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Landslide Susceptibility Modeling for Quarries Sites in Northeastern Missan: Using Fuzzy Logic Method

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ABSTRACT:

Landslides are recognized as one of the most dangerous and often occurring natural catastrophes worldwide. Quarrying activities can dramatically enhance the danger of landslides by destabilizing slopes through drilling and heavy machinery movements. The digging process disrupts natural drainage patterns, resulting in water retention that damages soil and rock structures. The main justification of the present work is producing a landslide susceptibility model for quarries sites in northeastern Misan. This means an evaluated mixture of different indices. By applying the fuzzy logic method to remote sensing and GIS techniques. The study used spectral indices derived from multispectral Landsat. The thematic layers (indices) are: "Clay Minerals Ratio (CMR), Iron Oxide Ratio (IOR), Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Normalized Difference Moisture Index (NDMI), Normalized Difference Water Index (NDWI), Bare Soil Index (BSI), and Normalized Difference Soil Index (NDSI)". The final landslide susceptibility map identified three risk zones: low, moderate, and high. The majority of quarries in northern areas are in a high-susceptibility zone, which indicates that quarry operations are a significant source of landslide danger, with northern quarries being high risk and northeastern quarries being moderate to low risk.

KEYWARDS: Susceptibility, **Quarries, Remote Sensing, Spectral Indices,** Fuzzy logic, GIS

1.INTRODUCTION:

Landslides are widely recognized as one of the most prevalent and destructive natural hazards globally. Over the last three decades, researchers across the world have developed a variety of approaches for mapping the susceptibility to landslides and hazard assessment (Schuster and Fleming, 1986). Landslide incidents are caused by a variety of interdependent factors, including:

both natural forces (e.g., earthquakes, stream erosion) and human actions (e.g., deforestation, mining). (Zhong *et al*., 2020), (Fadhil, R.M., and Ali, A.K., 2020) However, predicting the position and time of a landslide is a challenging task since geological features and slope angle parameters change significantly over short distances, and it is challenging to determine the timing, location, and severity of triggering events.Quarrying activities can dramatically enhance the danger of landslides by destabilizing slopes through drilling and heavy machinery movements (Al-Maamory and Al-Zubaidy, 2022). The digging process disrupts natural drainage patterns, resulting in water retention that damages soil and rock structures. Deforestation and plant clearance during quarry operations also impair slope stability, increasing the risk of erosion and mass wasting. In rare situations, poorly managed quarry sites have caused catastrophic landslides, threatening adjacent towns, ecosystems, and infrastructure (Al-Asadi, K.A., and Al-Khafaji, 2021) Proper land-use planning, slope reinforcement, and environmental impact assessments are critical for mitigating these hazards and ensuring sustainable quarrying methods. The remote sensing data utilized in this study were obtained from NASA's (Earth Explorer) website. The Operational Land Imager (OLI) prepares worldwide seasonal coverage of the land surface at a resolution of 30 m. Landsat 8 takes data from an altitude of 705 kilometers and a coverage area of about 185 kilometers. Some causes of landslides can be utilized as factors to determine their susceptibility. These factors can be used as an indicator to determine the risk of landslides (Pacheco Quevedo, 2023).

The main justification of the present work is producing a landslide susceptibility model for quarries sites in northeastern Misan. This means evaluated mixture of different indices. The used spectral indices derived from multispectral Landsat. The indices are: “Clay Minerals Ratio (CMR), Iron Oxide Ratio (IOR), Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Normalized Difference Moisture Index (NDMI), Normalized Difference Water Index (NDWI), Bare Soil Index (BSI), and Normalized Difference Soil Index (NDSI)”.

2. STUDY AREA:

2.1 GEOLOGIC SETTING

The under-investigation area is covered with Zagros foothill deposits consists of Holocene and Pleistocene alluvial sediments deposited by the Tigris River and its tributaries, principally silt, clay, and fine sand ((Jassim and Goff, 2006). Seasonal flooding promotes the deposition of nutrient-rich silts and clays along floodplains, increasing soil fertility and sustaining agriculture (Aqrawi *et al*.,2010). Further from the river, aeolian deposit sands and silts mingle with alluvial soils, adding variation to soil texture and composition., which evolved in the mountains to the east-northeast along the Iraqi-Iranian border (Ameen, 2005).

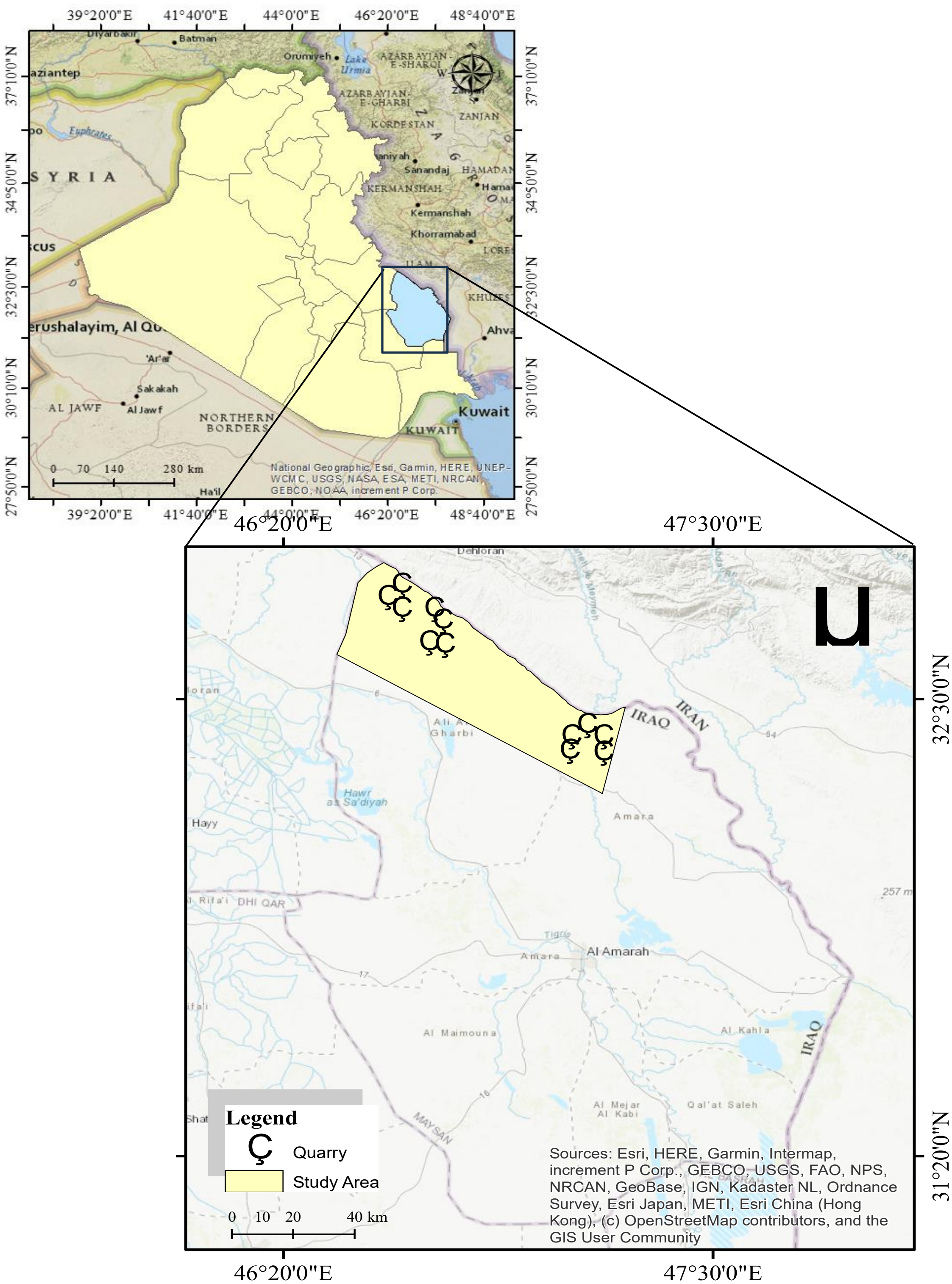

Fig.1 The Quarries site

3.METHODOLOGY:

Considering that, Landslides in an area are influenced by slope characteristics, lithology, soil type, and hydrologic/meteorological factors (Silalahi et al.,2009). Therefore, to create landslide susceptibility model. The study deals with landslide susceptibility mapping for quarry sites in North-Eastern Missan applying fuzzy logic. The following key causal factors were considered: lithology and soil composition, erosion control indicators, liquefaction and shear strength assessment, and erosion susceptibility. Thematic layers have been generated using a combination of remote sensing and GIS approaches Fig.2 and Table 1 illustrate the spectral parameters which used as factors to determine their susceptibility.

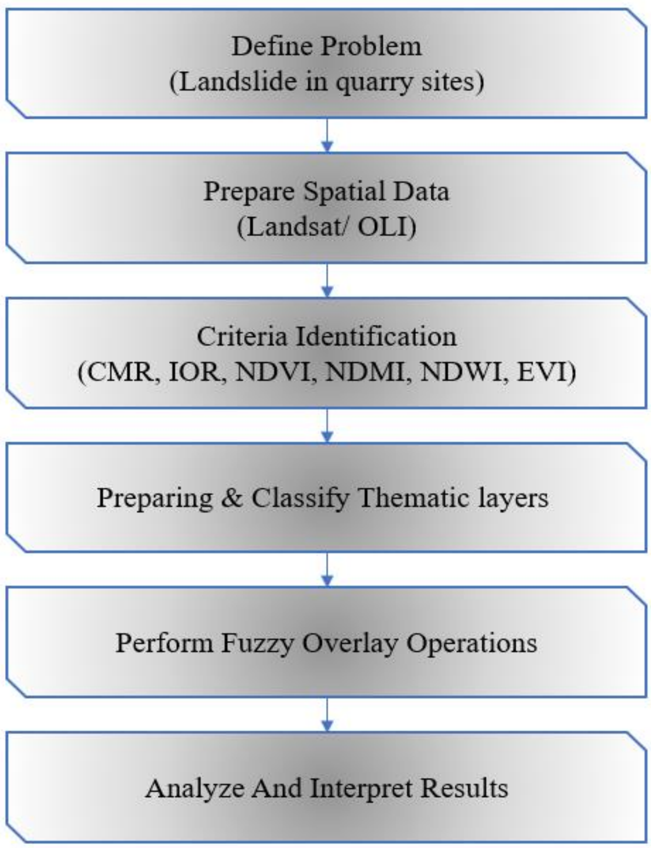

Fig.2 Procedure of The Study

- The Fuzzy Logic method/ The Fuzzy Logic approach created by Zadeh in 1965. It’s commonly used to handle complicated problems, and the membership function is utilized to represent the degree of membership based on a number of variables (Zadeh, 1965). Fuzzy logic membership enables the operator to assess if a location is suitable or inappropriate. The essential premise of fuzzy membership is to replace all layers' values with an integer range of 0 to 1, where 0 represents false and 1 represents true, and all values between 0 and 1 denote a transition from 1 to 0, as shown in the following equations (Benz et al., 2004):

$\mu(X) = 0 \; if \; x < min$ …………………………………………… (1)

$\mu(x) = 1 \; if \; x > max$ …………………………………………… (2)

$other \; wise \; \mu(x) = (x - min) \, (max - min)$ ……………… (3)

Table 1 Characteristic of Spectral Parameters

	Used Spectral Parameters	Mathematical formula	References
Lithology & Soil Composition	Clay Minerals Ratio (CMR)	CMR $= \frac{Band\ 6\ (1.6\ \mu M)}{Band\ 7\ (2.2\mu M}$ ………… (4)	(Hunt,1977)
	Iron Oxide Ratio (IOR)	IOR $= \frac{Band\ 4\ (0.66\ \mu M)}{Band\ 2\ (0.48\mu M}$ ………… (5)	(Hunt,1970)
Erosional Control Indices	Normalized Difference Vegetation Index (NDVI)	NDVI$= \frac{Band\ 5\ (0.85\mu M) - Band\ 4\ (0.66\mu M)}{Band\ 5\ (0.85\mu M) + Band\ 4\ (0.66\mu M)}$ …… (6)	(Jw,1973)
	Enhanced Vegetation Index (EVI)	EVI = 2.5*$\frac{Band\ 5\ (0.85) - Band\ 4\ (0.66)}{Band\ 5 + Band\ 6 * Band4 - 7.5 * band2 + 1}$ … (7)	(Huete and Liu, 1994) (Huete *et al.*,1997)
Liquefaction & Shear Strength	Normalized Difference Water Index (NDWI)	NDWI$= \frac{Band\ 3\ (0.56\ \mu M) - Band\ 5\ (0.86)}{Band\ 3\ (0.56\ \mu M) + Band\ 5\ (0.86)}$ …… (8)	(McFeeters,1996) (Gao, 1996)
	Normalized Difference Moisture Index (NDMI)	NDMI$= \frac{Band\ 5\ (0.85) - Band\ 6\ (1.6\ \mu M)}{Band\ 5\ (0.85) + Band\ 6\ (1.6\ \mu M)}$ …… (9)	(Wilson and Sader,2002) (Jin and Sader, 2005.
Erosion Susceptibility	Bare Soil Index (BSI)	BSI$= \frac{Band\ 6\ (1.6\ \mu M) - Band\ 7\ (2.2\mu M)}{Band\ 6\ (1.6\ \mu M) + Band\ 7\ (2.2\mu M)}$ ……. (10)	(Rikimaru and Miyatake, 2002)
	Normalized Difference Soil Index (NDSI)	NDSI$= \frac{Band\ 6\ (1.6\ \mu M) - Band\ 5\ (0.85)}{Band\ 6\ (1.6\ \mu M) + Band\ 5\ (0.85)}$ ……… (11)	(Escadafal, 1994)

- The Fuzzy Logic Overlay is necessary for applying Fuzzy logic to the criterion layers. The process includes describing the problem, establishing criteria, standardizing components, allocating weights, aggregating requirements, and testing the findings. In this work, fuzzy

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gamma operators were applied, based on fuzzy algebraic product and sum. (Shahabi and Ahmad, 2015).

4.THE RESULTS

The Fuzzy Logic approach was applied to the eight thematic layers (CMR, IOR, NDVI, EVI, NDMI, NDWI, BSI, and NDSI). To successfully build a comprehensive Landslide Susceptibility Map (LSM) for the quarry's sites. Figs. (3, 4,5, 6, 7, 8, 9, 10) illustrated the used spectral indices as thematic layers, which are subdivided into three classes (low, medium, and high).

a.

b.

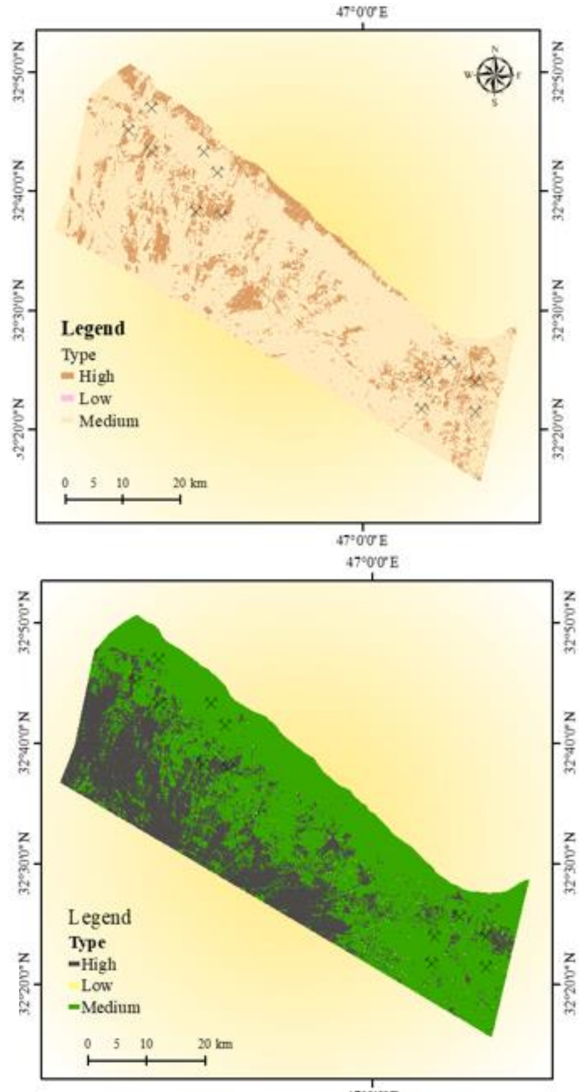

Fig. 3, a. CMR index, **b.** IOR index

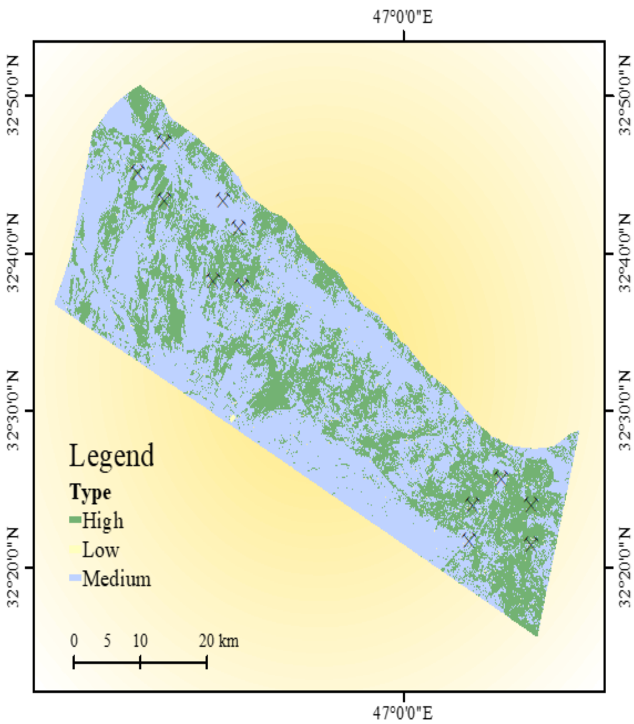

Fig.5 NDVI index

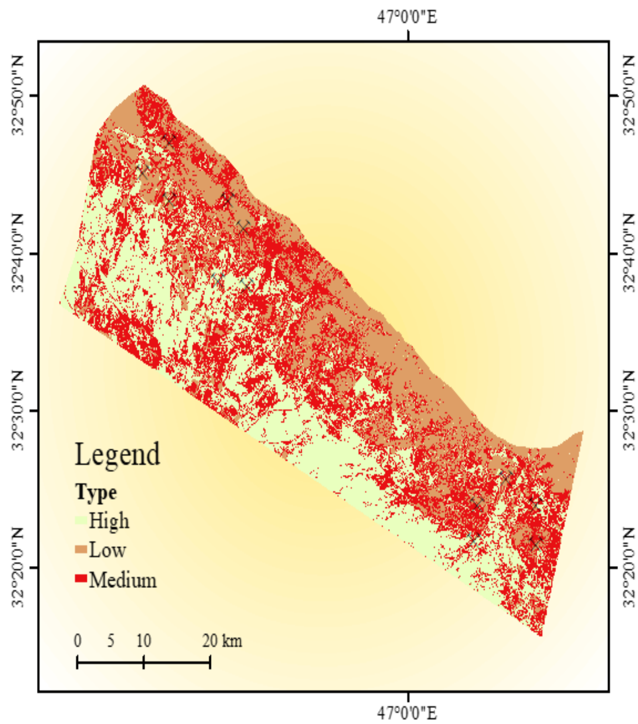

Fig.6 BSI index

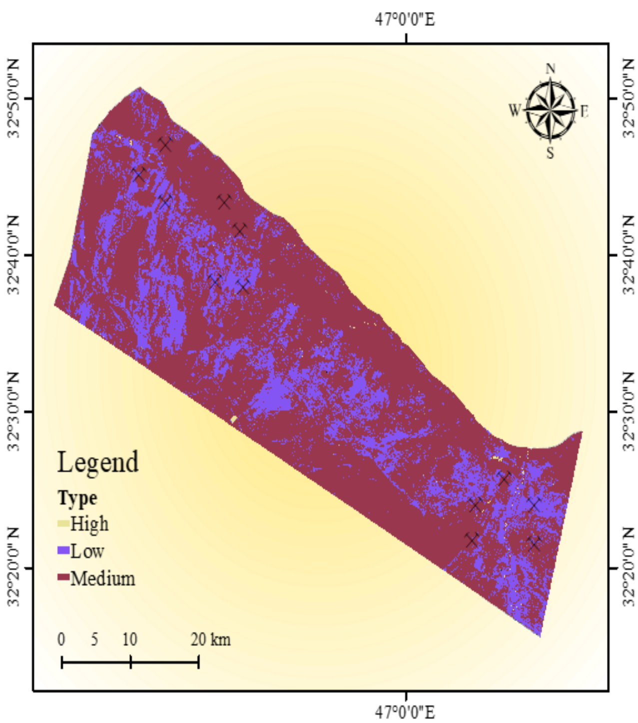

Fig.7 NDWI index

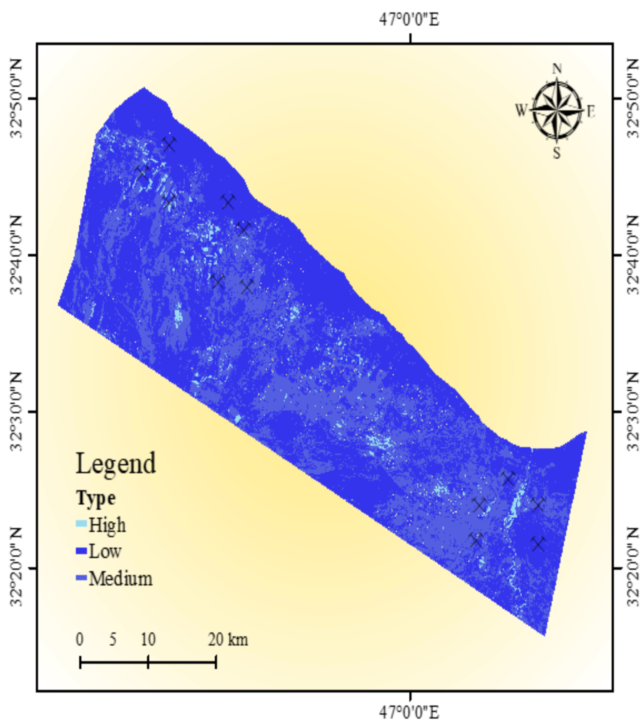

Fig.8 NDMI index

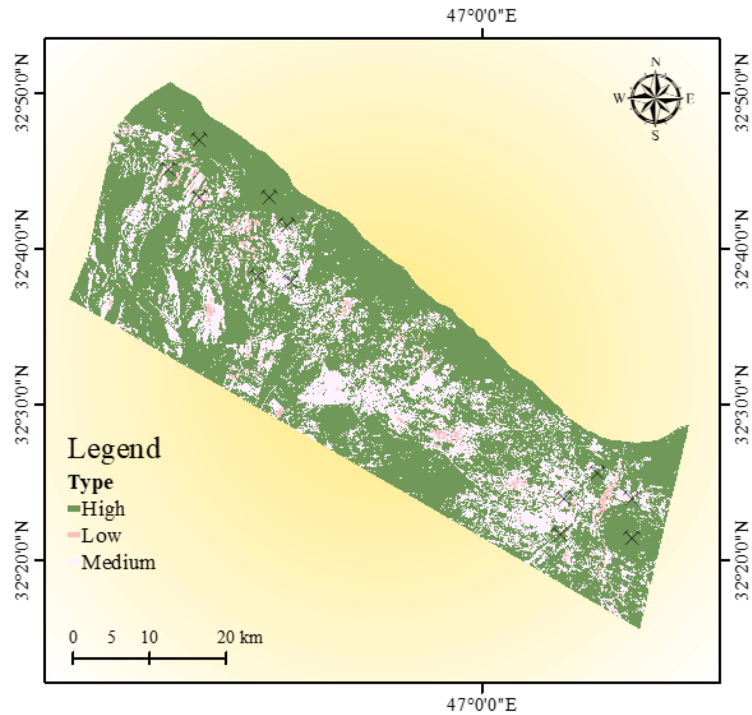

Fig.9 NDSI index

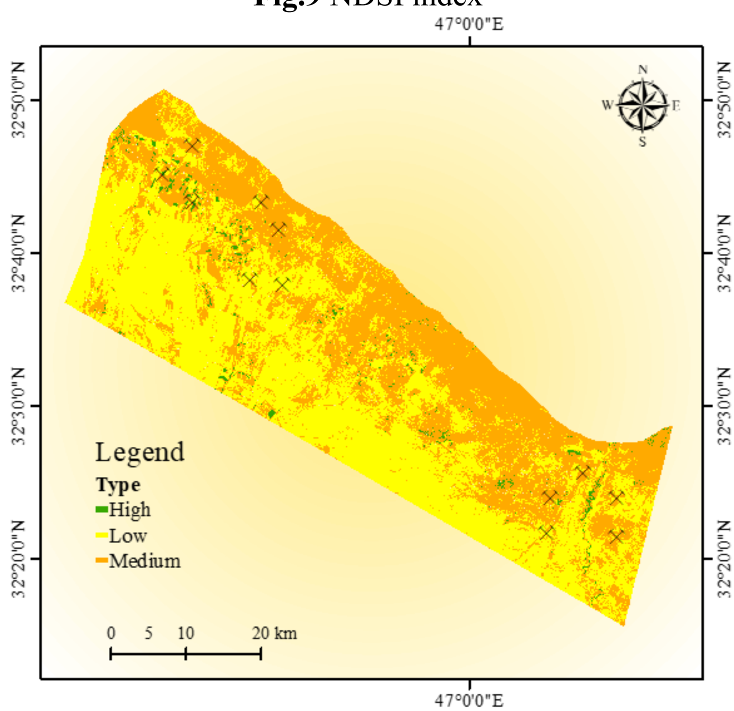

Fig.10 EVI index

The study area was zoned according to landslide susceptibility, resulting in a final map with three defined classes: low, moderate, and high. The findings show a clear spatial link between medium and high susceptibility zones and active quarrying operations.

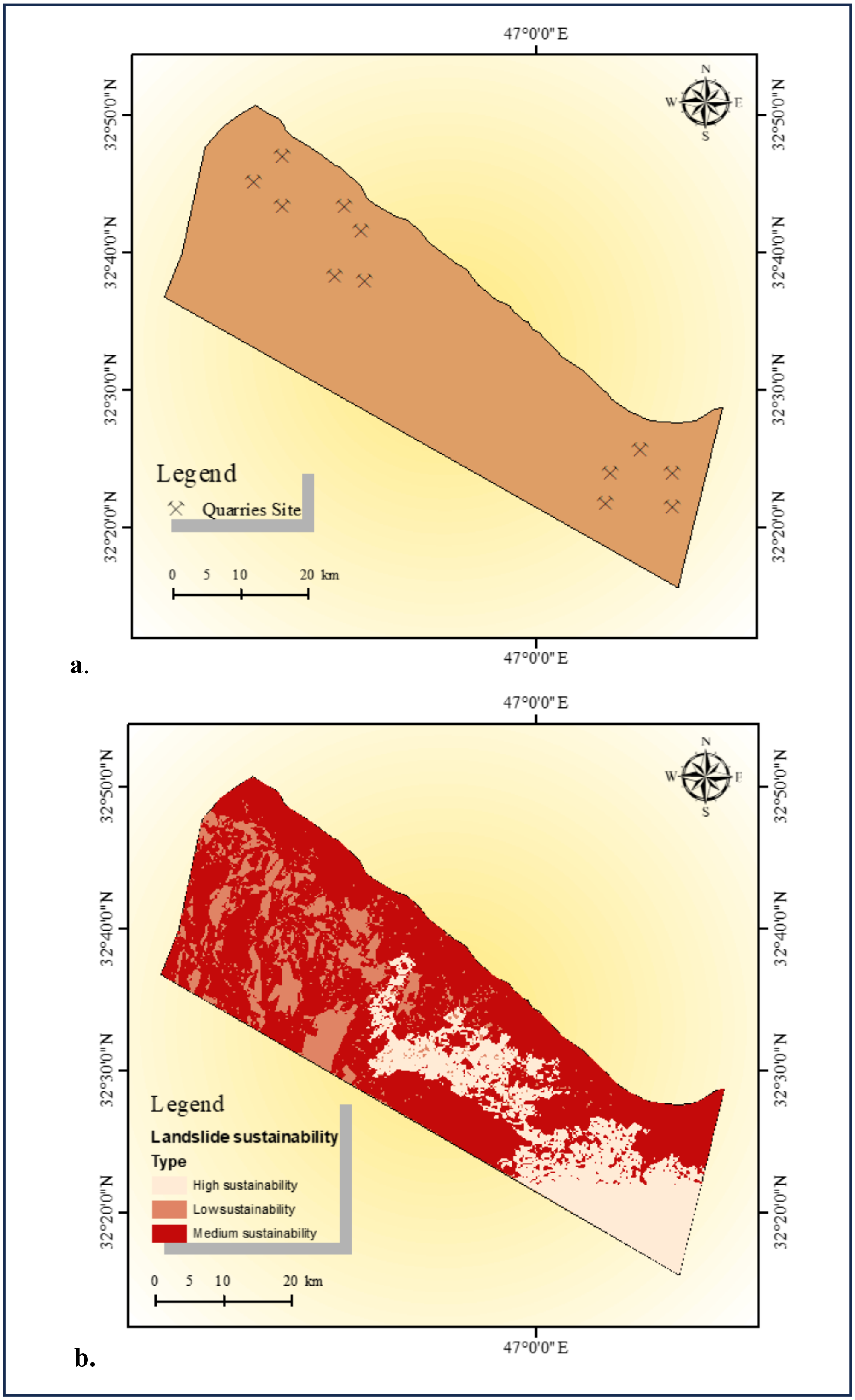

Fig.11 (a) location of active quarries, (b) Landslide Susceptibility Map (LSM)

5.DISCUSSION AND CONCLUSION

The culmination of the susceptibility analysis is a map (LSM) partitioned into three definitive zones: low, moderate, and high susceptibility. The majority of quarries in northern areas are in a high-susceptibility zone, which indicates that quarry operations are a significant source of landslide danger, with northern quarries being high risk and northeastern quarries being moderate to low risk. Planners and engineers must utilize the results of such studies to mitigate the hazard by selecting suitable locations for expansion. To reduce the risk of landslides in the research region, it is recommended to monitor deterioration and changes in natural vegetation cover. This work successfully combined Remote Sensing, GIS, and Fuzzy Logic to develop a landslide susceptibility map for quarries in northeastern Mississippi. It concluded that quarry operations are a major source of landslide risk in the area. The resulting map is a critical tool for planners and managers to reduce hazards by enforcing stronger laws, strengthening slopes, directing future construction away from high-risk areas, and monitoring vegetation. Future study could improve the model by including information on slope angle and rainfall.

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7.Declaration of Competing Interest:

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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