NBR Index-Based Fire Detection Using Sentinel-2 Images and GIS: A Case Study in Mosul Park, Iraq

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Abstract
Forest fires lead to severe damage to the environment and human health. Monitoring can be applied using remotely sensed data and in combination with Geographical Information Systems (GIS) based spatial analysis. Lately, Iraq subjected to many forest fires. In this study, the aim was to monitor and detect the burned areas in Mosul Park during the latest period which happened in June 2022. The hypothesis of the study was based on using Sentinel-2 images and the Normalized Burn Ratio (NBR) index. Two images have been used to compare burned areas; one during the fire events and another postfire. as well as, Normalized Difference Vegetation Index (NDVI) map has been used to identify the Park's characteristics. Moreover, Pearson's correlation (r) with Air Quality Index (AQI) was determined during the burning period. GIS-based processes resulted in detecting the area of burning where the burned area was 16.76 hectares and lay in the eastern part of the study area. Pearson correlation with AQI has resulted in 0.92, while the collinearity between the burned areas and AQI was 0.84. Accurate and prompt planning for fire-affected regions is essential for supporting fire affect assessment, calculating environmental losses, determining planning strategies, and monitoring vegetation recovery.

Keywords: Air Quality Index, Forest fires, Mosul Park, Normalized Burn Ratio, Pearson correlation.

1. Introduction

Forest fires are the second factor leading to ecosystem degradation after pollution [1], and are natural and man-made disasters that can endanger human life [2]. Forecasting fire hazards is important for preventing fires and allocating resources, and mapping fire risks is an effective way to measure regional risk [3]. Fire-risk controlling starts by assessing the most inflammable sites [2]. Information about the spatial pattern of fire hazards in a region plays a major role in forest succession[4], and environmental impacts [5]. Every year hundreds of hectares are damaged because of forest fires thus its necessary to apply the appropriate management for controlling and assessments [6]. With the advent of geographic information systems (GIS) and Remote Sensing (RS) [3] and [7], fire risk forecast has become popular in sophisticated fire-controlling scenarios [8]. GIS offers massive benefits in evaluating many geographical features and analyzing the events that develop according to these geographical features [9]. GIS identifies and prioritizes the geographical site of fire events and hotspots and enables map development to visualize the scenario results [6]. Besides, GIS develops forest fire hazard maps that attach potential fire regions to environmental factors [10]. Evaluating different map layers related to large regions in a short time [11]. Creating wildfire maps and obtaining spatial data information related to wildfires [12], helps manage fire risk [13]. Moreover, satellite images and RS technology are widely used to monitor forest fire behavior [14].

Recently, severe forest fires have occurred due to climatic influences, including dry periods [15]. Forest areas close to road networks and settlements are more exposed to fires as the possibility of man-made or accidental fires increases [11]. 70% of some forest fires are caused near main roads, with less than 500 m distance [16]. Forest fires can be responsible for severe air quality periods [17]. Where exposure to particulate matter [18] from wildfire smoke is associated with negative health effects [19] and may cause death [17]. Many factors are taken into consideration to detect the forest-fire

risk potentially such as; temperature, wind speed, distance from roads, rainfall, slope, altitude, land use, etc [15]. Many studies showed that topography, vegetation, fire history, and climatic factors are significant variables in forest-fire susceptibility modeling [10].
Several techniques are adopted to evaluate the probability of forest fires, such as analytical hierarchy process, support vector machines, fuzzy logic models, and system dynamics [8]. Also, statistical approaches such as Pearson correlation coefficient are used to analyze the relationship between forest fire events and other variables [20]. Besides, regression models are useful in predicting wildfire risks for instance geographically weighted regression, linear regression, and logistic regression [10]. The NBR index is applied to measure spectral changes post-fire events [21]. The ability of the Normalized Burn Ratio index to detect fire-events was investigated [22]. Since 2022 Incidents have become frequent in Iraq, including the outbreak of fires in Mosul Park, which covers an area of about 90 hectares. The effects of the fires have spread to large areas, and large parts of them have turned into burnt areas and ashes.

1.1. Research Objective and Design

Exposure to forest fire smoke is associated with adverse health effects on the human respiratory system. Thus this study aimed to create a burn area map in Mosul Park, Iraq from Sentinel 2A satellite imageries and determine the correlation between fire events and AQI in Mosul Park. Linear regression and Pearson correlation were adopted based on the results of Sentinel-2 image analysis and GIS tools. Moreover, two indices were used to detect the burnt areas. The NDVI was used to map the characteristics of Mosul Park and the NBR index was applied for mapping fire-events and post-fire during the year 2022 and discovering the affected areas.

2. Study Area

2.1 Methodology

The study area is Mosul Park which lies in Mosul city, Iraq (**Figure 1**). The study area occupies 90 ha and is bonded between latitudes (36° 21′ 40″ to 36° 23′ 20″) N, and longitudes (43° 06′ 06″ to 43° 07′ 40″) E. Mosul city is located in the north of Iraq and is characterized by temperatures of 20 °C-40 °C in the summer and 5 °C -15 °C in the winter [23]. Since 2017, Iraq has recorded multiple forest fire events, including the recent Mosul Park fire in June 2022. Thus it is important to embark on research on fire detection, and mapping fire events for evaluating affected areas, and risk assessment.

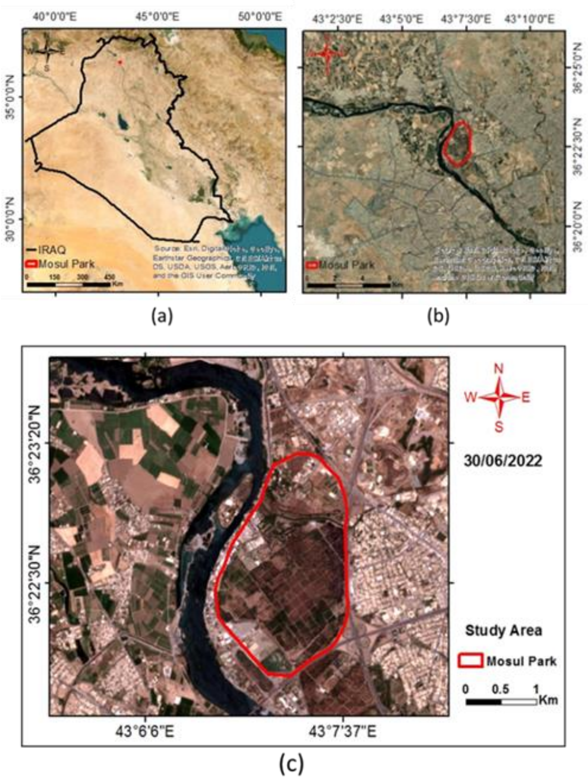

Figure 1: The study area map; (a) Iraq, (b) Mosul city north Iraq, and (c) Mosul Park

Table 1: The attributes of Sentinel-2 images

Image attributes	Fire-events	Post-fire
Image Type	Sentinel-2 L2A	Sentinel-2 L2A
Acquisition Date	30-06-2022	29-08-2022
Image Resolution	High 398 x 417 px	High 398 x 417 px
Cloud Cover	0.4 %	0 %
Coordinate System	WGS 84	WGS 84
Resolution	lat.: 0.0000724 deg/px (0.3sec/px) long.: 0.0000899 deg/px (0.3sec/px)	lat.: 0.0001448 deg/px (0.5sec/px) long.: 0.0001799 deg/px (0.6sec/px)
Map Projection	UTM	UTM
UTM Zone	38N	38N
Used Bands	B4, B8, B11, B12, B8A	B11, B12, B8A

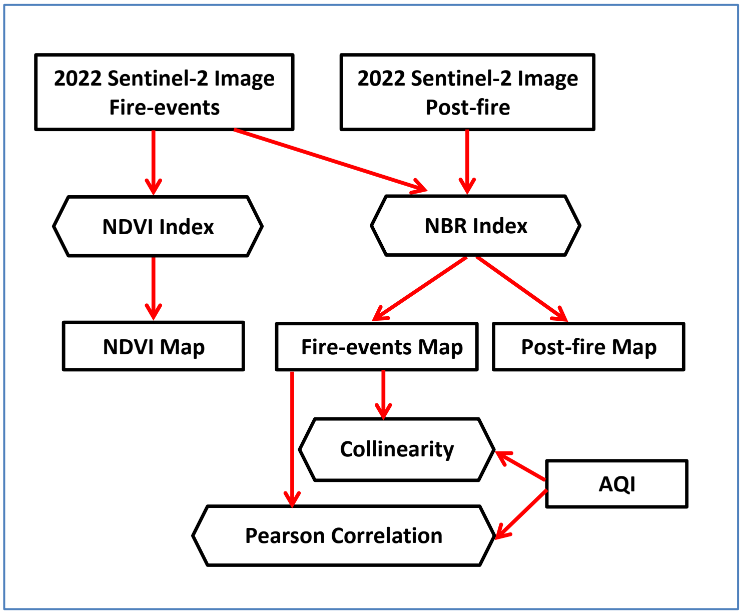

Figure 2: The methods used for fire detection and correlations

2.2 Data and Methods

The used data in this study was based on a satellite image of Mosul Park and AQI data in burned areas. Sentinel-2 images have been downloaded from https://apps.sentinel-hub.com/eo-browser/. The image attributes of the used data are described in **Table 1**. Furthermore, historical AQI data for Mosul city was downloaded from Air Matters through the website https://air-quality.com/place//d41bd7af?lang=en&standard=aqi_us. The methods used for fire detection and correlation of AQI with burned areas in this study are represented in **Figure 2**. Where two indices have been used to map the study area during fire events and post-fire. NDVI mapping was applied to identify the characteristics of the study area. Moreover, the NBR index was used to map the study area and detect burned areas based on three bands (B12, B11, and B8A) of Sentinel-2 images. NBR was applied at fire events and post-fire. Comparison has been done between burned areas and non-affected areas based on the NBR map. Besides, statistical analyses have been implemented; Pearson Correlation, and Linear regression. The applied method was to investigate the AQI relationship with the burned areas at fire-events.

ArcGIS10.3 is used to perform Mosul Park fire damage and detection of the affected area to analyze the severity of fire events using Sentinel-2 images. The equation that specifies the Normalized Burn Ratio (NBR) can be written as:

$$Sentinel2_{\mathrm{NBR}} = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}}$$

Equation 1

where here for Sentinel-2 image NIR: is band 8, and SWIR; is band 12. NBR is applied to present the affected areas in fire-events on a single map [21] and [24]. For NDVI, the equation can be specified as:

$$Sentinel2_{\mathrm{NDVI}} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$
Equation 2

here, RED: is band 4, and NIR: is band 8 [21] and [24]. The NDVI is a simple and effective index that can quantify green vegetation. It is based on the reflected light from the vegetation of a certain wavelength. NDVI was designed by Sentinel-2 image in the study area. Accordingly, spatial changes in vegetation and the distribution variation of vegetation due to fire can be distinguished.

The NDVI first advanced in 1974 which can be used for the prediction of vegetation and biomass changes fire-events. It's based on red and NIR that are reflected by vegetation [21].

Moreover, the Pearson correlation (r) equation between AQI and burned areas (B) in hectares for n pairs can be specified as;

$$r_{\mathrm{AQI\&B}} = \frac{n(\sum B*AQI)-(\sum B)(\sum AQI)}{\sqrt{[n\sum B^2-(\sum B)^2][n\sum AQI^2-(\sum AQI)^2]}}$$
Equation 3

Pearson correlation coefficient (r) is a common method for evaluating the linear relationship [24]. It results in a number between (-1 to 1) which describes the power and direction of the two variables' correlation. It reports the change of the variable based on the other one in the same direction. To apply the Pearson correlation coefficient we mapped the affected areas based on the Sintenel-2 image of fire-events. In order to evaluate air quality at different locations the affected areas were then divided into three sites; 5 ha, 5 ha, and 6.7 ha which were selected randomly. In each zone, we defined the AQI value with suitable positions in the study area of fired palaces. The value of AQI in each position was determined based on their spatial reliance on surrounding stations around the study area [25]. The r equation was applied based on AQI data in each zone with the covered burned area.

Moreover, the collinearity of AQI with the burned areas was analyzed and the linear coefficient correlation was determined.

3. Results and Discussion

3.1 Resultant fire Detection Maps

To detect the fire-affected sites in Mosul Park we used a fire-detecting spectral index, the Normalized Burn Ratio index (NBR) which is organized based on the equation (1). **Figure 3** represents the NBR Index map based on Sentinel-2 fire-events. NBR index map shows the affected areas in fire-events on a single map. Based on ArcGIS analysis results, the affected areas by the fire were about 16.7 ha. It can be easily noted by the shaded part that appears on the map. Furthermore, **Figure 4** represents NBR Index map based on Sentinel-2 post-fire. By comparison between maps can be visually seen the converted affected area to barren land.

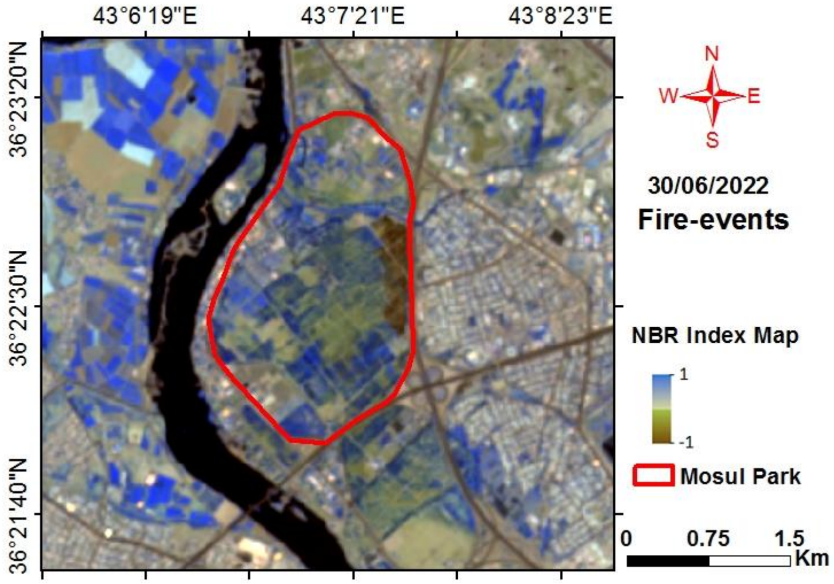

Figure 3: NBR index map based on Sentinel-2 fire-events

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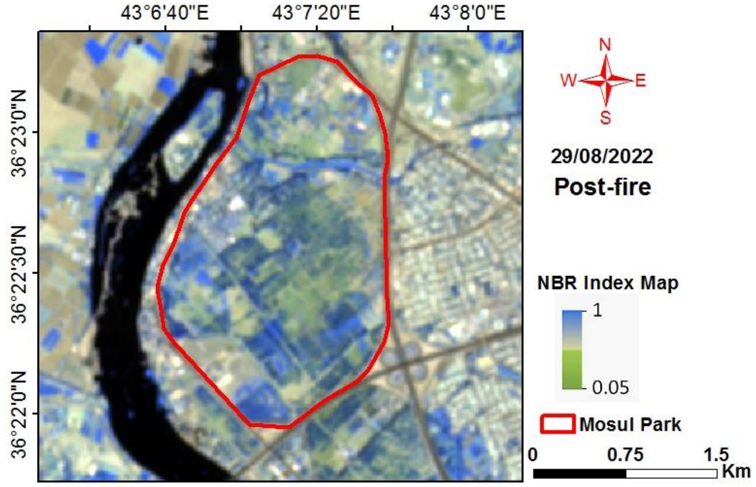

Figure 4: NBR index map based on Sentinel-2 post-fire

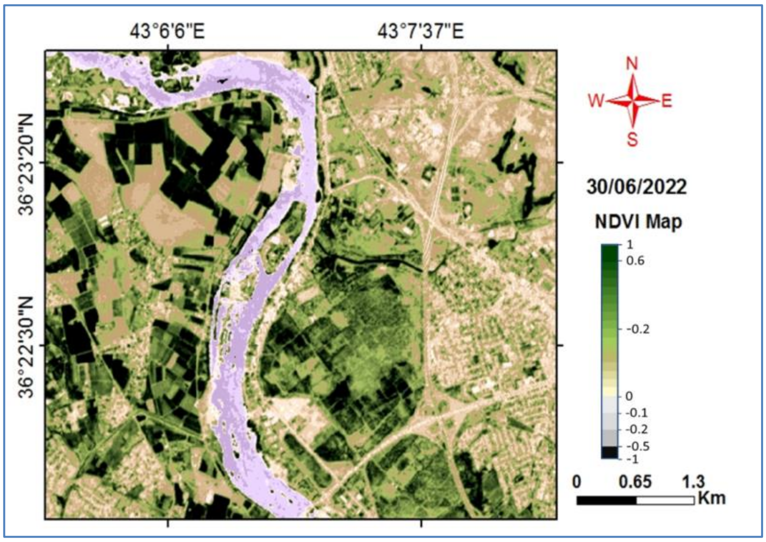

Figure 5: NDVI map of Mosul Park

3.2 Resultant NDVI Map

NDVI map was derived from Sentinel-2 image acquired on 30-06-2022 in the study area Mosul Park. Consequently, the vegetation spatial changes and the distribution variation caused by fire can be noted. NDVI for a given pixel results in (-1 to +1). NDVI less than 0.1 points to sand, rock, and barren lands. NDVI of (0.1 to 0.2) indicates to the soil, a shallow value. NDVI of (0.2 to 0.5) refers to shrub, grassland, and sparse vegetation spaces. More than 0.5 a high NDVI represents forests [21]. **Figure 5** represents the NDVI map of Mosul Park.

3.3 Statistical Analysis Results

Statistical analysis involved linear regression and Pearson correlation. Polynomial linear fitting is the base of the validation [26] and [27]. **Table 2** represents the statistical outputs. Moreover, **Figure 6** represents a GIS-based correlation processes map. Results of the correlations and regression process have shown significant relationships by (r = 0.92, and R^2 = 0.84) as shown in **Table 2**. Indicating a positive correlation between AQI and burned areas. Based on **Figure 6**, the recorded AQI values ranged between (360-402) which indicates very unhealthy air quality [18]. Correlations of AQI with burned areas are in a positive direction significantly increasing AQI which indicates a negative impact in fire-events.

Table 2: Statistical outputs

ID	Burned Areas (B) [ha]	AQI	(B*AQI)	$(B)^2$	$(AQI)^2$
Zone 1	5	360	1800	25	129600
Zone 2	5	377	1885	25	142129
Zone 3	6.7	402	2693.4	44.89	161604
Sum	16.7	1139	6378.4	94.89	433333
Pearson correlation	0.92				
Linear correlation	0.84				

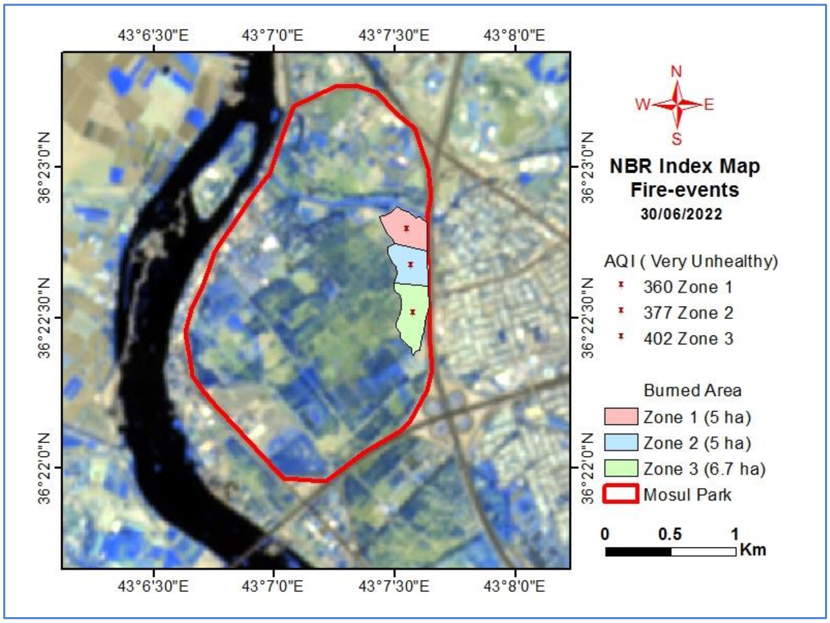

Figure 6: GIS-based correlation processes map

4. Conclusion

In this study, the fire detection map of Mosul Park was introduced based on Sentinel-2 Image and NBR index during fire-events and post-fire. Based on open source data and applications relationship between AQI and affected areas by the fire was investigated and demonstrated high correlations resulted in 84% and 92% accuracies. The results concluded 16.7 ha of the Park area was damaged. Based on NDVI the affected areas have been converted to bare land. Besides a positive correlation with worse air quality fire-events. Very unhealthy air was reported which has serious health impacts. By performing a GIS spatial analysis, wildfire risks are derived as the spatial analysis combines individual impact factors to display the full fire risk map. Forest fire maps are beneficial for natural hazard management for identifying high-potential fire risk areas. Also, extra efforts should be applied and more research must be conducted to support forest fire management. Additionally, more accurate sensors and imageries should be used for future investigation for fire-events detection.

References

[1] Razavi-Termeh, S. V., Sadeghi-Niaraki, A. and Choi, S. M., (2020). Ubiquitous GIS-Based Forest Fire Susceptibility Mapping Using Artificial Intelligence Methods. *Remote Sens.*, Vol. 12(10), 1-16. https://doi.org/10.3390/rs12101689.

[2] Gigović, L., Jakovljević, G., Sekulović, D. and Regodić, M., (2018). GIS Multi-Criteria Analysis for Identifying and Mapping Forest Fire Hazard : Nevesinje , Bosnia and Herzegovina. *Teh. Vjesn.*, Vol. 25(3), 891–897. https://doi.org/10.17559/TV20151230211722.

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[3] Zhao, P., Zhang, F., Lin, H. and Xu, S., (2021). GIS-Based Forest Fire Risk Model : A Case Study in Laoshan. *Remote Sens.*, Vol. 13(3704), 1–21, https://doi.org/10.3390/rs13183704.

[4] Ngoc-Thach, N., Bao-Toan Ngo, D., Xuan-Canh, P., Hong-Thi, N., Hang Thi, B. and Dieu, T. B., (2018). Spatial Pattern Assessment of Tropical Forest Fire Danger at Thuan Chau area (Vietnam) Using GIS-Based Advanced Machine Learning Algorithms : A comparative Study. *Ecol. Inform.*, Vol. 46, 74–85, https://doi.org/10.1016/j.ecoinf.2018.05.009.

[5] Busico, G., Giuditta, E., Kazakis, N. and Colombani, N., (2019). A Hybrid GIS and AHP Approach for Modelling Actual and Future Forest Fire Risk Under Climate Change Accounting Water Resources Attenuation Role. *Sustainability*, Vol. 11(24), 1-20. https://doi. org/10.3390/su11247166.

[6] Zahran, E. M. M., Shams, S. and Said, S. N. B. M., (2010). Validation of Forest Fire Hotspot Analysis in GIS Using Forest Fire Contributory Factor. *Syst. Rev. Pharm.*, Vol. 11(12), 249–255, https://doi.org/10.31838/srp.2020.12.40.

[7] Le, H. V., Bui, Q. T., Bui, D. T., Tran, H. H. and Hoang, N. D., (2020). A Hybrid Intelligence System Based on Relevance Vector Machines and Imperialist Competitive Optimization for Modelling Forest Fire Danger Using GIS. *ISEIS J. Environ. Informatics*, Vol. 36(1), 43–57, https://doi.org/10.3808/jei.201800404.

[8] Yang, W. and Jiang, X., (2020). Evaluating Forest Fire Probability Under the Influence of Human Activity Based on Remote Sensing and GIS. *Nat. Hazards Earth Syst. Sci.*, 1–16, https://doi.org/10.5194/nhess-2019-338 .

[9] Gülçin, D. and Deniz, B., (2020). Remote Sensing and GIS-Based Forest Fire Risk Zone Mapping: The Case of Manisa, Turkey. *Turkish J. For.*, Vol. 21(1), 15–24. https://doi.org /10.18182/tjf.649747.

[10] Eslami, R., Azarnoush, M., Kialashki, A. and Kazemzadeh, F., (2021). GIS-Based Forest Fire Susceptibility Assessment by Random Forest, Artificial Neural Network and Logistic Regression Methods. Vol. 33(2), 173–184. https://doi.org/10.26525/jtfs2021.33.2.173.

[11] Akay, A. E. and Şahin, H., (2019). Forest Fire Risk Mapping by Using GIS Techniques and AHP Method: A Case Study in Bodrum (Turkey). *Eur. J. For. Eng.*, Vol. 5(1), 25–35, https://doi.org/10.33904/ejfe.579075.

[12] Novkovic, I., Markovic, G. B., Lukic, D. and Tadic, M., (2021). GIS-Based Forest Fire Susceptibility Zonation with IoT Sensor Network Support, Case Study-Nature Park Golija, Serbia. *Sensors*, Vol. 21(19), 1-29. https://doi.org/10.3390/s21196520.

[13] Van Hoang, T., Chou, T. Y., Fang, Y. M. and Nguyen, N. T., (2020). Mapping Forest Fire Risk and Development of Early Warning System for NW Vietnam Using AHP and MCA/GIS Methods. *Appl. Sci.*, Vol. 10(12), 4348, https://doi.org/10.3390/app10124348.

[14] Naderpour, M., Rizeei, H. M., Khakzad, N. and Pradhan, B., (2019). Forest Fire Induced Natech Risk Assessment : A Survey of Geospatial Technologies. *Reliab. Eng. Syst. Saf.*, Vol. 191, https://doi.org/10.1016/j.ress.2019.106558.

[15] Mohammed, O. A., Vafaei, S., Kurdalivand, M. M., Rasooli, S., Yao, C. and Hu, T., (2022). A Comparative Study of Forest Fire Mapping Using GIS-Based Data Mining Approaches in Western Iran. *Sustainability*, Vol. 14(20), 1-13. https://doi.org/10.3390/su142013625.

[16] Novo, A., Fariñas-Álvarez, N., Martínez-Sánchez, J., González-Jorge, H., Fernández-Alonso, J. and Lorenzo, H., (2020). Mapping Forest Fire Risk-A Case Study in Galicia (Spain). *Remote Sens.*, Vol. 12(22), 1-21. https://doi.org/10.3390/rs12223705.

[17] Purnomo, E., Rahmasari, F., Trisnawati, D., Agustiyara, and Erviana, R., (2021). Observed Data of Forest Fire Hotspots effects on Respiratory Disorder by Arc-GIS in Riau Province, Indonesia. *IOP Conference Series: Earth and Environmental Science*, Vol. 717(1). 1-7, https://doi.org/10.1088/1755-1315/717 /1/012036.

[18] Hamed, H. H. Jumaah, H. J. and Kalantar, B., (2021). Predicting PM2. 5 Levels Over The North of Iraq Using Regression Analysis and Geographical Information System (GIS) Techniques. *Geomatics, Nat. Hazards Risk*, Vol. 12(1), 1778–1796. https://doi.org/10.1080/19475705.2021.1946602.

[19] Jumaah, H. J., Mansor, S., Pradhan, B. and Adam, S. N., (2018). UAV-based PM2.5 Monitoring for Small-Scale Urban Areas. *Int. J. Geoinformatics*, Vol. 14(4), 61-69.

[20] Ahmad, F. and Goparaju, L., (2018). Climate Change and its impact on Forest Fire in the State of Himachal Pradesh and Uttarakhand States of India : Remote Sensing and GIS Analysis. Vol. 7(2), 229–246, https://doi.org/10.2478/ctg-2018-0016.

[21] Yilmaz, O. Acer, U. Sanil, F. Gulgen, F. and Ates, A., (2023). Mapping Burn Severity and Monitoring CO Content in Türkiye' s 2021 Wildfires, Using Sentinel - 2 and Sentinel - 5P Satellite Data on the GEE Platform. *Earth Sci. Informatics*, Vol. 16(1), 1-20. https://doi.org/10.1007/s12145-023-00933-9.

[22] Wang, L., Qu, J. J. and Hao, X., (2008). Forest Fire Detection Using the Normalized Multi-Band Drought Index (NMDI) with Satellite Measurements. *Agric. For. Meteorol.*, Vol. 148(11), 1767–1776, https://doi.org/10.1016/j.agrformet.2008.06.005.

[23] Jumaah, H. J. Kalantar, B. Ueda, N. Sani, O. S. Ajaj, Q. M. and Jumaah, S. J., (2021). The Effect of War on Land Use Dynamics in Mosul Iraq Using Remote Sensing and GIS Techniques. *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS*, 2021, 6476–6479, https://doi.org/10.1109/igarss47720.2021.9553165.

[24] Mohammed, A. K., Kuri, A. Ahammed, S., Kazi, A. and Mohammed, A., (2023). A Google Earth Engine Approach for Anthropogenic Forest Fire Assessment with Remote Sensing Data in Rema-Kalenga Wildlife Sanctuary, Bangladesh. *Geol. Ecol. Landscapes*, 1–22, https://doi.org/10.1080/24749508.2023.2165297.

[25] Jumaah, H. J., Ameen, M. H., Mahmood, S. and Jumaah, S. J., (2023). Study of Air Contamination in Iraq Using Remotely Sensed Data and GIS. *Geocarto International*, Vol. 38(1), 1-18, https://doi.org/10.1080/10106049.2023.2178518.

[26] Jumaah, H. J., Ameen, M. H., Kalantar, B., Rizeei, H. M. and Jumaah, S. J., (2019). Air Quality Index Prediction Using IDW Geostatistical Technique and OLS-based GIS Technique in Kuala Lumpur, Malaysia. *Geomatics, Natural Hazards and Risk*, Vol. 10(1), 2185-2199, https://doi.org/10.1080/19475705.2019.1683084.

[27] Ameen, M. H., Jumaah, H. J., Kalantar, B., Ueda, N., Halin, A. A., Tais, A. S. and Jumaah, S. J., (2021). Evaluation of PM2.5 Particulate Matter and Noise Pollution in Tikrit University Based on GIS and Statistical Modeling. *Sustainability*, Vol. 13, 1-14. https://doi.org/10.3390/su13179571.