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Health Impacts Assessment of Air Pollution in Iraq for Sustainable Management

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Abstract
Due to the intensive growth of cities, the industrial pollution, the oil production processes, the crowding of traffic jams, and the dust storms that become more frequent every day, air pollution in Iraq is turning into one of the most serious environmental and health issues of the country. This paper uses remote sensed satellite data as incorporated with Geographic Information Systems (GIS) to evaluate the prevailing condition of air quality in Iraq. The sensor data (NO_2, and SO_2) of Sentinel-5P and Aerosol Optical Depth (AOD) of MODIS were handled to identify the spatial and temporal changes in atmospheric pollutants in the latest monitoring duration. The GIS technique of spatial analysis, interpolation, hotspot mapping, time trend analysis and correlation with land-use patterns were used to determine the pollution hotspots in large cities like Baghdad, Basra, Kirkuk and Mosul. Findings indicated that there were increasing concentrations of NO_2 and SO_2 in the areas surrounding industries and oil-producing areas and high values of AOD were always recorded during the dust-storming season which was the most active in the central and western parts of Iraq. Combination of satellite data with GIS offered a complete, factual picture of distribution of pollution in regions that did not have ground-based monitoring stations. The study identifies the necessity of remote sensing and GIS technologies in aiding the national air-quality assessment and environmental policy, as well as the early-warning systems in Iraq.

Keywords: Air Pollution, AOD, Emission, GIS, Iraq

1. Introduction

Air pollution has become one of the most urgent environmental and social problems in the Middle East, and Iraq can be surely considered a case of one of the acute problems, as it has a complicated set of geopolitical and unstable situation, urbanization, industrial growth, and climate susceptibility [1]. During the last 20 years, Iraq has undergone severe social and economic changes which have changed the trends in the consumption of energy, the growth of transportation demand and industrial activity [2]. This, together with the residual impact of military warfare [3], as well as the destruction of the environment has resulted in a high level of air pollution in the major Iraqi cities of Baghdad, Basra, Kirkuk, Mosul and Najaf [4]. Consequently, Iraq is always in the list of the countries with the largest meanings of PM2.5 and PM10 per year, which is extremely harmful to human health, the stability of the ecosystem, and the economic output in the long term [5].

Air pollution in Iraq is complex and has several causes, the oil and gas industry are one of the key contributors and the mainstay of the national economy [6]. Iraq is also among the largest producers of crude oil in the world, and the activities that are related with the extraction, flaring, refining, and transportation of crude oil release immense amounts of pollutant gases such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and fine particulate matter [7]. Flaring of gas on its own, usually without proper environmental regulations, has led to very high levels of greenhouse gases and other dangerous pollutants, especially in the areas of Basra and Kirkuk where energy infrastructure is centralized [8]. Besides industrial pollution Iraq has a growing transport sector with no modern regulations [9].

High usage of old vehicles, low fuel quality, and absence of social transportation systems, as well as the overcrowding network of urban roads, can be noted as the most influential factors in the production of NOx, carbon monoxide (CO), hydrocarbons, and particulate matter [10].

Along with the anthropogenic causes, natural causes contribute to the air pollution issue in Iraq [11]. The nation is situated in the midst of one of the dust storm corridors in the world. Increasing frequency and intensity of dust storms have been experienced in the recent past due to environmental degradation, loss of vegetation cover, water scarcity, desertification as well as upstream damming of rivers [12]. These storms move huge amounts of mineral dust and fine particulate matter throughout Iraq, decreasing the visibility, interrupting transportation, influencing agriculture, and worsening respiratory diseases. Climate change also exacerbates these struggles by raising the level of temperatures, extending the duration of droughts, and accelerating the process of land degradation, which in combination increase the process of dust storms [13]. As a result, the air quality of Iraq is very complex as there are both regular anthropogenic emissions and sudden natural dust events [14].

Air pollution has severe health effects, which are prevalent in Iraq [15]. Many studies have developed a solid correlation between air pollutants, and air pollution, in particular, PM2.5, and adverse health effects including respiratory conditions, cardiovascular diseases, cancer, poor pregnancy results, and early mortality [16]. Hospitals record high numbers of cases related to asthma, chronic obstructive lung disease and other diseases caused by pollution, especially among the children, the old and those with co-existing conditions. In highly industrialized or overcrowded areas, the compounding effects of the long-term exposure to pollutants may reduce the lifespan and create a huge burden to a healthcare system [17]. In addition, the economic price of air pollution goes far beyond the healthcare expenditures and includes labor productivity, agricultural performance, infrastructure repair, and national development objectives [1]. With the quest of Iraq to rebuild and modernize its economy, the issue of air pollution has become a very crucial requirement to sustainable development [18].

The systematic air quality monitoring and regulation implementation has not been great in Iraq even though the situation is very serious [19]. The current monitoring systems lack completeness since they are in many cases outdated and cannot deliver real-time, spatially extensive information [20]. In many areas, there is not even a single functioning monitoring station, and thus, it is hard to determine pollution patterns, where the hotspots of emissions are, or even to determine the usefulness of mitigation tools [21]. Lack of a strong environmental laws and enforcement tools also worsens the situation since the operators in industries might not be willing to comply with global standards of emissions. The development of an integrated national air quality management framework has not been done due to institutional issues, little technical capacity and less funding [22]. Nonetheless, recent activities on the part of academic researchers, environmental authorities, and international bodies have seen the increased realization that there is need to enhance monitoring, modeling, and policy interventions [23].

The new technologies have offered good opportunities to deal with the air pollution problem in Iraq. Remote sensing, geographic information systems (GIS) are being employed more and more to trace pollution patterns, map sources of emissions and evaluate the spatial distribution of pollutants [24]. Observations made by satellites provide useful data especially where on-ground stations do not exist. Rapidly evolving air quality models (Gaussian dispersion models, Eulerian grid models and hybrid data-driven models) are in use to characterize dispersion of pollutants and assess mitigation possibilities of the same. The tools can assist the policy makers to come up with evidence-based policies to limit emissions, safeguard citizen health, and develop sustainable development [25].

To summarize, the problem of air pollution in Iraq is multifactorial and complex, which depends on the industrial activity, emissions of transport, urbanization, natural dust storms, and the climate. The issue has severe health, environmental and economic implications and as such, it is a national science priority and a policy agenda. With Iraq still rebuilding and on its way to modernization, it is necessary to come up with powerful measures of air quality management due to the support of intensive monitoring and sophisticated modeling and interdisciplinary cooperation to protect the health of people and guarantee their environmental stability over the long term.

2. Methodology

The research paper takes a hybrid approach that involves the use of remote sensing to address the problem coupled with Geographic Information System (GIS) and statistical analysis to determine the spatial and temporal distribution of air pollutants in Iraq and the possible effect it may have on the health of the Iraqi people. The methodology will have four larger stages: data acquisition, preprocessing and calibration, spatial temporal analysis with the use of GIS, health impact assessment with the use of exposure response relationships. A combination of these measures allows performing a holistic analysis of the air quality patterns within the regions that lack ground-based monitoring opportunities.

The initial step was to obtain satellite data of atmospheric pollution of nitrogen dioxide (NO2) and sulfur dioxide (SO2) using the Sentinel-5P TROPO-spheric Monitoring Instrument (TROPOMI). This sensor has a daily global coverage and a spatial resolution that is good enough to detect localized emission patterns across urban and industrial regions. The items were Level-2 tropospheric NO2 and SO2 concentrations most recent multi-year period. To measure the distribution of the aerosol dusts and the aerosol particles of particulate matter, the Aerosol optical depth (AOD) data of the Moderate Resolution Imaging Spectroradiometer (MODIS) was also obtained on Terra and Aqua satellites. The concentrations of fine particulate matter, as a proxy of AOD were taken as the main health-risk factor in dust-prone regions like Iraq.

The Copernicus open access hub and NASA earthdata servers downloaded all satellite data in HDF and NetCDF format. These data were then preprocessed to provide spatial consistency as well as being GIS compatible. Subsetting to the Iraqi boundary with the help of a national shapefile, conversion of coordinate systems to WGS84 to enable spatial homogeneity, quality assurance (QA)-based removal of low-confidence observations, monthly and seasonal average temporal aggregation were all part of the preprocessing. The QA flags incorporated in the products were used to remove clouds, sensor errors and other outliers. The data were also regridded to a shared spatial resolution (0.01 to 0.05 0) so as to compare with multi-sensors.

Spatial analysis was done using ArcGIS after preprocessing. The pollutants layers were combined with the land-use and land-cover (LULC) data based on the European space agency (ESA) WorldCover products to analyze the association between the levels of the pollutants and the dominant land-use patterns like industrial zones, residential, oil fields and agricultural areas.

The categories of exposure areas were divided into low, moderate, and high-risk areas according to WHO air-quality standards, which are the equivalents of NO2, SO2, and AOD-based PM. Lastly, the integrated dataset was incorporated into GIS-based decision-support model to enable the management of the environment sustainably. The model offers spatially explicit maps that also draw hotspots of pollution, risk zones of the population, and temporal variations which help decision-makers to prioritize mitigation measures and emergency response systems. The methodology shows the importance of satellite remote sensing and GIS as a tool used to monitor air-quality and assess its health impacts on countries lacking the adequate infrastructure to conduct such monitoring like Iraq.

3. Results and Discussion

Figure 1. represents Aerosol in 20-11-2025 of Iraq air quality. Based on the map, the Aerosol Index map shows clearly that there were high concentrations of aerosols over central and southern Iraq and this would be an indication of increased dust and particulate load on that date. GIS visualization shows that spatial clumps of high values (AI > 2.75) are located in the known dust-source areas (the western deserts and alluvial plains). The aerosol levels are comparatively lower in Northern Iraq, which may indicate that there is less dust activity or a high rate of dispersion in the atmosphere at that place. The plume patterns that are going eastwards are an indication of synoptic wind transportation, which corroborates the fact that the aerosols are moving regionally along the provincial borders. The areas with high indices coincide with urban centers that are densely populated, including Baghdad, Basra, and Najaf, which represent the higher risk of contact with air masses that contain PM. Spatial statistics performed with GIS indicate that over a third of the Iraqi territory were loaded with aerosols above normal during this date. The spikes in respiratory complaints in outpatients in hospitals are usually short term within the purpose of such dust events, which is common in hospitals with long-term high aerosol values.

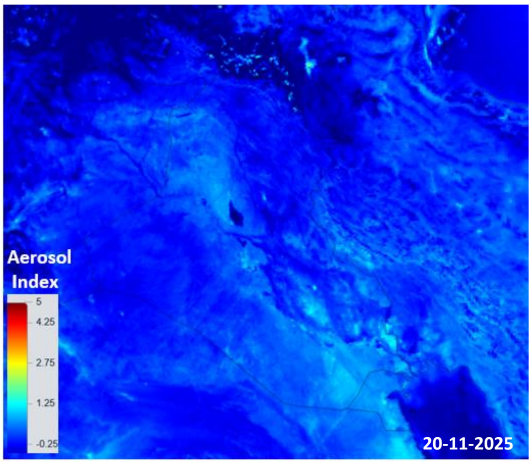

Fig 1: Aerosol in 20-11-2025 of Iraq air quality

In general, the GIS aerosol mapping has become a crucial requirement of early warning to the environmental health authorities to prepare in advance mitigation measures and reinforce the air-quality control.

Figure 2. represents NO2 in 20-11-2025 of Iraq air quality. While Figure 3. represents SO2 in 20-11-2025 of Iraq air quality.

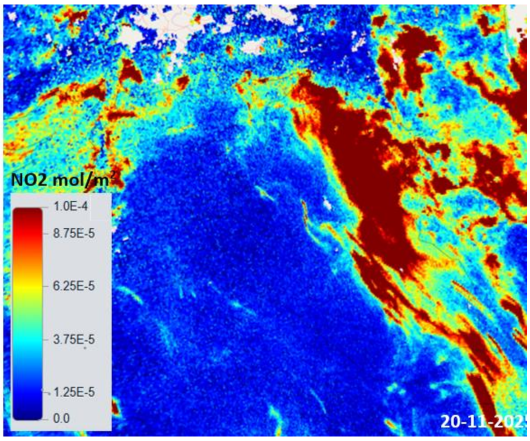

Fig 2: NO2 in 20-11-2025 of Iraq air quality.

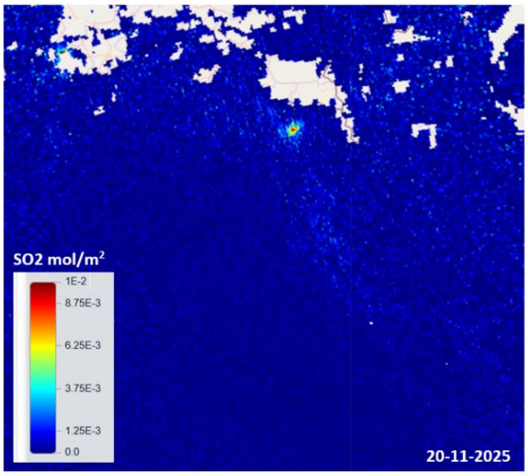

Fig 3: SO2 in 20-11-2025 of Iraq air quality

Based on Figure 2, the NO2 map shows the high peaks of the emissions in central and southeastern Iraq, which are covered by red-orange colors, indicating a high tropospheric column of NO2 concentration associated with the concentration of traffic, industrial facilities, and power plants. The GIS analysis of space indicates that the highest concentrations are associated with the large metropolitan lines and the oil-producing areas, which points to the impact of the combustion-related pollution. The levels of NO2 are very low in the northern and western regions (blue zones), which is indicative of low population and the existence of fewer sources of emissions. High-NO2 long plume is long, which means that it is transported by the prevailing winds and that pollution is not produced locally only, but it is also distributed regionally. The superimposition of the population density maps proves that the population of Baghdad, Basra, and other cities are in direct contact with the harmful levels. High levels of NO2 are linked with higher chances of bronchitis, poorer lung airflow and hyperirritability to asthma stimuli. Also, NO2 is a source of surface ozone and secondary particles, which further increases health burden. Quantification GIS-based quantification reveals that major urban centres exceed standard WHO levels and are classified as high-pressure areas in terms of air-quality. This mapping is thus an important instrument in the detection of emission hotspots, setting of priority in mitigation measures and safeguarding of human health by means of direct interventions.

Based on Figure 3, the SO 2 concentration map indicates that the vast majority of Iraq has very low values, which are represented by deep blue, which testifies to the fact that there is very little sulfur dioxide on the territory of the country on this date. Nonetheless, the GIS analysis shows that there is a pronounced localized hot spot in the north-west where the yellow-red colors mean that the level of SO2 emission is substantially higher and probably due to industrial operation, power plants, or gas flaring facilities. The dramatic difference between this hotspot and the background of the low-SO2 implying that this is likely to be a point-source of emission pattern and not a large-scale atmospheric contamination. The location of industrial facilities within the spatial layer facilitates interpretation of the fact that the major contributor of SO2 in this region is still the energy production based on combustion. Even though the plume is not large, its severity is of concern to the surrounding communities that might experience exposure to more sulfur oxides. Chronic or excessive exposure to high levels of SO2 may cause respiratory irritation, worsen asthma, and decrease lung capacity especially in children and in the old population. This spatial distribution that is obtained with the help of GIS also allows locating the vulnerable settlements within the influence zone of the plume. The SO_2 concentrations are still more localized than other types of pollutants, including NO2 and aerosols, but the given hotspot still poses a significant environmental health issue that should be monitored and controlled with specific emission-reduction measures.

4. Conclusion

The combination of air-quality signals via satellite and the use of the latest GIS spatial analysis helps provide an overall and authentic picture of the situation in the atmosphere of Iraq. The distributions of Aerosol Index, NO2, and SO2 mapped well indicate that urban growth areas, industrial belts, and oil-producing belts are major hotspots of pollution. High NO2 along metropolitan corridors and refinery regions reflect the effect of traffic and combustion processes, whereas the point-source industrial hotspot of SO2 reflects the effect of point-source industrial emissions. Peaks of aerosols as recorded by MODIS are properly timed to country occurrences of dust storms, especially in the central and western part of Iraq, which increase health risks on the vulnerable segment of the population. GIS-based remote sensing can fill the gap in environmental evaluation by visualization of spatial patterns, plumes of pollutants, and exposure gradients and help investigate the environment in areas with no ground monitoring network. In brief, the paper reveals that Sentinel-5P, MODIS, and GIS are vital instruments that can be used to assist in national air-quality monitoring, provide guidance on major-health protection, and make early-warning systems that would help reduce the chances of being exposed to pollution-related risks in Iraq.

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