

**The Best routes to placement the Piezoeleric
in holy Karbala using remote sensing and
GIS techniques**

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Abstract:

In this work explores the optimal placement of piezoelectric energy harvesting systems in the holy city of Karbala, Iraq, using (RS) and (GIS) Techniques. Piezoelectric technology, which converts mechanical energy from foot traffic and vehicular movement into electricity, offers a sustainable energy solution for high-pilgrimage areas Case Study (Arbaeen anniversary). By integrating spatial data, including pedestrian density, road networks, and land use patterns derived from satellite imagery and GIS analysis, this research identifies the most suitable locations for piezoelectric installations to maximize energy generation. Multi-criteria decision analysis (MCDA) techniques were applied to evaluate factors such as urban mobility, religious event schedules, and infrastructure suitability. The results highlight key zones near holy shrines (Al-Abbasia and, Al-Hussinaa) walkways, and major roads where piezoelectric tiles can efficiently harness energy from the constant movement of pilgrims. The Roads map results were extracted using the Arc-GIS Pro software.

Keywords: Holy Karbala, Arabian anniversary, Pilgrimage Routes, Piezoelectric energy, sustainable energy, Mlti-criteria analysis.

Introduction

The holy city of Karbala witnesses massive pedestrian movement, especially during religious events such as Arbaeen, where millions of pilgrims walk on designated routes. Harvesting energy from foot traffic using piezoelectric sensors presents a sustainable solution for powering streetlights, (Hamad, Ali, & Hassoon, 2022) charging stations, and other urban infrastructure. This project aims to identify the best routes for piezoelectric sensor placement by analyzing pedestrian density, road

types, and surface conditions using Remote Sensing (RS) and Geographic Information Systems (GIS) (Hassoon & Ali, 2021)

With the world's preoccupation with renewable energy sources such as wind, sunlight, rivers, seas, and others, some have turned to using the human body as a generator of electrical energy. Research is currently competing to find the most successful innovations to extract this type of economical electricity) Kareem & Hassoon, 2023)

.One researcher measured the electrical power that can be generated by a person jogging for minutes at approximately 1,000 watts. This means that the resulting electricity could be used in various applications, such as powering mobile phones, laptops, and music players. As nanotechnology enters its practical stages, others are considering a shoe that generates electricity up to 20 watts while walking. This innovation's design involves the passage of a trapped fluid (Khalid, Ahmed, & Khaleel, 2024).

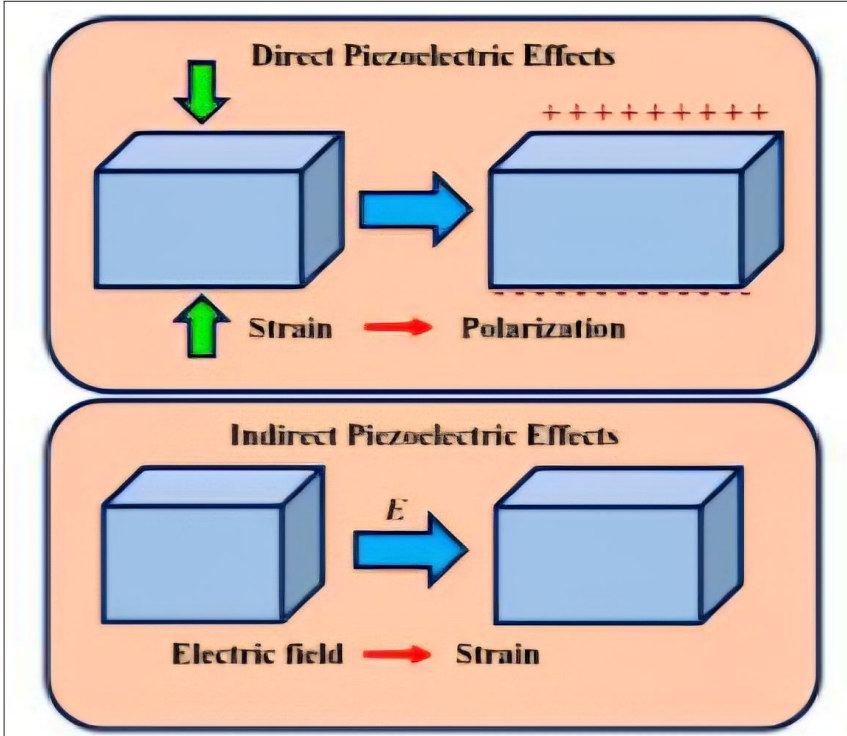
into one of two chambers at the bottom of the shoe, the first located under the instep and the second under the heel. When the instep is pressed, this fluid is forced through an electrical generator, which absorbs the energy and converts it into electricity. The fluid then reaches the chamber below the heel. When the person steps with their heel, this fluid is expelled back to the first chamber it came from, passing through the electrical generator, and so on (Curies & Curie, 1880) .

Most innovations in extracting electrical energy from body movement have faced numerous challenges in design methods and cost. In the case of the aforementioned shoe, many questions arise, most notably the user's comfort level when wearing this shoe while walking and how to connect it to electrical devices (Piezo Products, n.d.).

Piezoelectric energy

The word piezo originates from the Greek word piezein ,meaning pressure. Piezoelectricity is the process of using crystals to convert mechanical energy into electrical energy, or vice versa. It is the ability of certain materials to generate alternating current (AC) voltage when subjected to mechanical pressure or vibration, or to generate vibration when subjected to AC voltage. Piezoelectricity is found in many of the electronic devices we use in our daily lives, from quartz watches to speakers and microphones. Jacques and Pierre Curie discovered the piezoelectric effect in 1880. They found that pressure applied to a quartz crystal generates an electric charge in the crystal, which is the direct property of this effect. Later, they also verified that an electric field applied to the crystal causes the material to deform, thus discovering the inverse property of this effect (Kwok, Lai, Chan, & Choy, 1997)).

The piezoelectric effect converts vibrational kinetic energy into electrical energy, i.e., It is the ability of certain materials to generate an electrical charge in response to applied mechanical stress. Piezoelectric generators (energy harvesters) provide a powerful and reliable solution by converting wasted vibrational energy in the environment into usable electrical energy. They are therefore ideal for applications that require charging batteries, supercapacitors, or directly powered remote sensing systems. This piezoelectric effect has two properties: the first is direct piezoelectricity, or the direct effect, meaning the material has the ability to convert mechanical stress into electrical charge. The second is indirect piezoelectricity, or the reverse effect, where the applied electrical potential is converted into mechanical strain energy. Figure (1) illustrates the direct and indirect piezoelectric effect) (Hassan & Khanjer, 2023)



Objectives

- Map high-traffic pedestrian routes in Karbala using GIS and satellite imagery.
- Analyze road surface types (asphalt, concrete, etc.) to determine suitability for piezoelectric tiles.
- Estimate potential energy generation based on pedestrian flow data.
- Recommend optimal locations for piezoelectric sensor installation to maximize efficiency.

3. Methodology

1. Data Collection

- Satellite & OpenStreetMap's: High-resolution images to classify road types and pedestrian pathways.
- Crowd-Sensing Data: Mobile GPS data, Wi-Fi hotspots, and social media check-ins to track movement patterns.
- Field Surveys: Ground truthing to verify road materials and foot traffic intensity.

2. GIS Analysis

- Spatial Overlay: Combine pedestrian density maps with road surface data.
- Network Analysis: Identify key routes (main roads, secondary paths, and pilgrimage routes).
- Suitability Modeling: Use weighted criteria (traffic volume, surface durability, proximity to power needs).

Expected Outcomes

- A GIS-based suitability map highlighting optimal piezoelectric sensor locations.
- Energy generation estimates for different routes.
- Recommendations for integrating piezoelectric tiles into urban planning.

Results and Discussion

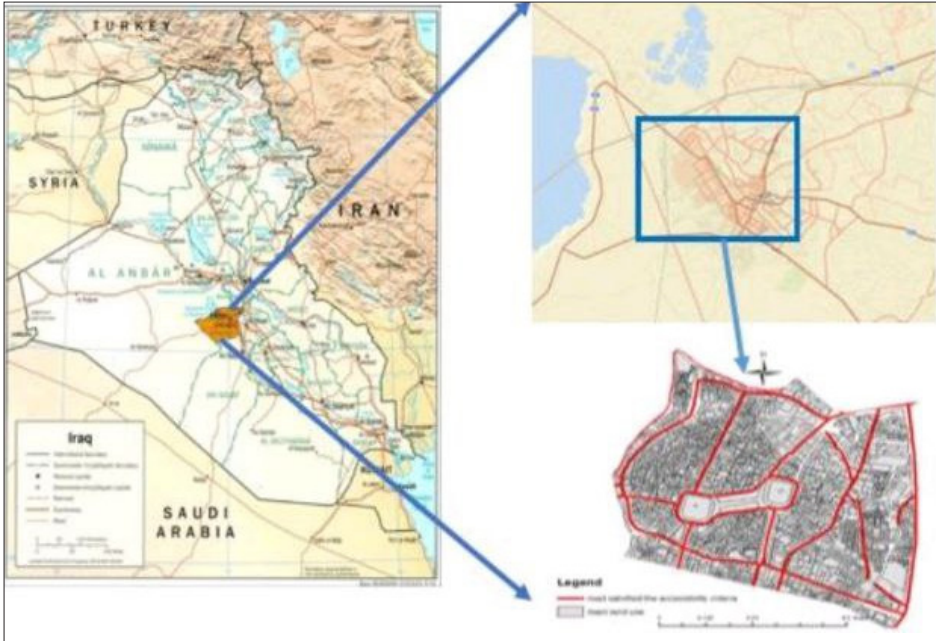


Figure .2 the location of holy Karbala in Iraq and the routes taken by Pilgrimages.

The Interactive Holy Karbala Map

This project is an interactive web application that displays all the main and secondary roads in the holy city of Karbala, with a focus on the routes leading to the shrines of Imam Hussein and Imam Abbas (peace be upon them).

Achievements

A. Geographic Data Collection and Analysis A)

- Comprehensive data was obtained from OpenStreetMap for the city of Karbala.
- Extracting and filtering road and route data.
- Determining the precise coordinates of the two holy shrines.
- Converting the data to Geo JSON format for use in the application.

B. Interactive Application Developmen

- Creating a modern, responsive React application.
- Integrating the Leaflet library for interactive maps.
- Designing an attractive user interface that is appropriate for the religious theme.
- Full support for the Arabic language and right-to-left text.

C. Interactive Features

- Interactive display of all road types with clear color coding.
- Ability to filter roads by type (main, secondary, pedestrian, etc.).
- Special signs for the two holy shrines with detailed information.
- Pop-up windows that display road information when clicked.
- A comprehensive map key that explains the meaning of colors and icons.

D. Design and Experience

- Responsive design that works on all devices.
- Calm colors that are appropriate for the religious theme.
- Easy-to-use interface. Easy to use and understand.
- Fast performance and efficient data loading.

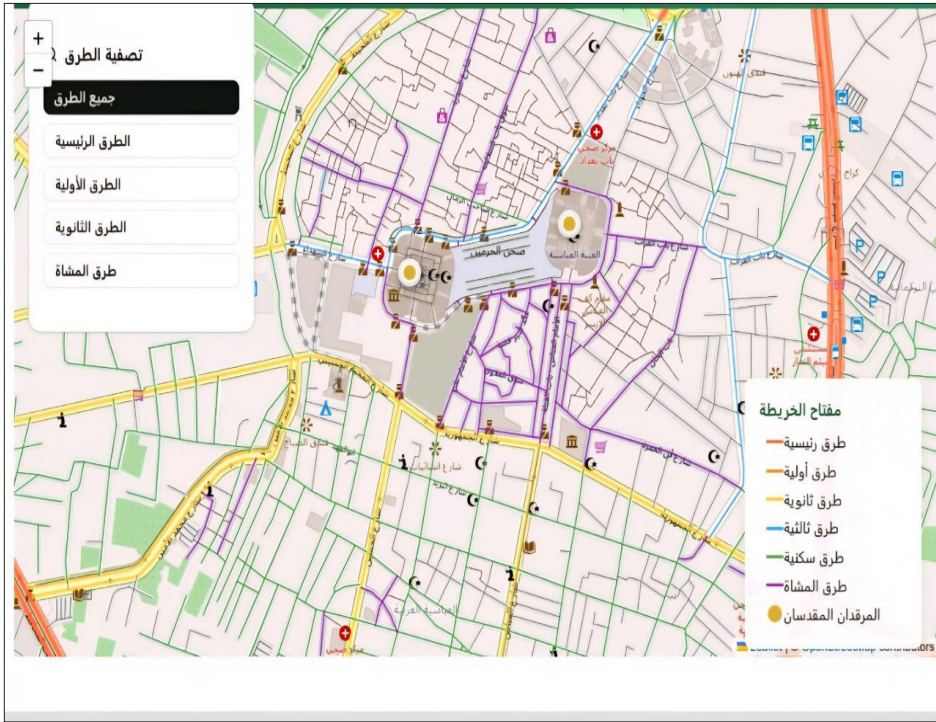


Figure 3. Interactive map of Holy Karbala

Conclusion

This project will provide a data-driven approach to deploying piezo-electric energy harvesting in Karbala, ensuring maximum efficiency and sustainability. By leveraging GIS and Remote Sensing, we can transform high-traffic pilgrimage routes into smart, energy-generating pathways.

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Spatial-Temporal Distribution of Particulate Matter in holy Karbala Governorate by using Remote Sensing Dataset and GIS

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Abstract:

Karbala is one of the most sacred religious cities in Iraq, visited by millions of pilgrims from all over the world, especially during important religious seasons, such as Ashura and the Al-arbaeen pilgrimage, which leads to millions of crowds. This study addresses the temporal and spatial distribution of PM_{2.5} particulate matter in Karbala Governorate using remote sensing data and techniques and Geographic Information Systems (GIS) software. PM_{2.5} particulate matter are considered hazardous air pollutants associated with respiratory and cardiovascular health risks, and their risks increase in crowded areas, especially during the annual gatherings of millions of pilgrims.

The study used satellite data to monitor the concentration levels of these particles during the Al-arbaeen pilgrimage period and analyzed them geographically using GIS to identify the areas most exposed to pollution within the city and surrounding areas during the period January-December, 2024. The results showed variations in particulate matter concentrations across locations and time periods, with the highest values recorded in areas close to the holy shrines and on the main roads leading to them, where transportation and human activity increase. Seasonal weather conditions also affected the accumulation of pollutants, especially during periods of high crowd density, which increases particulate emissions due to increased activities and vehicle traffic.

The study emphasizes the need to use remote sensing and geographic information systems (GIS) technologies as effective tools for monitoring air quality in the holy city of Karbala, given their critical environmental and health importance in light of the large number of pilgrims. This contributes to advance planning and the necessary measures to reduce pollution and protect the health of the governorate's indigenous population and visitors.

Keywords: Karbala, PM_{2.5}, WHO, Al-arbaeen pilgrimage, Ventusky

Introduction

The use of remote sensing data and GIS tools in monitoring and management of the environmental conditions within Karbala Governorate has become an essential scientific research due to the rising need of accurate, timely, and affordable environmental data to aid in sustainable management of resources and urban design and planning (Kadhim et al., 2023). During the past decades, the development of satellite imaging and geospatial analysis altered the environmental assessment practice to the extent that land use, water body, and ecological changes could be evaluated in detail (Sameer, 2023). The importance of the technologies in question is especially apparent during the fast urbanization of Karbala, depletion of water resources, and land cover changes, which pose dangers to the ecological balance and socio-economic growth (Aal-shamkhi et al., 2017). Several studies have reported significant decreases in areas covered by water and significant growths of urban land and the necessity of efficient monitoring tools (Rashed et al., 2024; Mohammed et al., 2018). Regarding particulate matter pollution, remote sensing data together with Geographic Information Systems (GIS) can be successfully used to analyze the spatial-temporal pattern of PM_{2.5} and PM₁₀ distribution in Karbala. With this approach, air quality can be mapped at high-resolutions, revealing important spatial variations and possible health-related threats associated with particulate pollution. Such circumstances as seasonal weather conditions and mass events, like the pilgrimage Arbaeen, affect the distribution of PM_{2.5} and PM₁₀ in the region greatly. The meteorological factors and air pollutants interaction is intricate which causes significant changes in the air quality all through the year, especially during mass gatherings. Arbaeen pilgrimage, visited by millions of people, adds to ve-

hicular emissions and causes the generation of dust, therefore, increasing particulate matter concentration. Such events are particularly dangerous due to combined high temperatures and high PM, and this aspect needs special public health measures (Nsour, 2020).

Past studies give a evidence about these dynamics. As an example, the article by (Aghababaeian & Etedali 2024) has not dealt specifically with the influence of seasonal weather and mass presence on the distribution of PM but with the health risks of dangerous weather conditions during Arbaeen. Their study raises the extreme temperature and dust storms that are typical of the Iraqi summers which increase the levels of PM. In the meantime, such studies as that by (Ali et al. 2024) established that the air quality tends to be solider during winter months, and a considerable rise in particulate matter during summer months with PM_{2.5} as the prevailing pollutant on 84-88 percent of days. Nevertheless, this paper did not particularly examine the impacts of mass events. Moreover, (Al-Anbari et al. 2018) noted the highest levels of PM_{2.5} in December, April, and May, which may be caused by seasonal weather patterns and a rise in vehicles emissions related to large events like the Arbaeen pilgrimage. Although such events generate the spikes in pollution, they do trigger the local authorities to implement the air quality management strategies, which might result in the improvements of the air quality monitoring and preparedness in the long-term perspective.

Materials and Methods

1. Study Area:

Karbala Governorate is located in the central region of Iraq at the geographical coordinates of latitude (320:12'00.0" to 320:48':00.00") N and longitude of (430:30'00.00" to 440:18':00.00") E, Fig.1. It represents one of the most important governorates in terms of its geographical and religious location, as it contains the shrines of Imam Hussein ibn Ali and his brother Abbas (peace be upon them), making it a destination for millions of visitors annually, especially on major religious occasions such as the Arbaeen of Imam Hussein.

It is bordered to the north by Baghdad Governorate, to the east by Babil Governorate, to the south by Najaf Governorate, and to the west by Anbar Governorate. The governorate covers an area of approximately 5,034 km². According to estimates by the Central Statistical Organization for the year 2023, the governorate's population reached approximately 1.4 million people, distributed between the city center (Karbala) and a number of its affiliated districts and sub-districts, such as Ain al-Tamr, al-Hindiya, and al-Hur (Euaa, 2024).

According to the Köppen climate classification, Karbala falls within the hot desert climate (BWh), experiencing long, extremely hot summers, with temperatures often exceeding 45°C during July and August, while winters are mild to cool, with temperatures sometimes dropping below 10°C in January. Rainfall is low, typically not exceeding 100–150 mm annually, concentrated in the winter months (November to March) (Weam and Iman, 2021). It is also occasionally exposed to dry northwesterly winds, known locally as the Northern wind which can contribute to dust storms at certain times of the year.

Figure 1: The location of the study area

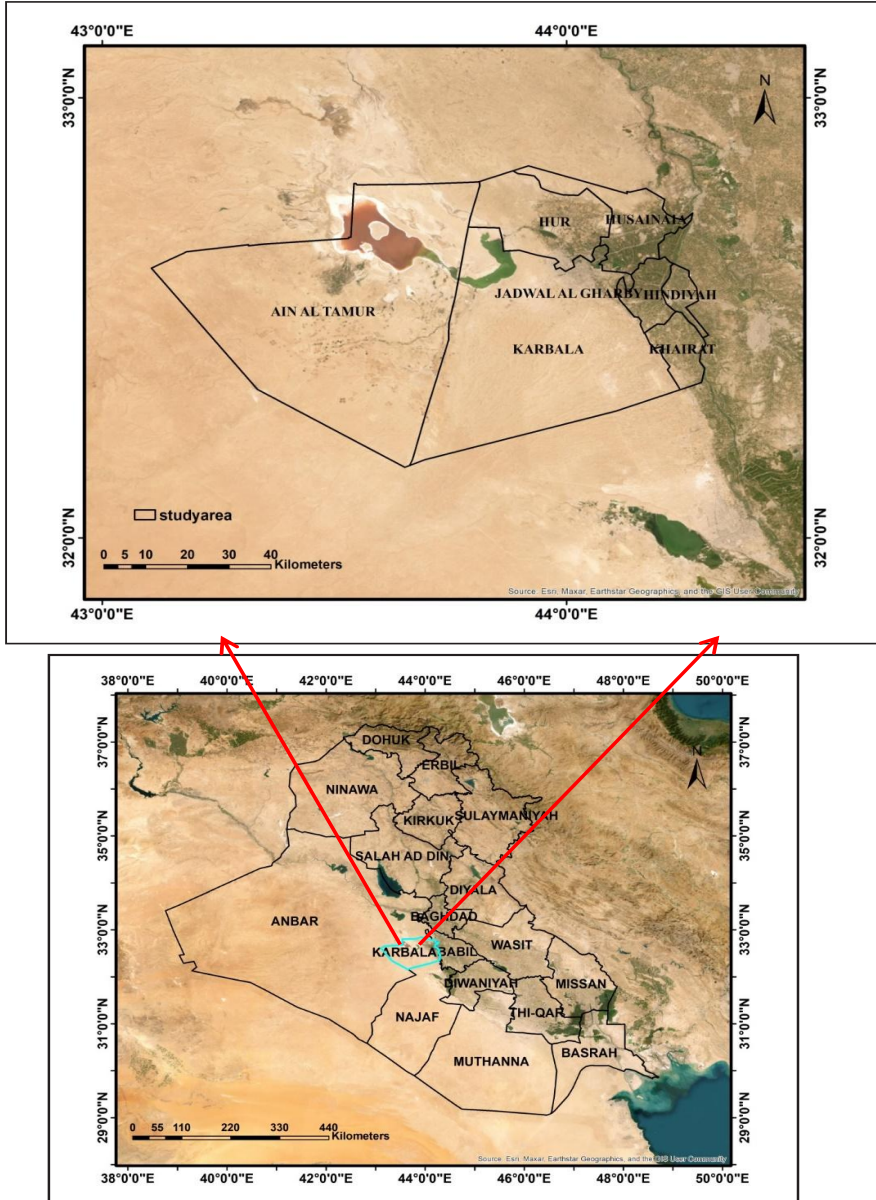


Figure 1: The location of the study area

2.Data sources:

As previously mentioned, the holy city of Karbala is one of the most important religious centers in Iraq and the Islamic world, attracting millions of pilgrims annually. Population density and traffic peak during major religious occasions, most notably the Arbaeen pilgrimage, due to the shrines of Imam Hussein and his brother Abbas, peace be upon them. This high density of pilgrims and vehicles, particularly in the city center of Karbala and the areas surrounding the Two Holy Shrines (such as the Hussein and Abbas neighborhoods, and Al-Rawda Street), contributes to high levels of air pollution, particularly particulate matter (PM2.5). Due to the absence of permanent environmental monitoring stations dedicated to measuring air pollutants inside the borders of the Karbala Governorate, the current study relies on data gathered via the Ventusky website. Six sites were selected and the PM2.5 data were downloaded based on the geographical distribution illustrated in Fig. 2.

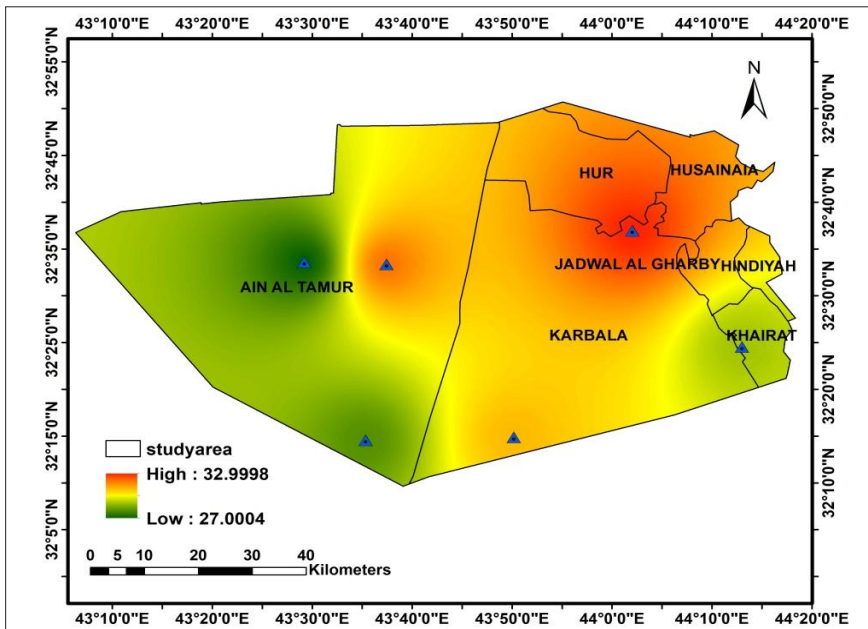


Figure 2: location of the selected sites

The data included daily coverage for the entire year 2024, enabling high-resolution analysis of temporal variations. After collecting the data, it was organized and processed using statistical analysis software and spreadsheets, and divided into four groups representing the climatic seasons (spring, summer, fall, and winter). The seasonal averages for each particle type were then calculated, along with the annual average, which represents the overall average for 2024. Ventusky uses the Automatic/Global SIL-AM model (<https://www.ventusky.com/>) to extract Aerosol Optical Depth (AOD) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua and Terra satellites with a spatial resolution of 1 km * 1 km.

Results and Discussions

Notably, the research confirms the vulnerability of Karbala's environmental system to rapid urbanization and climate-related challenges. The observed particulate matter distribution patterns underscore the necessity of targeted air quality management strategies, particularly during high-risk periods such as summer months and major holy visit events. The interaction between meteorological factors and air pollutants emerged as a particularly nuanced aspect of our investigation. The data reveals that the climatic elements and human activities collectively influence particulate matter concentrations, presenting a complex environmental challenge that requires multifaceted intervention approaches. Previous studies focused on health risks during extreme weather, while our study provides a more comprehensive spatial analysis of pollution dynamics. This approach offers local authorities and policymakers a more detailed understanding of environmental conditions, potentially informing more effective urban planning and public health strategies. In Fig. 3 a high value of PM 2.5 concentrate at south of Karbala governorate during winter season, while lowest value

concentrate at east and west of the governorate. Our findings reveal a significant correlation between high PM_{2.5} concentrations and potential health risks, which align with and extend previous epidemiological research in urban environmental health. The observed particulate matter levels in our study area substantially exceeded recommended regular thresholds, suggesting an urgent need for targeted intervention strategies.

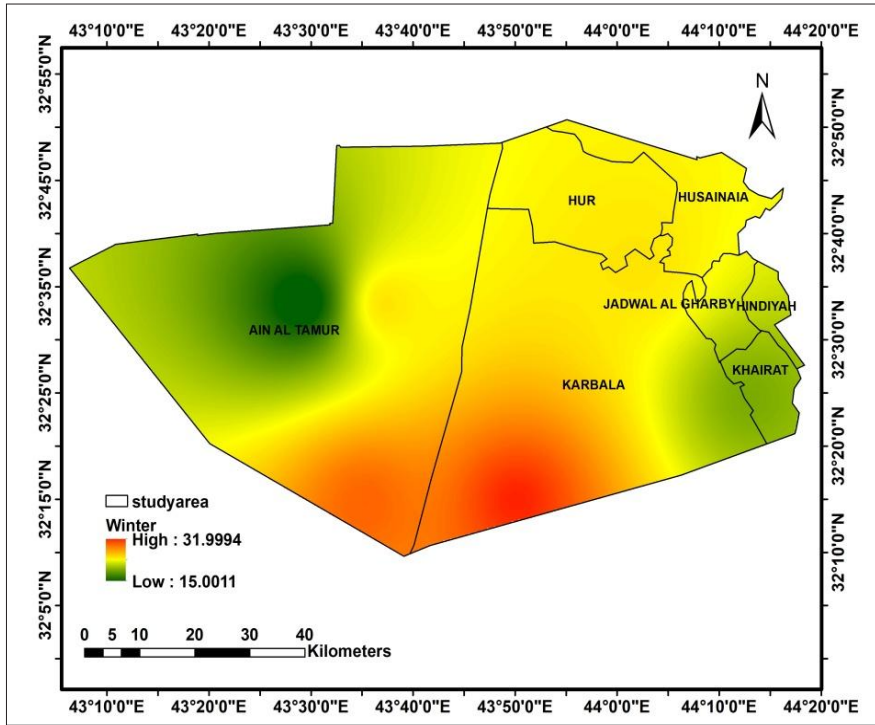


Figure 3: Spatial distribution of PM_{2.5} in winter

In Fig. 4 a high value of PM 2.5 concentrate at east of Karbala governorate during spring season, while lowest value distribute at the central part of the governorate.

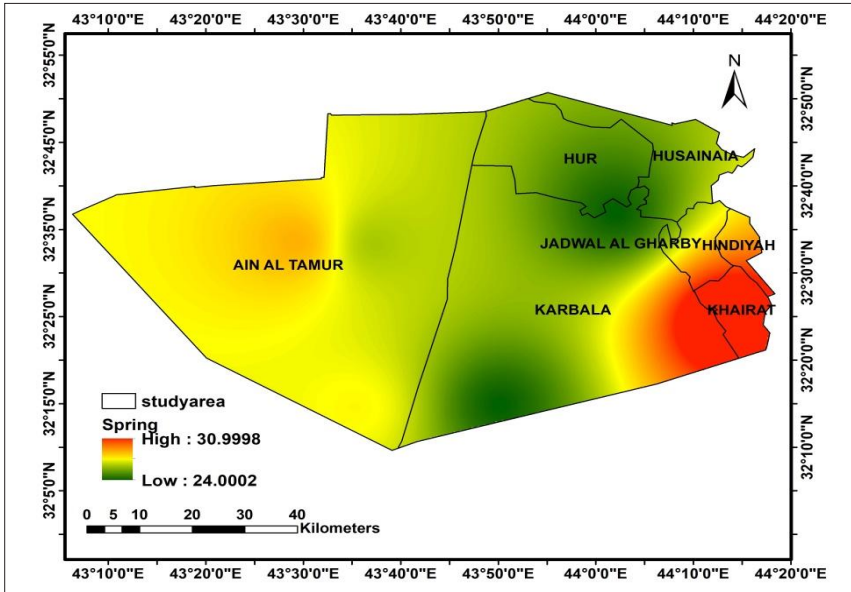


Figure 4: Spatial distribution of PM2.5 in spring

In Fig. 5 a high value of PM 2.5 concentrate at northern part of Karbala governorate during summer season, while lowest value align at the southern part of the governorate.

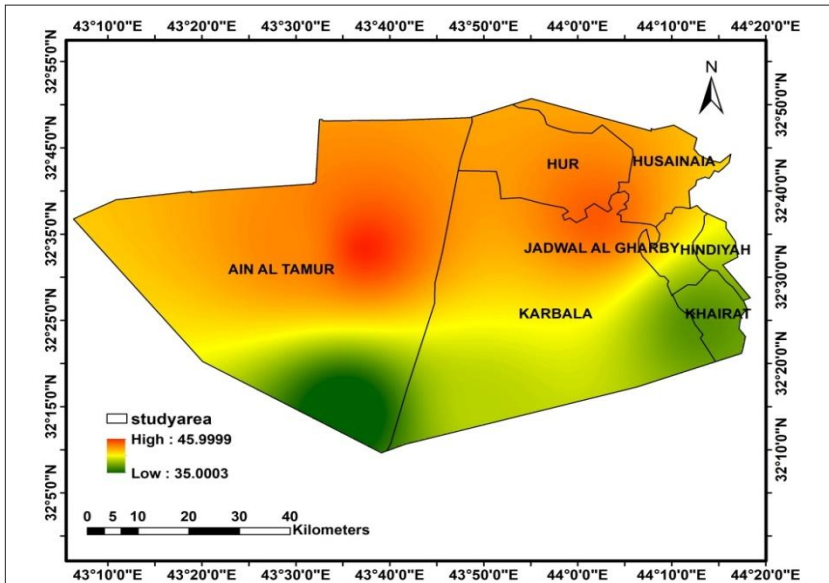


Figure 5: Spatial distribution of PM2.5 in summer

In Fig. 6 during autumn season a high value of PM 2.5 concentrate at center of Karbala governorate, while lowest value distribute at the western part of the governorate.

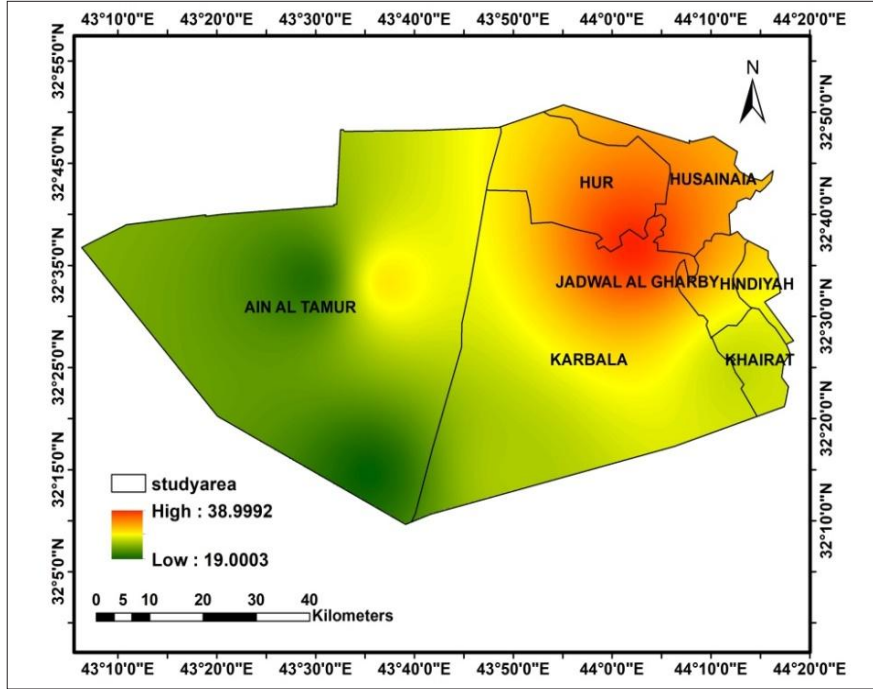


Figure 6: Spatial distribution of PM2.5 in Autumn

The annual average of PM2.5 reveal to high concentration of PM2.5 at capital city of Karbala governorate which is the holy city of Karbala Fig. 7. This might back to the high density of urbanization and holy events during the year, Fig. 8 and 9. Therefore, an action required to reduce the risk of PM 2.5 in that area.

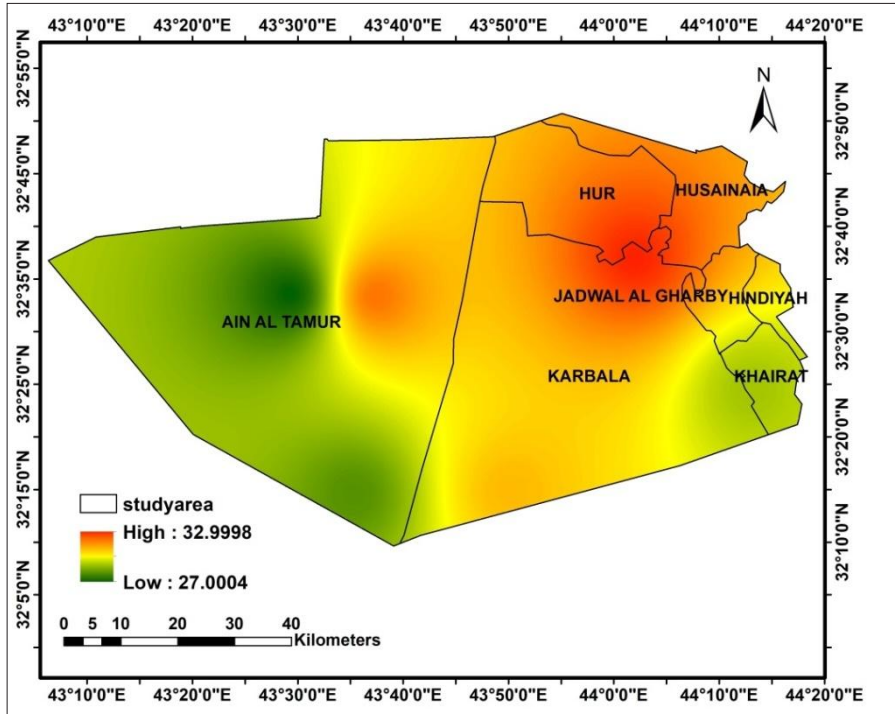


Figure 7: Annual spatial distribution of PM2.5



Figure 8: Al-Abbas's Holy Shrine during the Arbaeen Pilgrimage 2024

(25 August, 2024)



Figure 9: Al-Abbas’s Holy Shrine after the Arbacaen Pilgrimage 2024 (24 Sept. 2024)

Table 3 lists the min. and max. annual PM2.5 concentrations according to the maps (2-6).

Table 3 : The seasonal and annual PM2.5 values of the 2024 in Karbala

Seasons and annual	PM2.5 values 2024	
	Min.	Max.
Winter	15.0	32.0
Spring	24.0	31.0
Summer	35.0	46.0
Autumn	19.0	39.0
Annual	27.0	33.0

The results shows, that seasonal climate changes significantly affect the spatial distribution of particulate matter in Karbala Governorate. In the summer, high temperatures, low humidity, and increased wind speeds resuspend fine particles in the air, leading to higher concentrations, especially in urban and open areas. In the winter, low temperatures and relatively calm air movement lead to increased particulate accumulation in the layers near the ground surface, particularly in densely populated residential areas with household emissions. During spring and fall, a marked variation in spatial distribution is observed due to the continuous changes in wind patterns and temperatures, making some areas more susceptible to particulate matter accumulation than others. This seasonal variation highlights the importance of understanding climate factors in assessing the risks of particulate matter pollution and planning mitigation measures.

The results of the analysis indicated that the concentration of PM_{2.5} in the Karbala Governorate was higher than what was allowed by both Iraqi national environmental standards and World Health Organization (WHO)-approved environmental standards (10µg/m³) (Profile on Environmental and Social Considerations in Iraq, 2011, WHO 2006) as shown in Fig.10. High amounts of air pollution are present, as indicated by this exceedance, directly endangering the environment and public health. Because these tiny particles can worsen existing health problems and raise rates of morbidity and mortality, this pollution is especially concerning for vulnerable groups, particularly individuals who have chronic respiratory disorders like lung disease, bronchitis, and asthma.

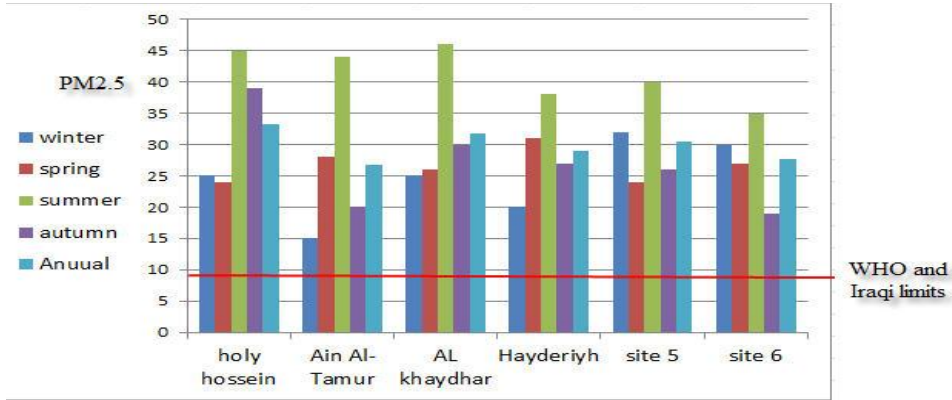


Figure 10: Comparing PM2.5 concentration levels to WHO and Iraqi regulatory standards

Conclusions

In conclusion, the integration of remote sensing data and GIS techniques is a crucial tool for effectively monitoring and managing the environmental challenges faced by Karbala City, particularly in light of rapid urbanization and significant air pollution from events like the Arbaeen (40) visit. The study on the temporal and spatial distribution of PM2.5 (particulates matter) in Karbala city using remote sensing data and GIS software has shed light on the hazardous air pollutants associated with respiratory and cardiovascular health risks. The analysis of satellite data during the Al-Arbaeen visit period discovered variations in particulate matter concentrations across locations and time periods, with the highest values recorded in areas close to the holy shrines and main roads, where transportation and human activity increase, especially during periods of high crowd density. This emphasizes the essential need to employ remote sensing and GIS technologies as effective tools for monitoring air quality in the holy city of Karbala, particularly due to the significant health implications for the large number of visitors and the native population, leading

to the advancement of planning and measures to reduce pollution and protect public health. The findings highlight the importance of addressing air quality concerns in pilgrimage sites and the surrounding areas, especially during important religious seasons, and highlight the potential impact of seasonal weather conditions on particulate matter accumulation, calling for proactive measures to mitigate the associated health risks. Overall, this study provides valuable insights into the environmental and health challenges in Karbala and presents a compelling case for the integration of advanced technologies in environmental monitoring and management to safeguard the well-being of the local population and visitors. The findings underscore the urgent need for enhanced air quality management strategies to safeguard public health and ensure sustainable resource management in this ecologically sensitive region.

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