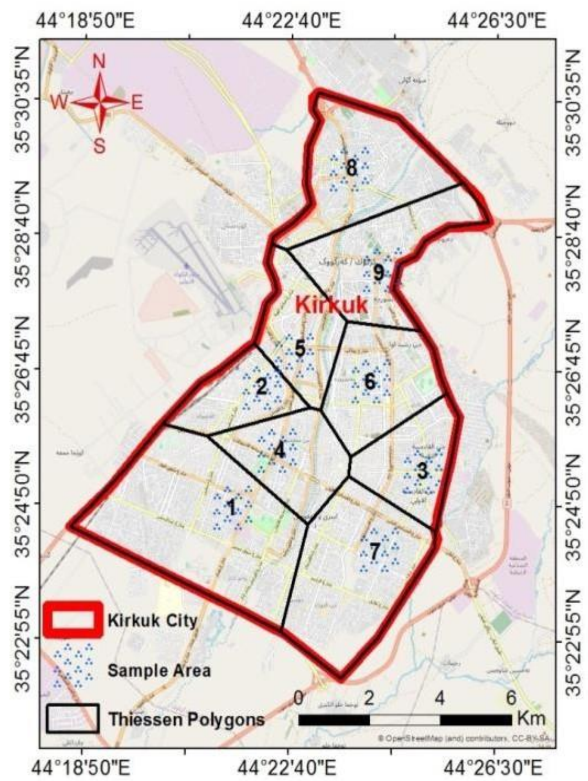
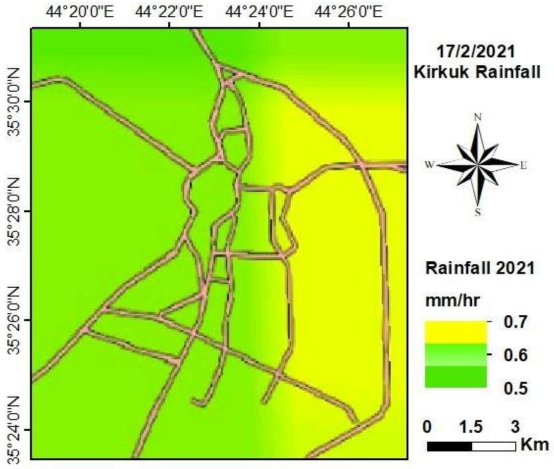
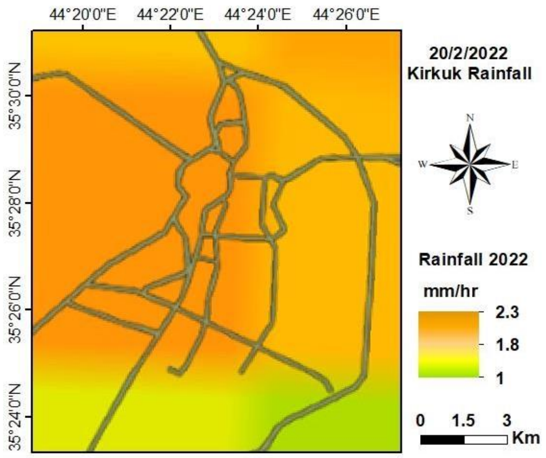


Fig. 6 Thiessen polygons of rainfall data.

Furthermore, the rainfall rate in Kirkuk city for; (a) 2021, and (b) 2022 is shown in Figure 7. Likewise, based on remotely sensed rainfalls data, the rainfalls in 2021 ranged between (0.5 and 0.7) mm/hr which represents the maximum rainy day, while in 2022 the maximum rainy day was on 20 Feb with ranges of (1 - 2.3) mm/hr.



(a)



(b)

Fig. 7 Rainfall rate in Kirkuk city for; (a) 2021, and (b) 2022.

Based on 2021 spatial distribution map data, regions 2, 7, and 9 showed normal ranges of acid rain of less than 7. While region 1 south of the city of Kirkuk recorded a pH value of 5.5 which is classified as less acidic. Other areas within the regions (3, 4, 5, 6, and 8) ranged from (7.1 to 8.8) which is considered as no acidic ranges and with increasing alkalinity.

Based on the 2022 spatial distribution map, regions 1, 2, and 9 showed normal ranges of acid rain which ranged between (6.1 to 7). However, region 3 over the southeast of the study area reported pH values in the range of (5.5-5.6) which were also low values and referred to as less acidic. On the other hand, the regions within 4 to 8 showed high pH values ranging between (7.3 and 10.2) reporting the alkalinity of rainfall water. The very high pH values were in regions 5 and 7 which ranged between (9.2 and 10.2) and were classified as high alkaline water. Based on Sameen and Al-Jumaily (2015) pH values ranged from 6.01 to 7.74.

The average precipitation was within low concentrations during the two periods of study. Lately, the study area has examined water scarcity and rainfall lack (Hadi et al., 2022). Generally, Iraq was suffering from a lack of rainfall (Habbeb et al., 2022; Jumaah et al., 2022), it lost a high water capacity in the past years, where rainfall reduced from the normal levels by 40% (Jumaah et al., 2023b). However, Kirkuk station has the lowest frequency of the Precipitation Concentration Index (PCI) (Al-Shamarti, 2016).

Conclusion

This research gathered rainfall samples from the rainy months of January 2021 to November 2022. The methodology is based on laboratory tests and GIS-based analysis. The pH status of rainfall in Kirkuk city is high. Laboratory tests showed high pH values, which ranged between (5.5 – 10.2). Therefore, the rainwater in the study area can be referred to as alkaline. The least acidity was found in the southern and southeastern parts of the city with a 5.5 PH value. Moreover, high validation accuracy was obtained indicating how precise the model was in predicting the values of unknown regions. Precipitation concentrations calculated by Thiessen polygons roughly coincide with daily precipitation obtained from remotely sensed images. Remote sensing and GIS techniques are best suited for estimating and modeling. Besides its health effects, acid rain has a detrimental impact on buildings it accelerates the corrosion of materials, causes discoloration and staining, damages roofing materials, weakens masonry, and poses a threat to historical and cultural heritage. As the study area has recently faced high levels of air pollution, it is recommended to apply new research on acid depositions. Consequently, it is essential to implement measures to reduce acid rain, such as controlling sulfur dioxide and nitrogen oxide emissions, to mitigate these negative effects on buildings and preserve our architectural and cultural heritage.

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