An Integrated Geomorphological Spatial Modeling Framework for Military Land Suitability Assessment and Operational Decision Support: A Case Study from Central Iraq

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Abstract:
Military terrain evaluation has traditionally relied on individual topographic parameters, often overlooking the integrated influence of geomorphological processes on operational suitability. This study develops a GIS-based geomorphological framework to evaluate military land suitability in Salah Al-Din Governorate, Iraq, through the integration of terrain analysis and multi-criteria spatial modelling. A 30-m Digital Elevation Model, Landsat and Sentinel imagery, and geological, soil, drainage, road, and land-cover datasets were used to derive eight geomorphometric variables, which were combined with military terrain factors including mobility, observation, key terrain, natural obstacles, avenues of approach, and offensive and defensive suitability. The Analytic Hierarchy Process (AHP) and weighted overlay techniques were employed to generate an integrated military suitability model. The results indicate that low-relief terrain occupies 77.60% of the study area, whereas areas with high and very high mobility represent 51.78% of the total area. Elevated ridges overlooking transportation corridors constitute the most suitable locations for observation and defensive deployment, while river networks, rugged uplands, and dissected terrain significantly constrain movement and channel operational routes. Model validation demonstrated high performance, achieving a mean Spatial Matching Rate of 86.9%, Overall Accuracy of 85.7%, and RMSE of 17.3 m. The study demonstrates that integrating geomorphometric variables with military terrain functions provides a more realistic representation of operational suitability than conventional terrain-based assessments and offers a transferable spatial decision-support framework applicable to comparable semi-arid environments following local calibration.

Keywords: Military geomorphology; Geographic Information Systems (GIS); Military terrain analysis; Geomorphometric analysis; Multi-Criteria Decision Analysis (MCDA); Land suitability; Salah Al-Din Governorate; Iraq.

1. Introduction

Over the past few decades, military geomorphology has emerged as an advanced applied field at the meeting point of the earth sciences and military science. It examines how geomorphological characteristics influence the planning of military operations, and how suitable terrain is for movement, deployment, control, and the selection of strategic sites. Terrain is no longer treated merely as a spatial backdrop to combat; it has become a decisive factor in modern military planning, since it bears directly on rates of movement, room for maneuver, supply lines, fields of view, the concealment of forces, and the efficient use of operational resources. Advances in remote sensing, geographic information systems (GIS), and digital elevation models (DEM) have in turn transformed the way terrain is studied, shifting it from conventional description toward quantitative analysis grounded in spatial modeling and digital simulation, and providing more precise tools for supporting military decisions in different geographical settings.

Recent years have seen a marked expansion in the use of geospatial technologies in military research. Satellite imagery, digital elevation models, three-dimensional analysis, and multi-criteria spatial analysis have become core tools for judging how far terrain will support military operations. These capabilities have made it possible to build digital models that assess trafficability, identify the best deployment sites, evaluate lines of sight, and select optimal routes, as well as estimate the natural and human hazards liable to reduce operational efficiency. The trend reflects a broader move away from reliance on field experience and conventional maps toward digital analytical environments in which a large number of spatial variables are combined within quantitative models that can be measured and verified.

The recent literature confirms this shift clearly. Guth (2011) drew attention to the value of applied geomorphological maps in interpreting terrain characteristics of military significance, while de Matos-Machado et al. (2019) demonstrated that high-resolution LiDAR data can detect, analyze, and automatically classify military landforms, thereby sharpening our understanding of the historical military landscape. Perarnau et al. (2022) showed that combining slope, lithology, and land use provides a sound scientific basis for interpreting the influence of terrain in military environments, and recent Iranian studies have confirmed that GIS and geomorphological analysis are effective tools for evaluating defensive positions and supporting military planning, particularly in coastal and mountainous areas. Taken together, these studies indicate that digital geomorphological analysis has become a fundamental component of modern military modeling, although the indicators used and the degree to which they are integrated still vary considerably from one study to another.

Despite the methodological progress evident in earlier work, most of it has concentrated on single terrain attributes, on the evaluation of specific defensive positions, or on conventional spatial analysis tools. Studies that bring digital geomorphological analysis together with multi-criteria decision analysis (MCDA), viewshed analysis, and least-cost path analysis within a single spatial model for assessing military suitability remain limited internationally, and are almost entirely absent in Iraq. Arid and semi-arid environments, with their pronounced terrain contrasts and distinctive geomorphology, have likewise received little applied attention, notwithstanding their strategic importance for military planning and the management of spatial security.

Salah Al-Din Governorate is among the most strategically significant areas in Iraq. Its central location, its geomorphological diversity, the course of the Tigris through it, and the contrast among its terrain units, which range from floodplains and plateaus to undulating ground and structural escarpments, are joined by a road network that links northern Iraq with the center and the west of the country. These characteristics have made the governorate the theater of a number of military operations over recent decades, which underlines the need to assess its geomorphological attributes from a quantitative spatial perspective in order to identify the areas most suitable for movement, deployment, and control, and to support military planning and decision-making.

The present study therefore sets out to build an integrated spatial model for assessing military suitability in Salah Al-Din Governorate, combining geographic information systems, remote sensing, and digital elevation models with multi-criteria analysis in order to determine which areas are most suitable for military operations according to a set of geomorphological and physical indicators. Its scientific contribution lies in developing a quantitative analytical framework that unites terrain analysis, trafficability assessment, visibility analysis, and optimal route selection within one model that can be applied in arid and semi-arid environments, thus filling a clear gap in the Arabic and Iraqi literature and offering a scientific tool in support of military planning and spatial security management.

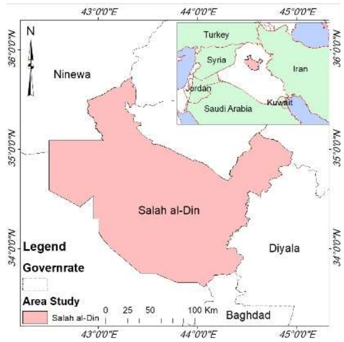
2. Study Area

Salah Al-Din Governorate lies in the central part of Iraq, between latitudes 33°30′ and 35°00′ N and longitudes 42°50′ and 44°45′ E, and covers an area of about 24,363 km², which makes it one of the largest Iraqi governorates. It forms a geographical node connecting northern Iraq with the center and the west of the country, bordered by Nineveh, Kirkuk, and Erbil to the north, Diyala to the east, Baghdad to the south, and Al-Anbar to the west, a position that gives it strategic weight for transport, movement, and military operations.

The study area is notable for the clear diversity of its geomorphological units. It contains the floodplains extending along both banks of the Tigris, sedimentary plateaus, undulating ground, and structural escarpments, together with a variable drainage network, all of which bear directly on trafficability, lines of sight, and the potential for military deployment and positioning. The central location of the governorate and the variety of its physical characteristics have also made it the theater of several military operations in recent decades, so it serves as an appropriate case for applying models of military suitability based on geographic information systems, remote sensing, and digital elevation models.

Figure (1) shows the geographical location of Salah Al-Din Governorate within Iraq, its administrative boundaries, and its position in relation to the neighboring governorates. This is the spatial framework on which all the spatial and geomorphological analyses in this study were based.

Figure (1): Geographical location of the study area (Salah Al-Din Governorate) within Iraq.



3. Materials and Methods

The study adopted an applied geomorphological approach built on the integration of geographic information systems, remote sensing, digital elevation models, and multi-criteria spatial analysis, the aim being to convert surface characteristics into quantitative variables that can be combined in models for evaluating trafficability, fields of view, key terrain, natural obstacles, avenues of approach, and offensive and defensive suitability. This structure is consistent with the objective of the study, which is to build an integrated geomorphological model to support military decision-making rather than to analyze the elements of the environment separately.

3.1 Data

The study drew on spatial and digital data from multiple sources, including topographic, geological, soil, and land use maps, digital elevation models, satellite imagery, and climatic and hydrological data, together with GPS measurements and field observations. These data were selected against four main criteria: completeness of spatial coverage, reliability of the producing authority, suitability of the spatial resolution to the scale of the study, and the possibility of integrating them within a single geodatabase.

Table 1. Primary maps used in the study

No.	Map type	Scale	Producing authority	Year	Main use
1	Topographic map	1:100,000	Iraqi General Directorate of Survey	2023	Verification of elevation, roads, drainage, settlements, and terrain features
2	Geological map	1:250,000	Iraq Geological Survey, GEOSURV	2023	Analysis of lithology, geological formations, and structural controls
3	Soil map	1:250,000	Iraqi Ministry of Agriculture	2022	Assessment of soil texture, bearing capacity, moisture response, and trafficability
4	Land-use and land-cover map	1:100,000	Ministry of Water Resources and author processing	2024	Classification of agricultural land, barren surfaces, vegetation, water, and built-up areas
5	Administrative map	1:250,000	Central Statistical Organization of Iraq	2024	Delineation of the study area and administrative units

Table (1) shows that the base maps were not used for display purposes alone; they also served to verify the digital layers, interpret the geological structure, classify soil properties, and review the road and drainage networks. These data are consistent with the tables of study materials and tools presented in the thesis.

Table 2. Satellite imagery used in the study

No.	Satellite/product	Sensor	Spatial resolution	Year	Source	Main use
1	Landsat 8	OLI	30 m	2024	USGS	Land-cover interpretation and spectral verification

2	Landsat 9	OLI-2	30 m	2025	USGS	Updating land-cover information
3	Sentinel-2	MSI	10 m	2025	Copernicus/ESA	Detailed land-cover classification
4	Google Earth Pro imagery	High-resolution imagery	Less than 1 m in selected locations	2025	Google	Visual verification of roads, crossings, and field locations

Sentinel-2 was adopted as the highest-resolution source for land cover classification, Landsat 8 and 9 were used for temporal and regional review, and Google Earth Pro imagery served for visual verification rather than as an independent quantitative layer.

Table 3. Digital elevation models

No.	Elevation model	Spatial resolution	Producer	Release/year adopted	Role in the study
1	SRTM DEM	30 m	NASA/USGS	Global release adopted in 2015	Primary model for terrain analysis
2	ASTER GDEM V3	30 m	NASA/METI	2019	Comparative verification of terrain and elevation
3	Processed DEM	30 m	Prepared by the researcher in ArcGIS Pro	2025	Final corrected DEM used in modelling

The 30 m SRTM DEM was the principal model, while ASTER GDEM V3 was used only for comparative checking. A processed elevation model was then produced within ArcGIS Pro for use in the morphometric and military analyses.

Table 4. Climatic and hydrological data

No.	Dataset	Period/year	Source	Analytical use
1	Air temperature	1992–2025	Iraqi Meteorological Organization and Seismology	Thermal conditions and operational heat stress
2	Rainfall	1992–2025	Iraqi Meteorological Organization and Seismology	Soil wetness and seasonal mobility
3	Relative humidity, wind, pressure, and evaporation	1992–2025	Iraqi Meteorological Organization and Seismology	Visibility and operational weather interpretation
4	Rivers and dams	2024	Iraqi Ministry of Water Resources	Water obstacles and crossings
5	Hydrological information	2024	Iraqi Ministry of Water Resources	Drainage, canals, marshy depressions, and seasonal barriers

The climatic and hydrological data were used to interpret seasonal variation in movement, visibility, moisture, and the condition of watercourses; they were not all treated as independent criteria in the final models.

Table 5. Field and validation data

No.	Data type	Collection period	Accuracy/data form	Use
1	Field observations	2024–2025	Descriptive and spatial records	Verification of landforms and surface conditions
2	GPS locations	2025	Approximately ±3–5 m	Positional validation
3	Field photographs	2025	Georeferenced photographs	Documentation of geomorphological units
4	Actual movement routes	2024–2025	Polyline	Validation of mobility models
5	Observation and control positions	2024–2025	Point	Validation of viewshed and key terrain

6	Bridges, crossings, and obstacles	2024–2025	Points and polygons	Validation of obstacle and approach models
7	Offensive and defensive positions	2024–2025	Points and areas	Validation of suitability models

The verification stage relied on several independent sources, including GPS, field observations, satellite imagery, and official maps, which limits the bias that arises from depending on a single source.

3.2 GIS Database

A single geodatabase was created to bring together all point, line, polygon, and raster layers. The preparation stage included georeferencing, reprojection, clipping, rescaling, cell alignment, elevation model processing, topology repair, and inspection for missing and anomalous values.

3.2.1 Coordinate system

All data were reprojected to:

WGS 84/UTM Zone 38N

WGS 84/UTM Zone 38N is a projected coordinate reference system expressed in metres. It allows valid calculation of distance, area, slope, drainage density, and accumulated movement cost.

A projected system was adopted because military spatial analysis requires accurate metric measurements; distance, density, and cost calculations cannot properly be carried out on geographic coordinates measured in degrees.

3.2.2 Clipping and analysis extent

The layers were clipped to the boundaries of the study area, while an adequate spatial margin was retained when running the drainage and visibility analyses so that drainage networks and lines of sight would not be cut off at the administrative boundary.

3.2.3 Spatial resolution

A final cell size was adopted of:

$$30 \times 30 \text{ m}$$

The final analytical raster cell measures 30 m by 30 m. This resolution was selected because SRTM DEM was the primary terrain dataset and because resampling it to a finer grid would create artificial spatial detail.

Table 6. Resampling methods

Data type	Resampling method	Reason
DEM and continuous surfaces	Bilinear interpolation	Preserves gradual numerical variation
Geology, soil, and land-cover classes	Nearest neighbour	Preserves original categorical codes
Classified suitability rasters	Nearest neighbour	Prevents artificial intermediate classes
Satellite bands before classification	Bilinear or cubic where required	Supports continuous reflectance processing

3.2.4 Raster alignment

SRTM was adopted as the snap raster, and the following parameters were standardized:

- Cell size: 30 m
- Processing extent: study-area boundary
- Mask: study-area polygon
- Snap raster: SRTM DEM
- Output coordinate system: WGS 84/UTM Zone 38N

3.2.5 DEM processing

Processing of the elevation model included:

1. checking No Data cells;
2. removing artificial digital sinks using Fill;
3. deriving flow direction;
4. calculating flow accumulation;
5. comparing elevation values with ASTER and with the topographic maps;
6. reviewing anomalous values;
7. avoiding excessive smoothing that would erase genuine terrain variation.

3.2.6 Vector data processing

The following operations were carried out:

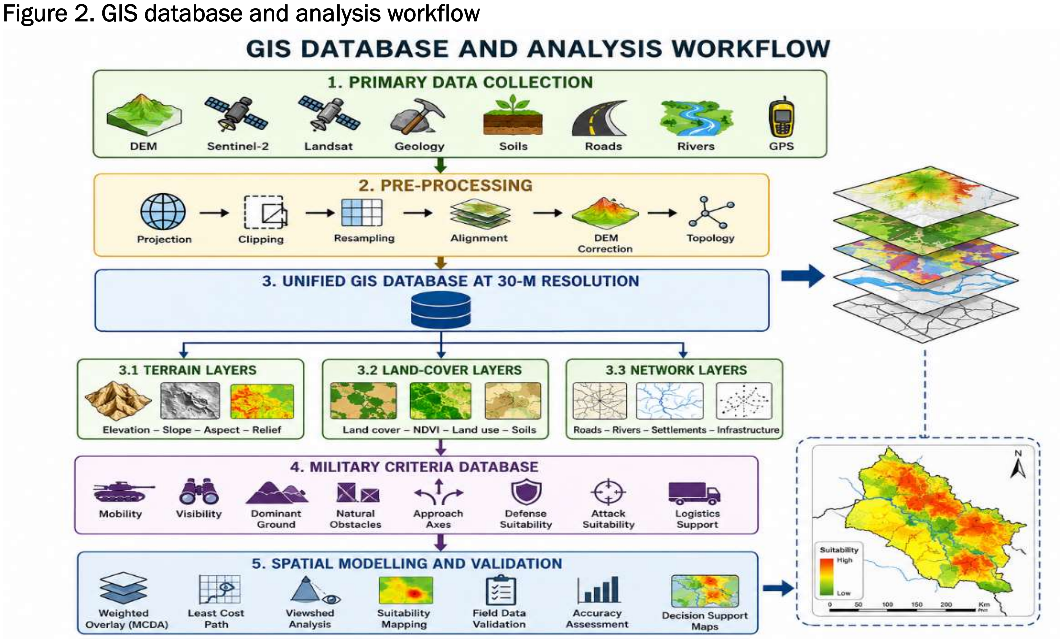
- Repair Geometry;
- removal of duplicate features;

- correction of breaks in the road network;
- checking the connectivity of watercourses;
- applying Snap where required;
- matching roads and rivers against recent imagery;
- standardizing fields and units within the geodatabase.

Table 7. GIS database quality-control procedures

Quality component	Test	Acceptance criterion
Coordinate reference	Projection and datum check	One projected CRS for all layers
Raster completeness	NoData assessment	No internal gaps
Cell alignment	Snap and extent check	Full raster alignment
Road topology	Connectivity check	No unexplained breaks
Drainage topology	Flow consistency	Hydrologically connected network
Positional accuracy	GPS and imagery comparison	Generally within one 30-m cell
Categorical integrity	Class-code review	No artificial mixed classes
Field consistency	Field and image comparison	Spatial agreement with observed conditions

Figure 2. GIS database and analysis workflow



The GIS database integrates terrain, land-cover, hydrological, transportation, and field layers into a unified 30-m analytical framework before military spatial modelling.

3.3 Geomorphological Variables

The geomorphological variables were derived from the corrected SRTM model. They comprised elevation, slope, aspect, curvature, hillshade, the terrain ruggedness index, the topographic position index, local relief, and drainage density.

3.3.1 Elevation

$$E_i = z_i$$

E_i is the elevation value of raster cell i, and z_i is the vertical terrain value obtained from the DEM. Elevation was used to delimit plains, plateaus, uplands, and depressions, but it was not interpreted in isolation; it was read alongside slope, visibility, and TPI.

3.3.2 Slope

Slope was calculated using Horn's algorithm:

$$\frac{\partial z}{\partial x} = \frac{(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)}{8r}$$
$$\frac{\partial z}{\partial y} = \frac{(z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)}{8r}$$
$$S = \tan^{-1}\left[\sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2}\right]$$

$z_1$to $z_9$are elevation values in a 3 × 3 neighbourhood, $r$is raster-cell size, and $S$is slope angle in degrees.

Table 8. Slope classification for military obstacle assessment

Slope class	Obstacle category	Operational interpretation
0–5°	No significant obstacle	Easy movement
>5–15°	Partial obstacle	Moderate reduction in speed
>15–30°	Strong partial obstacle	Difficult for heavy vehicles
>30–45°	Major obstacle	Generally unsuitable for normal vehicle movement
>45°	Very severe obstacle	Conventional movement largely restricted

These classes follow the slope classification adopted in the study, and they are interpreted in relation to soil, moisture, and vehicle type rather than as fixed mechanical thresholds valid in every case.

3.3.3 Aspect

$$A = \operatorname{atan2}\left(\frac{\partial z}{\partial y}, -\frac{\partial z}{\partial x}\right)$$
$$0^\circ \leq A < 360^\circ$$

$A$is the azimuth of maximum downslope direction, measured clockwise from north.
Aspect was used to interpret exposure, vulnerability, the direction of visibility, and the orientation of the terrain toward avenues of approach.

3.3.4 Curvature

$$C = \frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2}$$

$C$is the second spatial derivative of elevation. It distinguishes convex, concave, and planar terrain according to the GIS sign convention.
Curvature served to identify escarpments, depressions, runoff concentration paths, and areas that are either stable or subject to water convergence.

3.3.5 Hillshade

$$H = 255[\cos Z \cos S + \sin Z \sin S \cos(A_z - A)]$$

$H$is hillshade brightness, $Z$is solar zenith angle, $S$is slope, $A_z$is illumination azimuth, and $A$is terrain aspect.
Hillshade was used for interpretation and display only, and was not entered as an independent criterion in the WLC in order to avoid duplicating the effect of slope and aspect.

3.3.6 Terrain Ruggedness Index

$$TRI_i = \sqrt{\sum_{j=1}^{8} (z_j - z_i)^2}$$

TRI_imeasures local elevation variability around cell i. Higher values indicate rougher terrain.
High values are associated with reduced speed of movement and greater surface resistance.

3.3.7 Topographic Position Index

$$TPI_i = z_i - \bar{z}_{N(i)}$$

$TPI_i$is the difference between the elevation of cell $i$and the mean elevation of its neighbourhood.

$$TPI > 0 \Rightarrow \text{ridge or locally high terrain}$$
$$TPI < 0 \Rightarrow \text{valley or locally low terrain}$$

TPI was used to identify positions that are elevated relative to their surroundings, rather than relying on absolute elevation alone.

3.3.8 Local relief

$$R_i = z_{max,N(i)} - z_{min,N(i)}$$

R_i is local relief, calculated as the difference between maximum and minimum elevation within a selected neighbourhood.

3.3.9 Drainage density

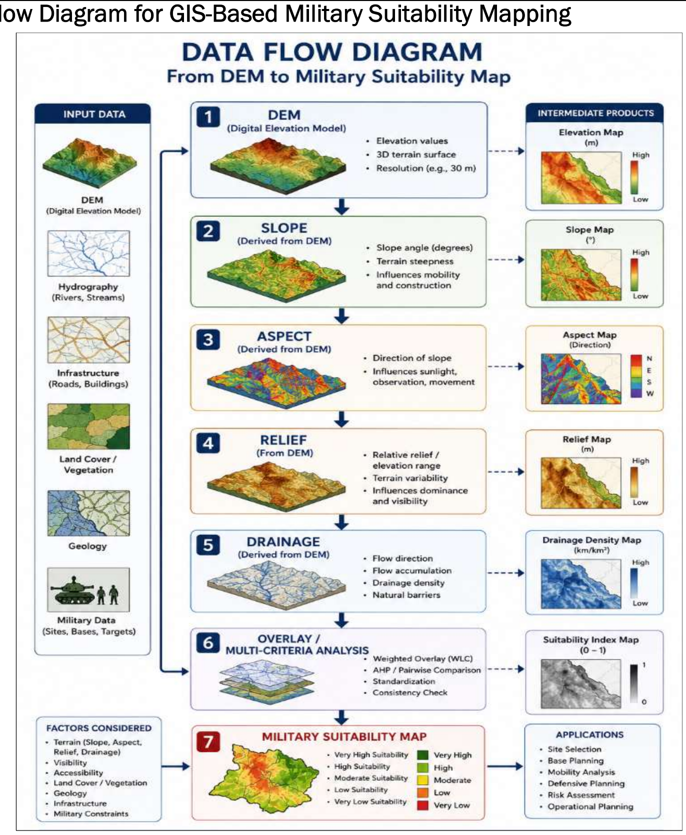
$$D_d = \frac{\sum_{k=1}^{m} L_k}{A}$$

D_d is drainage density, $\sum L_k$ is total channel length, and A is the analysis-unit area.
High density is associated with a more dissected surface, a greater number of crossing points, and a higher cost of movement.

Table 9. Geomorphological variables and military relevance

Variable	Unit	Geomorphological meaning	Military relevance
Elevation	m	Absolute height	High terrain and low corridors
Slope	degree	Surface steepness	Movement difficulty
Aspect	degree	Slope orientation	Exposure and visibility
Curvature	Derived value	Surface convexity/concavity	Ridges and depressions
Hillshade	0–255	Shaded terrain representation	Visual interpretation
TRI	Index value	Local roughness	Movement resistance
TPI	m	Relative terrain position	Key terrain and valleys
Local relief	m	Vertical amplitude	Terrain dissection
Drainage density	km/km²	Channel concentration	Obstacles and crossings

Figure 2. Data Flow Diagram for GIS-Based Military Suitability Mapping



3.4 Military Terrain Factors

The military terrain factors were selected on the basis of their direct relationship to movement, observation, control, protection, and supply. The movement factors comprised slope, soil, land cover, natural obstacles, roads, and watercourses, while the key terrain factors comprised visibility, elevation, slope, and proximity to roads, valleys, crossing points, and vital installations.

Table 10. Military terrain factors

Factor	Main model	Influence direction	Operational justification
Slope	Mobility and obstacles	Negative for movement	Reduces speed and accessibility
Soil	Mobility	Class-dependent	Controls bearing capacity
Land cover	Mobility and concealment	Class-dependent	May restrict movement or increase concealment
Natural obstacles	Mobility and defence	Negative for movement	Rivers, canals, and steep terrain restrict access
Roads	Mobility and logistics	Positive with proximity	Supports manoeuvre and resupply
Watercourses	Mobility	Negative	Create crossing requirements
Elevation	Key terrain	Positive when linked to visibility	Supports observation and control
TPI	Key terrain	Positive for ridges	Identifies locally commanding terrain
Viewshed	Observation	Positive	Measures surveillance potential
TRI/local relief	Mobility	Negative	Indicates rough terrain
Distance to crossings	Approaches	Context-dependent	Channels movement
Distance to infrastructure	Key terrain	Context-dependent	Increases strategic value

Table 11. Adopted movement-cost criteria and weights

Criterion	Weight (%)	Reclassification scale
Natural obstacles	30	1–10
Slope	25	1–10
Road network	20	1–10
Soil	10	1–10
Land cover	10	1–10
Watercourses	5	1–10
Total	100	—

A value of 1 represents the lowest cost of movement, while 10 represents the highest. The weights show that natural obstacles and slope together accounted for 55% of the total influence on the cost surface.

Table 12. Adopted key-terrain criteria and weights

Criterion	Weight (%)
Viewshed	30
Elevation	25
Slope	20
Proximity to roads	15
Proximity to valleys and crossings	5
Proximity to vital infrastructure	5
Total	100

Visibility carried the highest weight in the key terrain model, since an elevated position derives its military value not from height alone but from its capacity to overlook and dominate the surrounding ground.

Table 13. Functional structure of military terrain models

Model	Main inputs
Mobility	Slope, soil, land cover, obstacles, roads, watercourses

Viewshed	DEM and observer locations
Key terrain	Viewshed, elevation, slope, roads, crossings, infrastructure
Natural obstacles	Rivers, channels, steep slopes, unstable deposits
Avenues of approach	Cost surface and movement origins/destinations
Offensive suitability	Mobility, approaches, roads, obstacles, observation
Defensive suitability	Key terrain, viewshed, natural protection, obstacles, logistics

3.5 Spatial Modeling

The spatial modeling comprised the assignment of weights, standardization of the criteria, weighted linear combination, construction of the cost surface, visibility analysis, and least-cost path analysis.

3.5.1 AHP weighting

The pairwise comparison matrix was constructed:

$$A = [a_{ij}]_{n \times n}$$

$$a_{ij} = \frac{1}{a_{ji}}, \ a_{ii} = 1$$

Ais the pairwise-comparison matrix, and a_{ij}represents the relative importance of criterion icompared with criterion j.

Table 14. Saaty pairwise-comparison scale

Value	Verbal judgement
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
Reciprocals	Opposite preference

Priority vector

$$Aw = \lambda_{max} w$$

$$\sum_{i=1}^{n} w_i = 1$$

wis the normalized weight vector, and $\lambda_{max}$is the principal eigenvalue.

Consistency test

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

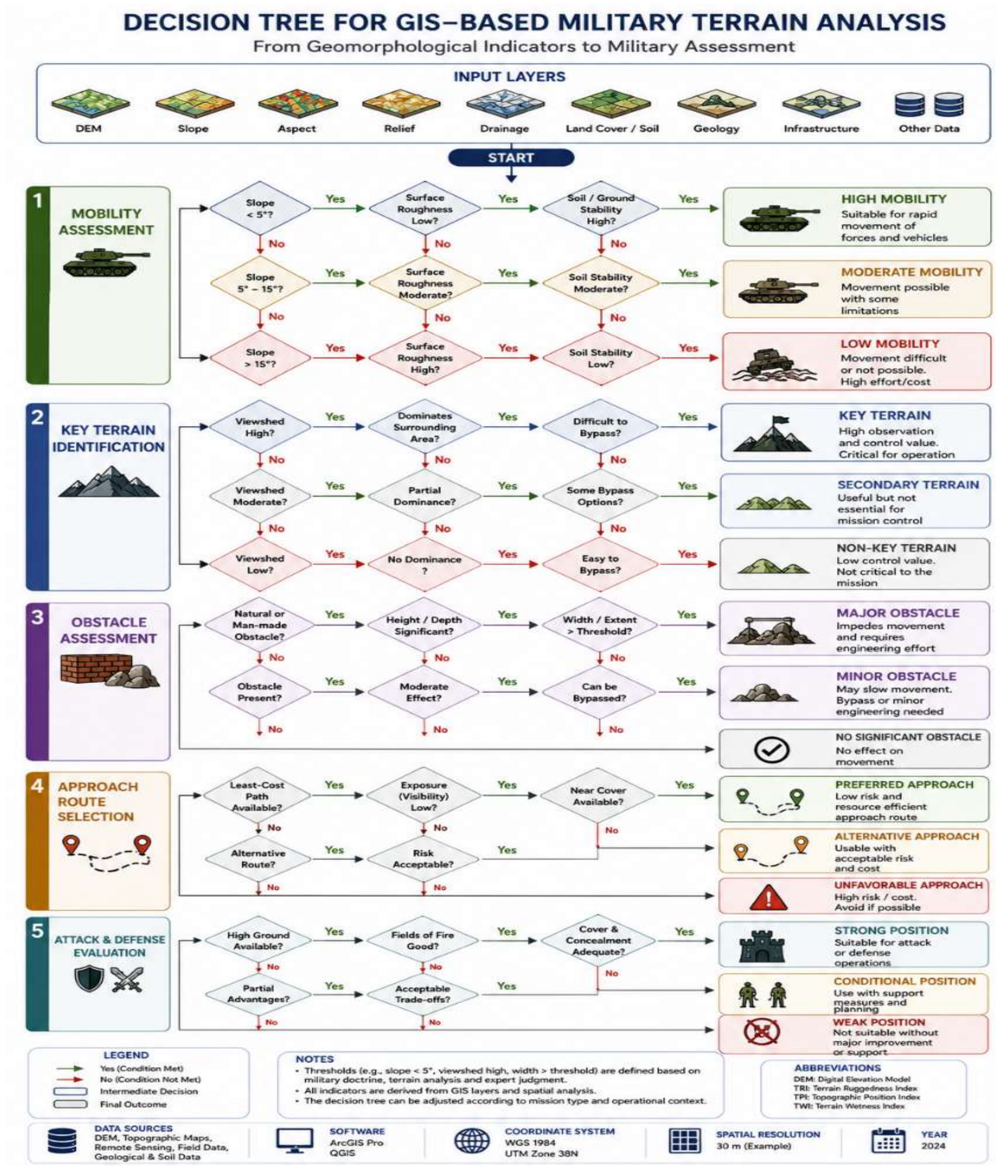
$$CR = \frac{CI}{RI}$$

CIis the consistency index, CRis the consistency ratio, and RIis the random consistency index. The matrix is acceptable when $CR < 0.10$.

Table 15. Random consistency index

□	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Figure 5. Decision Tree for GIS-Based Military Terrain Analysis



3.5.2 Standardization

For criteria with an ascending effect:

$$x_i' = \frac{x_i - x_{min}}{x_{max} - x_{min}}$$

Suitability increases as the original criterion value increases.
And for criteria with a descending effect:

$$x_i' = \frac{x_{max} - x_i}{x_{max} - x_{min}}$$

Suitability decreases as the original criterion value increases.

Table 16. Standardization scales

Model	Scale	Meaning
Movement-cost surface	1–10	1 = lowest cost, 10 = highest cost
Key terrain	1–5	1 = very low, 5 = very high
Offensive suitability	Five classes	Very low to very high
Defensive suitability	Five classes	Very low to very high
Viewshed	Binary or cumulative	Not visible/visible
Constraints	0–1	Prohibited/permitted

3.5.3 Weighted linear combination

$$S = \sum_{i=1}^{n} w_i x_i^{'}$$

subject to the constraints:

$$S = \left(\sum_{i=1}^{n} w_i x_i^{'}\right) \prod_{k=1}^{m} C_k$$

Sis final suitability, $w_i$is criterion weight, $x_i^{'}$is standardized criterion value, and $C_k$is a Boolean constraint.

Movement-cost model

$$CS = 0.300 + 0.25S + 0.20R + 0.10T + 0.10L + 0.05W$$

CSis movement cost, Ois natural obstacles, Sis slope, Ris road-network resistance, Tis soil resistance, Lis land-cover resistance, and Wis watercourse resistance.

Key-terrain model

$$KT = 0.30V + 0.25E + 0.20S + 0.15R + 0.05D + 0.05I$$

KTis key-terrain suitability, Vis viewshed, Eis elevation, Sis slope suitability, Ris road accessibility, Dis proximity to valleys and crossings, and Iis proximity to vital infrastructure.

3.5.4 Viewshed analysis

$$\theta_t = \tan^{-1}\left[\frac{(Z_t + H_t) - (Z_o + H_o)}{D_{ot}}\right]$$

A cell is considered visible when:

$$\theta_t > \max(\theta_1, \theta_2, \ldots, \theta_{t-1})$$

$\theta_t$is the vertical angle from observer to target. A target cell is visible when its vertical angle exceeds the maximum angle of all intervening cells.

Table 17. Viewshed parameters

Parameter	Adopted/recommended setting
DEM resolution	30 m
Observer offset	1.7 m for ground observation
Target offset	0 m unless target height is specified
Earth curvature	Applied for long-distance analysis
Refraction	Default or explicitly stated
Maximum distance	Defined according to scenario

Cumulative viewshed

$$CV_i = \sum_{j=1}^{m} V_{ij}$$

$CV_i$is cumulative visibility, representing the number of observers that can see cell i.

3.5.5 Least-cost path

For movement between two cells:

$$c_{ij} = \frac{F_i + F_j}{2} \times r$$

and for the diagonal direction:

$$c_{ij} = \frac{F_i + F_j}{2} \times r\sqrt{2}$$

$c_{ij}$is transition cost between adjacent cells, and ris raster-cell size.

Accumulated cost

$$C(v) = \min_{u \in N(v)} [C(u) + c(u, v)]$$

C(v)is the minimum accumulated cost required to reach cell v.

Dijkstra principle

$$d(v) = \min[d, (v)d(u) + c(u, v)]$$

d(v)is the current minimum cost to cell v, and the algorithm updates it whenever a lower-cost route is found.

Backlink

$$B(v) = \arg \min_{u \in N(v)} [C(u) + c(u, v)]$$

B(v)identifies the neighbouring cell that provides the minimum accumulated cost path to cell v.

Table 18. Spatial modelling outputs

Model component	Output
AHP weighting	Criterion weights
Standardization	Comparable raster scales
WLC	Suitability index
Cost surface	Per-cell movement resistance
Cost distance	Minimum accumulated cost
Backlink	Direction of least-cost movement
Least-cost path	Optimal movement corridor
Viewshed	Visible and non-visible terrain
Key-terrain model	Commanding terrain suitability

3.6 Validation

Verification was based on comparing the model outputs with independent field and reference data. The comparison covered actual movement routes, observation posts, key terrain, obstacles, bridges and crossings, and attack and defense positions. The verification areas covered west of Samarra, the Makhoul hills, Al-Ayth, east of Samarra, the river islands, and Al-Ishaqi Island.

3.6.1 Spatial matching rate

$$\mathrm{SMR} = \frac{L_m}{L_t} \times 100$$

SMRis the spatial matching rate, $L_m$is the matched route length, and $L_t$is the total reference-route length.

3.6.2 Overall accuracy

$$\mathrm{OA} = \frac{\sum_{i=1}^{k} n_{ii}}{N} \times 100$$

OAis overall accuracy, $n_{ii}$is the number of correctly classified observations, and Nis the total number of observations.

3.6.3 Producer's accuracy

$$\mathrm{PA}_i = \frac{n_{ii}}{\sum_j n_{ij}} \times 100$$

PA_imeasures the proportion of reference observations correctly classified.

3.6.4 User's accuracy

$$\mathrm{UA}_i = \frac{n_{ii}}{\sum_j n_{ji}} \times 100$$

UA_imeasures the probability that a modelled class is correct on the ground.

3.6.5 Kappa coefficient

$$\kappa = \frac{P_o - P_e}{1 - P_e}$$

κmeasures agreement beyond chance, where $P_o$is observed agreement and $P_e$is expected agreement.

3.6.6 Positional RMSE

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[(x_i - \hat{x}_i)^2 + \left(y_i - \hat{y}_i\right)^2\right]}$$

RMSEmeasures average positional deviation between observed and modelled locations.

Table 19. Final validation results

Model	SMR (%)	OA (%)	RMSE (m)	Accuracy level
Military mobility	81.3	81.8	22.5	High
Visibility and observation	88.8	86.3	16.2	High
Key terrain	84.5	85.0	17.1	High

Natural obstacles and avenues of approach	87.8	86.0	16.8	High
Offensive suitability	89.0	87.0	16.3	High
Defensive suitability	90.0	88.0	15.1	High

Table (19) shows that the movement model recorded the lowest relative accuracy, owing to the complexity of the agricultural and riverine environments and to changes in the condition of canals, drains, and soil moisture, whereas the defensive suitability model achieved the highest spatial agreement because it rests on more stable variables such as key terrain, visibility, and natural obstacles. The results confirm that offensive suitability reached an agreement of 89%, while defensive suitability reached 90%.

Table 20. General validation summary

Indicator	Mean value
Mean spatial matching rate	86.9%
Mean overall accuracy	85.7%
Mean RMSE	17.3 m
General assessment	High accuracy

Table 21. Additional validation results

Case	Matching rate (%)	OA (%)	RMSE (m)
Visibility in hilly terrain	88	86	16.5
Mobility in eastern Samarra	79	81	24.7
Offensive suitability	89	87	16.3
Defensive suitability	90	88	15.1
Logistics and road network	91	90	13.6

Table (21) shows that the supply and road network model achieved the highest accuracy, thanks to the stability of the network and the ease with which it can be represented, whereas movement accuracy fell east of Samarra because of the density of agricultural canals and drains and the changing condition of the surface.

3.6.7 Sensitivity analysis

The sensitivity of the model was tested by adjusting the weights:

$$\Delta w_i = \pm 10\%, \ \pm 20\%$$

The remaining weights were then renormalized:

$$w_j' = w_j \left(\frac{1 - w_i'}{1 - w_i} \right), \ j \neq i$$

$w_i'$is the modified weight of the tested criterion, while w_j'represents the rescaled weights of the remaining criteria.

The percentage change in the classes was calculated:

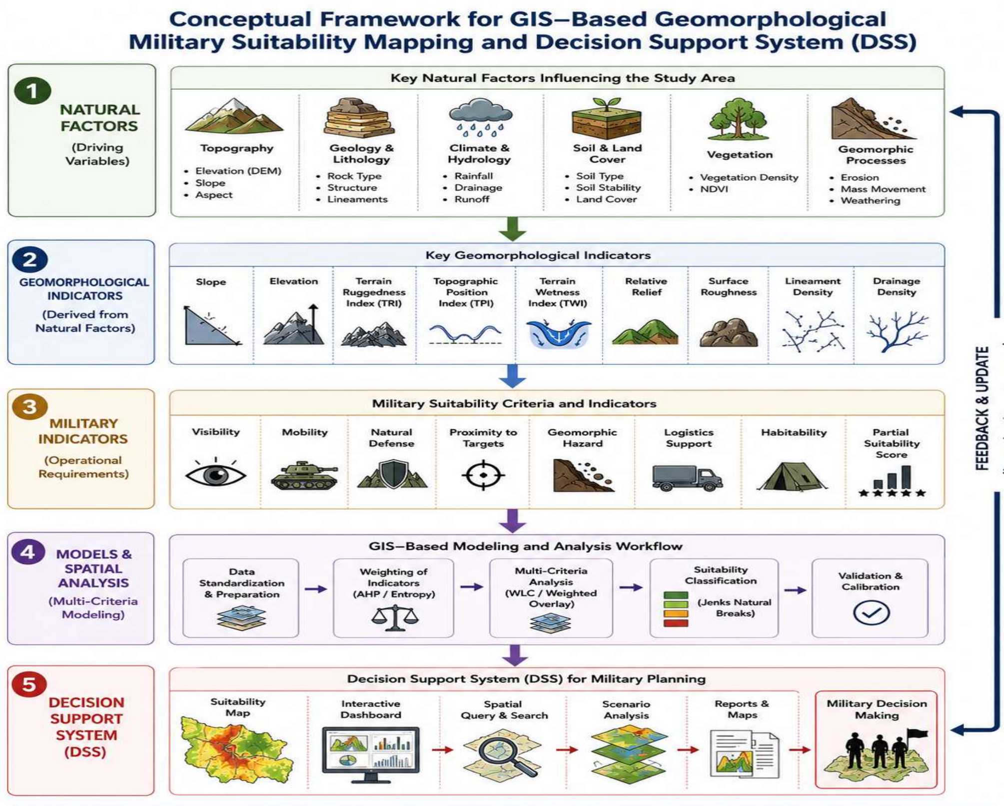
$$CCR = \frac{N_{changed}}{N_{total}} \times 100$$

CCRis the class-change rate, indicating the proportion of cells that changed suitability class after weight modification.

Table 22. Sensitivity scenarios

Scenario	Modification
Base	Adopted expert weights
S1	Slope weight +10%
S2	Slope weight −10%
S3	Natural obstacles +20%
S4	Road-network weight +20%
S5	Equal weights
S6	Removal of the most correlated criterion
S7	Alternative standardization approach

Figure 1. Conceptual Framework for GIS-Based Geomorphological Military Suitability Assessment



4. Results

The results of the spatial analysis show that the study area is not a homogeneous operational surface. It consists of geomorphological units that differ in elevation, slope, degree of dissection, drainage density, and land cover, and this variation is reflected directly in trafficability, the extent of visibility, the location of key terrain, the severity of natural obstacles, the direction of approaches, and offensive and defensive suitability. Integrating these components produced seven interrelated spatial models, which were combined into a final military suitability map and then tested against independent quantitative indicators.

The results are presented along four lines. The first analyzes the geomorphological structure, the second interprets its military effect, the third discusses the integrated suitability model, and the last evaluates spatial and statistical accuracy.

4.1 Geomorphological Analysis

The geomorphological analysis showed that the study area covers 24,400.76 km², distributed among five main terrain units: the Jazira Plateau, the sedimentary plain, the uplands, the foothills, and the floodplain. The Jazira Plateau formed the largest unit by area, while the floodplain ranked last, as Table (23) shows.

Table 23. Areal distribution of the main geomorphological units

No.	Geomorphological unit	Area (km²)	Percentage (%)	Dominant terrain characteristics
1	Jazira Plateau	11,147.24	45.68	Broad plateau, low to moderate relief, local depressions, scattered sand dunes
2	Depositional Plain	6,272.34	25.71	Mostly flat alluvial surface with low gradients
3	Uplands	3,013.39	12.35	Makhoul, Hamrin, and Balkana uplands; dissected and locally steep terrain
4	Piedmont Zone	2,451.53	10.05	Transitional undulating terrain between uplands and plains

5	Floodplain	1,516.26	6.21	Low-lying fluvial terrain, riverbanks, islands, channels, and recent deposits
Total	—	24,400.76	100.00	—

Source: GIS analysis based on the processed DEM and geomorphological map.

The Jazira Plateau occupies 11,147.24 km², equivalent to 45.68% of the total area, and extends mainly across the western parts of the study area. Despite its generally flat character it is not a uniform surface, since it contains gentle undulations, local depressions, seasonal watercourses, and sand dunes, particularly near Wadi Al-Tharthar and in the parts lying west of the Tigris. These features produce local differences in the bearing capacity of the surface, so that gravelly, well-compacted surfaces offer better ground for movement, whereas resistance increases in belts of loose sand and in damp depressions.

The sedimentary plain ranks second with an area of 6,272.34 km², or 25.71%, and is concentrated in the central and southern parts and along both banks of the Tigris. Its low slopes and continuous surface make it, geomorphologically speaking, the environment most suitable for movement and deployment, although agricultural canals, drains, and urban expansion alter that judgment in some of its parts, especially east of Samarra.

The uplands occupy 3,013.39 km², or 12.35% of the area, and are represented mainly by the Makhoul, Hamrin, and Balkana hills. Elevations in parts of the Hamrin hills range between 250 and 600 m, while the Makhoul heights reach about 360 m at some locations. The digital elevation model showed that these uplands differ from their surroundings more than any other part of the study area in terms of relative elevation, slope, and dissection, which makes them influential for visibility and control on the one hand and restrictive for vehicle movement on the other.

The foothills cover 2,451.53 km², or 10.05%, and form a transitional belt in which slopes shift from gentle to moderate and where alluvial fans, valleys, and seasonal watercourses intersect. The floodplain occupies 1,516.26 km², only 6.21%, yet its operational influence exceeds its share of the area because of its association with the Tigris, the river islands, the bluffs, the canals, and the crossing points.

This distribution shows that the generally flat lands, represented by the Jazira Plateau, the sedimentary plain, and the floodplain, together make up:

$$45.68 + 25.71 + 6.21 = 77.60\%$$

while the uplands and foothills represent:

$$12.35 + 10.05 = 22.40\%$$

Equation 12. Relative dominance of low-relief terrain

$$LRT = P_{JP} + P_{DP} + P_{FP} = 77.60\%$$

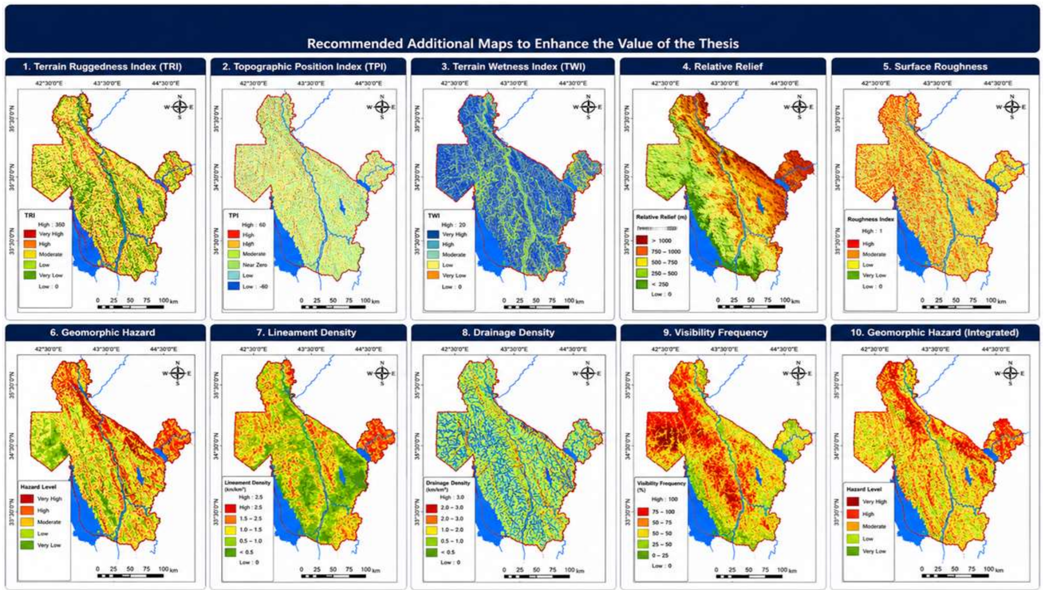
where:

- LRT= low-relief terrain proportion,
- P_{JP}= percentage of the Jazira Plateau,
- P_{DP}= percentage of the Depositional Plain,
- P_{FP}= percentage of the Floodplain.

Low-relief terrain occupies 77.60% of the study area, indicating a general regional tendency toward open or gently undulating surfaces. However, this percentage should not be interpreted as equivalent to unrestricted movement, because soils, drainage channels, sand dunes, land cover, and infrastructure introduce local resistance.

These results should be presented in Map 3, which shows the spatial distribution of the five geomorphological units, together with the Tigris, the Makhoul and Hamrin hills, the Jazira Plateau, the sedimentary plain, and the floodplain.

Figure 3. Geomorphometric Analysis Maps



4.1.1 Elevation and relative terrain position

The elevation analysis revealed a clear contrast between the river lowlands, the plateau surfaces, and the northern and northeastern uplands. The military value of elevation was not tied to absolute height alone, but to how far a site rises above its surroundings and overlooks roads, crossings, and valleys. Some escarpments of moderate height therefore had greater operational value than sites that were absolutely higher but surrounded by surfaces of similar elevation.

This is consistent with the concept of topographic position, in which positive TPI values indicate escarpments and local summits while negative values represent valleys and depressions. The highest positive values were concentrated in the Makhoul and Hamrin hills and along the escarpments overlooking the Tigris valley, whereas negative values appeared in the deeply incised valleys, local depressions, and drainage channels. This pattern is more useful for identifying key terrain than reliance on elevation alone (Weiss, 2001).

4.1.2 Slope and terrain ruggedness

The distribution of slope showed that extensive areas of the Jazira Plateau and the sedimentary plain fall within the lower slope classes, while steep slopes were concentrated in the Makhoul and Hamrin hills and along the escarpments and river bluffs. High ruggedness values were associated with almost the same areas, particularly where rocky escarpments intersect short, deeply incised valleys.

This correspondence shows that slope and ruggedness express two different aspects of surface difficulty: slope measures the steepness of the incline, whereas TRI measures local variation between neighboring cells. A surface may therefore be gently inclined yet rough, gravelly, or broken, just as it may be steep but uniform. Riley et al. (1999) stress that the ruggedness index is a measure of local variation in elevation, not a direct substitute for slope.

Slopes were classified into five military classes, beginning with 0–5° as the least restrictive to movement and ending with slopes above 45°, which pose a severe obstacle to the normal movement of vehicles. The last two classes were confined to limited belts within the uplands and escarpments, while the first and second classes prevailed across most of the western, central, and southern parts.

4.1.3 Drainage and fluvial dissection

The drainage network showed a clear difference between the plateau, hill, and river environments: channel density increased in the hill belts and their foothills, and in the farmland connected to the canals and drains east of Samarra. High drainage density points to a more dissected surface and a larger number of crossing points, which raises the cost of movement even where the general slope is low.

Drainage density is expressed by the following relationship (Horton, 1945):

$$D_d = \frac{\sum L}{A}$$

where:

- D_d= drainage density,
- $\sum L$= total channel length,
- A= unit area.

Higher drainage-density values indicate a more dissected surface and a greater frequency of stream or canal crossings. In military terrain analysis, this commonly increases movement resistance and concentrates traffic at bridges, culverts, and fords.

The practical significance of this finding is evident east of Samarra, where the canals and drains were not merely hydrological features but became a network of linear obstacles that channeled the movement of forces toward particular farm tracks and crossings. Field verification confirmed that the drainage network was the governing factor in route selection within this environment.

Table 24. Operational interpretation of the principal geomorphological environments

Geomorphological environment	Dominant physical characteristics	Mobility implication	Observation implication	Main operational constraint
Jazira Plateau	Broad, gently undulating surface	Generally high, locally reduced by dunes and depressions	Wide visibility in open areas	Loose sand and seasonal depressions
Depositional Plain	Low slope and continuous surface	High to very high	High exposure and limited concealment	Canals, settlements, and agricultural networks
Uplands	High relief, steep slopes, ridges, and valleys	Low outside existing routes	High from ridges and summits	Steepness, rock outcrops, and channel dissection
Piedmont Zone	Moderate slopes and dissected transition terrain	Moderate and spatially variable	Moderate to high from local ridges	Seasonal channels and changing gradients
Floodplain	Flat but hydrologically complex	Variable and crossing-dependent	Locally restricted by banks and vegetation	Rivers, channels, islands, soft deposits

Source: Derived from DEM, drainage, land-cover, and field-validation results.

4.2 Military Terrain Analysis

The military analysis of the terrain showed that the geomorphological variables do not act in isolation but interact in shaping the operational capability of the ground. A gentle slope does not guarantee ease of movement if it is combined with wet soil or dense canals; elevation does not amount to key terrain if the field of view is restricted; and a natural obstacle may raise the defensive value of a position while lowering its suitability for attack. This reading is consistent with the KOCOA model, which treats key terrain, observation and fields of fire, cover and concealment, obstacles, and avenues of approach as one interconnected system (Department of the Army, 2019).

4.2.1 Military mobility

The trafficability model divided the study area into five classes, as Table (25) shows.

Table 25. Military land-mobility classes

No.	Mobility class	Area (km²)	Percentage (%)	Geomorphological–military interpretation
1	Very high	4,802.67	19.68	Flat and weakly dissected surfaces with limited natural resistance
2	High	7,833.54	32.10	Gently undulating and relatively stable surfaces with good road accessibility

3	Moderate	5,328.94	21.84	Terrain affected by moderate slopes, drainage, land-cover, or soil resistance
4	Low	4,317.70	17.69	Dissected terrain, greater slope, weak soils, or multiple obstacles
5	Very low	2,117.90	8.68	Steep, rugged, hydrologically constrained, or loose-sediment terrain
Total	—	24,400.76	100.00	—

Source: Weighted-overlay analysis of slope, natural obstacles, roads, soils, land cover, and watercourses.

The results show that the very high and high capability classes together occupy:

$$4{,}802.67 + 7{,}833.54 = 12{,}636.21 \text{ km}^2$$

and account for:

$$19.68 + 32.10 = 51.78\%$$

of the study area. This means that more than half of the area has surface characteristics permitting relatively good military movement, particularly in the sedimentary plains, across wide parts of the Jazira Plateau, and on the surfaces close to the main roads.

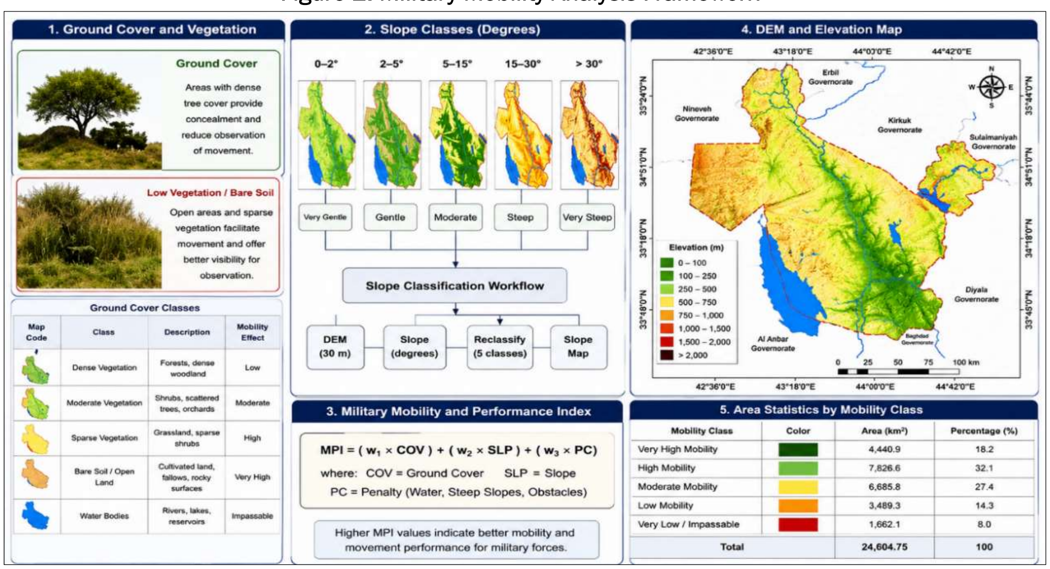
By contrast, the low and very low capability classes occupy:

$$4{,}317.70 + 2{,}117.90 = 6{,}435.60 \text{ km}^2$$

that is:

$$17.69 + 8.68 = 26.37\%$$

Figure 2. Military Mobility Analysis Framework



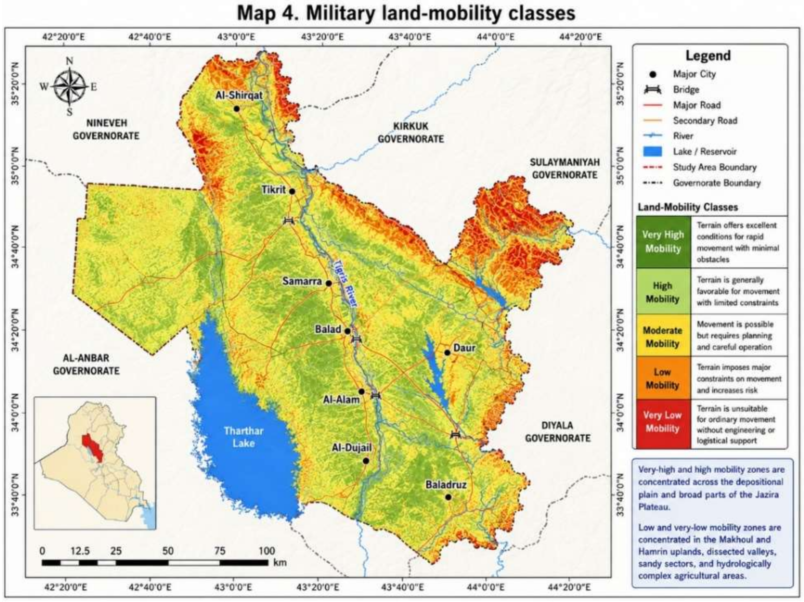
of the area. This ground is concentrated in the Makhoul and Hamrin hills, the rocky escarpments, the valleys, and the areas affected by sand dunes, canals, and drains. The intermediate class amounts to 5,328.94 km², or 21.84%, and forms a transitional belt that may turn into good or poor going depending on seasonal conditions, the type of vehicle, and the availability of roads and crossings.

These results reveal that describing the area as largely plains does not imply complete freedom of movement, since 26.37% of the area is subject to severe constraints, and part of the intermediate class may become restricted during the rainy season. The map is therefore more useful than a regional average, because it identifies the actual locations where movement deteriorates.

These results should be represented in Map 4.

Map 4. Military land-mobility classes

Map 4. Military land-mobility classes



Very-high and high mobility zones are concentrated across the depositional plain and broad parts of the Jazira Plateau. Low and very-low mobility zones are concentrated in the Makhoul and Hamrin uplands, dissected valleys, sandy sectors, and hydrologically complex agricultural areas.

4.2.2 Visibility, observation, and dead ground

The viewshed analysis showed that visibility improves on the open plain, along the higher escarpments, and at positions overlooking roads, bridges, and crossings, and deteriorates behind slopes, in deeply incised valleys, along river bluffs, and in the depressions lying between the hills.

The proportion of visible area from the various observation points ranged from low values at masked positions to about 97% at some sites commanding wide fields of view, depending on the position and height of the observer and on the nature of the terrain. This variation confirms that visibility is not a fixed property of a geomorphological unit but the outcome of the geometric relationship between the observer and the surrounding surface.

A dead ground index was used to determine the masked areas:

Equation 13. Dead Ground Index

$$\mathrm{DGI} = \frac{A_{DG}}{A_T} \times 100$$

where:

- DGI= Dead Ground Index,
- A_{DG}= dead-ground area,
- A_T= total assessed area.

Higher DGI values indicate a larger proportion of terrain concealed from direct observation, whereas lower values indicate stronger visual control and reduced opportunities for concealed movement.

Dead ground was concentrated behind the reverse slopes of the Makhoul and Hamrin hills, in the valleys, depressions, and river bluffs, and also appeared within the river islands and along the banks of the Tigris because of the meanders of the channel, the height of the banks, and the vegetation cover. Conversely, dead ground diminished on the open sedimentary plain and west of Samarra, where the surface is level and visual obstructions are few.

This finding agrees with the analysis of Guth (2011), which shows that the military value of high ground depends on the actual field of command rather than on height in the abstract, and it is also consistent with the observation and fields of fire principle in KOCOA (Department of the Army, 2019).

4.2.3 Key terrain

The key terrain map showed that the highest degrees of suitability were not distributed across all the elevated areas, but were concentrated on the escarpments and summits that combined the following characteristics:

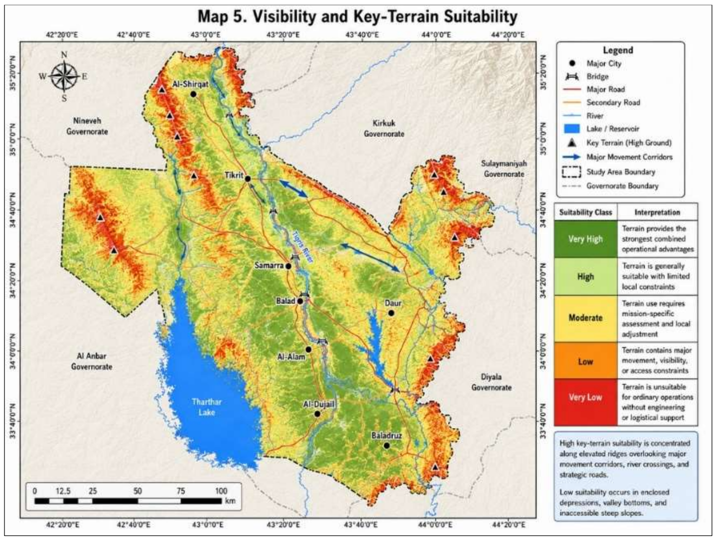
- a clear elevation relative to the surrounding areas;
- a wide field of view;

- command over a movement axis, road, or crossing;
- a slope that permits positioning and access;
- relative proximity to logistic infrastructure or important installations.

These characteristics appeared clearly in parts of the Makhoul and Hamrin hills, on the escarpments overlooking the Tigris valley, and at positions commanding roads and crossings. Isolated or very steep summits lacking access, on the other hand, scored lower despite their height, because the difficulty of supply and positioning limited their operational value.

This confirms that key terrain is a composite functional concept and not a synonym for elevation, which accords with military analysis that ties the value of a position to its ability to influence the mission and control the important axes (Department of the Army, 2019).

Map 5. Visibility and key-terrain suitability



High key-terrain suitability is concentrated along elevated ridges overlooking major movement corridors, river crossings, and strategic roads. Low suitability occurs in enclosed depressions, valley bottoms, and inaccessible steep slopes.

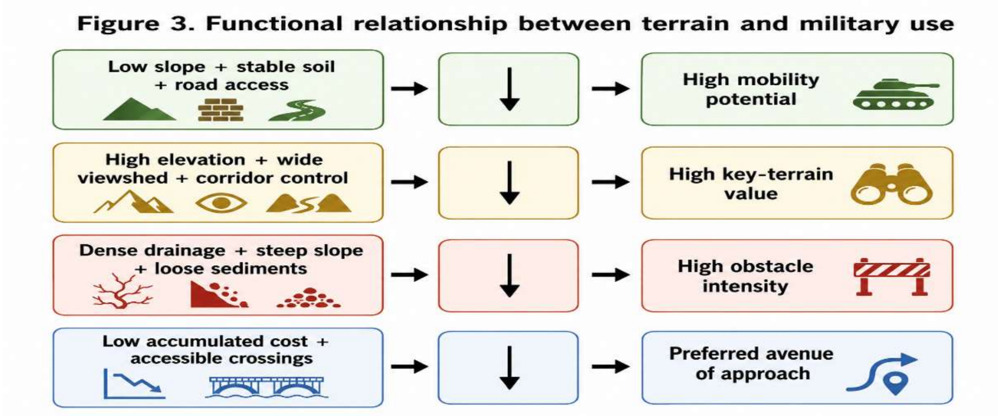
4.2.4 Natural obstacles and avenues of approach

The obstacle model showed that the Tigris, the canals and drains, the seasonal valleys, the steep slopes, and the loose sandy deposits are the most important constraints on movement. The severity of the obstacle was not uniform everywhere, however: it ranged from a partial obstruction that can be crossed to a barrier that channels movement almost entirely toward the crossings and roads.

In the agricultural environment east of Samarra, the canals and drains directed movement toward the bridges and farm tracks and forced routes to deviate from a straight line. In the Makhoul hills, by contrast, the escarpments and valleys concentrated the avenues of approach within the natural passes and depressions, which made them more exposed to observation and control.

Least-cost path analysis showed that the optimal route was not always the shortest in distance but the one with the lowest cumulative resistance. The finding demonstrates the value of combining slope with the road network, obstacles, soil, and land cover, since relying on distance alone may suggest routes that cross watercourses or slopes that are difficult to traverse.

Figure 3. Functional relationship between terrain and military use



Military terrain performance results from combinations of terrain conditions rather than from any single geomorphological variable.

Table 26. Summary of military terrain outcomes

Terrain component	Highest-performing environment	Lowest-performing environment	Principal controlling factor
Mobility	Depositional plain and stable plateau surfaces	Makhoul–Hamrin uplands and channel-dense agricultural land	Slope, obstacles, and road access
Visibility	Open plains and elevated ridges	Reverse slopes, valleys, and riverbanks	Line-of-sight obstruction
Key terrain	Ridges overlooking routes and crossings	Enclosed or inaccessible terrain	Viewshed and relative elevation
Concealment	Valleys, depressions, reverse slopes, and vegetated river zones	Open depositional plain	Dead-ground proportion
Defensive suitability	Elevated and obstacle-supported positions	Open terrain lacking protection	Key terrain and natural obstacles
Offensive suitability	Accessible, low-cost corridors with logistical support	Steep, dissected, or crossing-dependent terrain	Mobility and avenue continuity

4.3 Integrated Suitability Map

The integrated suitability map was the final product of combining the models of movement, visibility, key terrain, natural obstacles, avenues of approach, offensive suitability, and defensive suitability. The purpose of the combination was not to produce an arithmetic average of separate maps, but to build a spatial representation of the functional relationships among them, so that suitability rises where ease of movement coincides with the possibility of observation and access and with few obstacles, or where the characteristics of a site match a specific defensive function.

The final model was expressed by the following relationship:

Equation 14. Integrated Military Suitability Index

$$\mathrm{IMSI} = \sum_{i=1}^{n} w_i M_i$$

where:

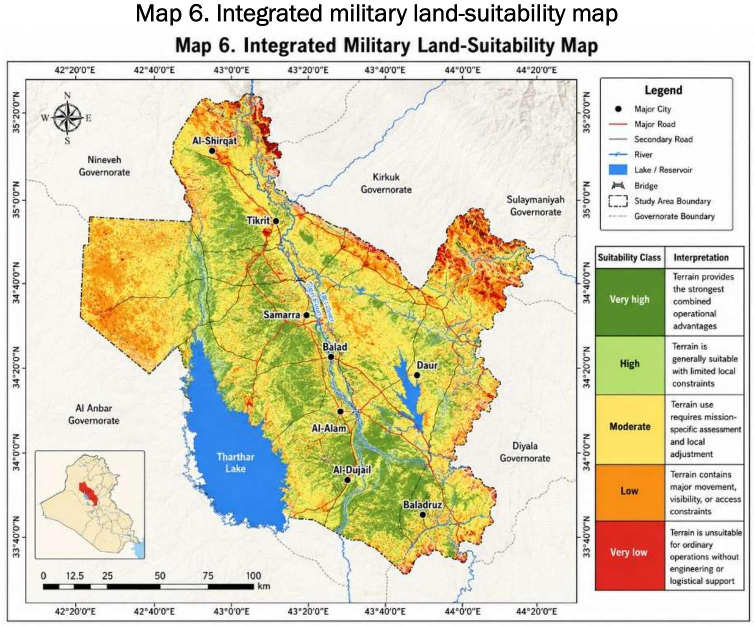
- IMSI= Integrated Military Suitability Index,
- w_i= weight assigned to model i,
- M_i= standardized output of model i,
- n= number of integrated models.

The final suitability score is the weighted sum of the standardized partial-model outputs. Higher values represent terrain where the combined conditions of movement, observation, access, and operational control are more favourable.

The final map revealed four main spatial patterns:

First, belts of high suitability on level or gently undulating ground, especially where they lie close to roads and away from the main obstacles. These areas offer the best options for movement, deployment, and logistic support, although they are more exposed on the open plains.
Second, belts of high defensive value in the uplands and along the escarpments that provide wide fields of view and command over the avenues of approach, particularly in parts of the Makhoul and Hamrin hills. These positions are not necessarily the best areas for movement, but they offer greater value for positioning, observation, and defense.
Third, belts of moderate suitability in the foothills and on the transitional surfaces, which combine acceptable movement potential with some topographic advantages but are affected by changes in slope, the density of valleys, and the distance between roads.
Fourth, belts of low suitability in the deeply incised valleys, on steep slopes, in loose sandy deposits, in farmland crossed by many canals and drains, and on the islands and in areas whose crossing depends on a limited number of points.
The result makes clear that military suitability is not a single concept valid for every mission: an area highly suitable for movement may be poorly suited to defense because it is exposed, while the uplands may be excellent for observation and defense yet poor for heavy movement. The integrated suitability map should therefore be read together with the component maps, and should not be used on its own when the type of mission differs.

Map 6. Integrated military land-suitability map



The integrated map differentiates between open high-mobility terrain, strategically commanding uplands, transitional terrain, and strongly constrained zones. It should be interpreted as a decision-support layer rather than a substitute for mission-specific intelligence.
The structure of the model indicates that the movement outputs formed the basis for estimating the scope for maneuver, while visibility and key terrain defined the areas of control. The obstacle layer added the effect of rivers, canals, slopes, and loose deposits, the avenues of approach identified the best directions of advance, and the offensive and defensive models then brought these results together in a comprehensive functional assessment.
A necessary scientific note: the accompanying files contained no final numerical table giving the area and percentage of each class in the integrated final map. No assumed area values have therefore been entered in this section. They should be extracted from the final layer in ArcGIS using the Tabulate Area or Zonal Histogram tool and inserted in the table below before submission to the journal.

Table 27. Area distribution of the integrated military suitability classes

Suitability class	Area (km²)	Percentage (%)
Very high	976.03	4.00
High	5,124.16	21.00
Moderate	13,908.43	57.00
Low	3,172.10	13.00

Very low	1,220.04	5.00
Total	24,400.76	100.00

4.4 Accuracy Assessment

Spatial verification showed that the models achieved high levels of accuracy: spatial agreement exceeded 81% in all the final models, overall accuracy ranged between 81.8 and 88.0%, and RMSE ranged between 15.1 and 22.5 m. Table (28) presents the detailed results.

Table 28. Accuracy assessment of the military terrain models

Model	Spatial Matching Rate, SMR (%)	Overall Accuracy, OA (%)	RMSE (m)	Accuracy level
Military mobility	81.3	81.8	22.5	High
Visibility and observation	88.8	86.3	16.2	High
Key terrain	84.5	85.0	17.1	High
Natural obstacles and avenues of approach	87.8	86.0	16.8	High
Offensive suitability	89.0	87.0	16.3	High
Defensive suitability	90.0	88.0	15.1	High

Source: Field validation, GPS observations, satellite-image comparison, and operational-reference data.

The defensive suitability model achieved the highest agreement at 90.0%, the highest overall accuracy at 88.0%, and the lowest RMSE at 15.1 m. This indicates that the variables underlying the model, such as key terrain, visibility, obstacles, and natural protection, were more stable spatially and closer to the positions actually used.

The offensive suitability model came second, with 89.0% agreement, an overall accuracy of 87.0%, and an RMSE of 16.3 m, which shows that the model captures the relationship between the avenues of approach, ease of movement, the road network, and low obstacle severity.

The visibility and observation model recorded 88.8% agreement, an overall accuracy of 86.3%, and an RMSE of 16.2 m. Its accuracy varied with the environment: agreement reached 92% in open environments and 89% in hill environments, but fell to 78% in agricultural and riverine environments. The last figure reflects the influence of trees, buildings, vegetation cover, and high banks, features that the DEM does not represent with full accuracy.

The obstacles and avenues of approach model recorded 87.8% agreement, an overall accuracy of 86.0%, and an RMSE of 16.8 m, while the key terrain model recorded 84.5% agreement, an overall accuracy of 85.0%, and an RMSE of 17.1 m.

The movement model ranked last, though it remained within the high accuracy range, with 81.3% agreement, an overall accuracy of 81.8%, and an RMSE of 22.5 m. Its higher relative error is bound up with changes in the condition of farm tracks, canals, water, and land cover, and with the fact that actual movement may be shaped by tactical and logistic factors that the model does not include.

The case east of Samarra bears out this explanation, with 79% agreement, an overall accuracy of 81%, and an RMSE of 24.7 m, results below the average because of the density of canals and drains and changes in water levels and vegetation cover.

Table 29. Environment-specific validation of selected models

Validation environment/model	SMR (%)	OA (%)	RMSE (m)	Interpretation
Visibility in open terrain	92	—	—	Excellent agreement due to limited surface obstruction
Visibility in hilly terrain	89	86	16.5	High agreement, with local DEM-related deviations
Visibility in agricultural and riverine terrain	78	—	—	Reduced accuracy because of vegetation, buildings, banks, and canals
Mobility in eastern Samarra	79	81	24.7	Good but lower than other environments
Offensive suitability	89	87	16.3	High
Defensive suitability	90	88	15.1	High
Logistics and road-network model	91	90	13.6	Highest local efficiency because of road-network stability

4.4.1 Overall model performance

The overall mean spatial agreement was:

$$\bar{SMR} = 86.9\%$$

and the mean overall accuracy was:

$$\bar{OA} = 85.7\%$$

while the mean spatial error was:

$$\bar{RMSE} = 17.3 \text{ m}$$

Table 30. Overall accuracy summary

Indicator	Mean value	General interpretation
Mean Spatial Matching Rate	86.9%	High spatial agreement
Mean Overall Accuracy	85.7%	High classification accuracy
Mean RMSE	17.3 m	Error below the 30-m analytical cell size
Overall model assessment	High	Suitable for regional operational decision support

The mean RMSE of 17.3 m is smaller than the 30 m analytical cell size, being equivalent to:

$$\frac{17.3}{30} \times 100 = 57.67\%$$

of the width of a single cell. The mean spatial deviation therefore remained within less than one analytical cell, an acceptable level for a regional model built on 30 m SRTM data.

Equation 15. Relative RMSE to raster resolution

$$RRMSE = \frac{RMSE}{R_s} \times 100$$

$$RRMSE = \frac{17.3}{30} \times 100 = 57.67\%$$

where:

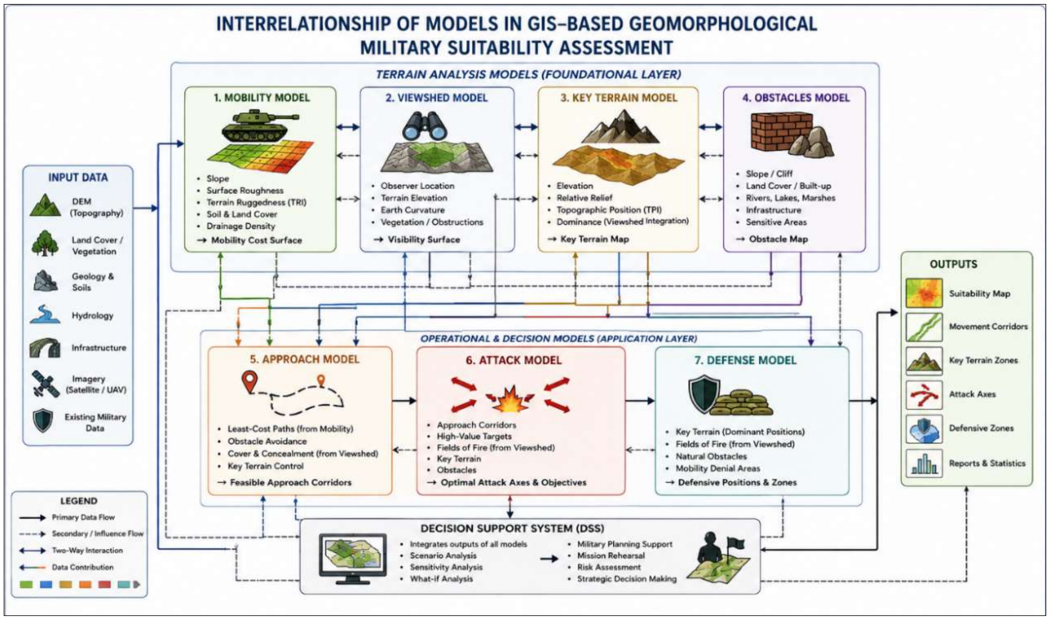
- RRMSE= relative positional error,
- RMSE= mean positional root mean square error,
- R_s= raster spatial resolution.

The mean positional error represents 57.67% of one raster-cell width and remains below the 30-m spatial resolution used in the analysis.

Taken together, the results indicate that the composite models performed somewhat better than the basic ones: offensive and defensive suitability achieved the highest levels of agreement because each combined information on movement, visibility, obstacles, key terrain, and roads within a single output. This does not mean that adding layers automatically raises accuracy; the improvement came from integrating variables with different functions and from correcting the weaknesses of each component model.

The evaluation procedure follows the recommendations of Congalton and Green (2019), who stress that no single measure should be relied upon and that overall accuracy, class accuracy, spatial error, and independent verification should be combined. The Kappa coefficient should likewise be treated as a supplementary indicator rather than a sole criterion, since it is sensitive to the prevalence and distribution of classes; the interpretation of the results here therefore rested mainly on OA, SMR, and RMSE.

Figure 4. Integrated GIS-Based Military Suitability Models and Decision Support System (DSS)



5. Discussion

The results confirm that the relationship between geomorphology and military operations in Salah Al-Din Governorate is not a linear one that can be explained by a single variable, but the outcome of interaction among elevation, slope, dissection, the drainage network, soil, land cover, roads, and watercourses. The spatial model showed that the same characteristic may be an advantage in one operational context and a constraint in another: the uplands provide command, visibility, and protection, yet they may restrict movement and supply, whereas the plains ease the movement of troops and vehicles but increase exposure and reduce the scope for natural concealment. This accords with the military approach to terrain analysis, which does not classify landforms as suitable or unsuitable in absolute terms but ties their value to the type of mission, the direction of movement, accessibility, and the degree of control over important axes (Department of the Army, 2019; Guth, 2011).

5.1 Geomorphological control of military terrain

The results showed that the predominance of surfaces with low dissection does not imply a homogeneous operational environment. Although the Jazira Plateau, the sedimentary plain, and the floodplain together account for 77.60% of the study area, local differences in loose sand, agricultural canals, drains, soil moisture, river bluffs, and urban expansion produced marked variation in the cost of movement. Classifying the area in general terms as level or gently undulating is therefore not sufficient to judge its military suitability unless it is accompanied by detailed analysis of surface and linear features.

This finding illustrates the difference between conventional terrain analysis and military geomorphological analysis: the former describes the height and inclination of the surface, whereas the latter converts these properties into indicators tied to movement, observation, protection, and access. The results east of Samarra confirmed the difference, since gentle slopes did not produce high trafficability everywhere because of the density of canals and drains and changes in soil moisture and crop cover. The spatial agreement of the movement model in this environment fell to 79% and RMSE rose to 24.7 m, against a general mean of 17.3 m, which shows that fine hydrological and agricultural obstacles may matter more than regional slope.

This confirms that slope should not be used on its own in analyzing trafficability, since the efficiency of movement is determined by the interaction of inclination, surface roughness, the bearing capacity of the soil, drainage density, and the availability of roads and crossings. The TRI expresses local variation in elevation while slope expresses its rate of change, so combining the two yields a better account of areas that may appear gently inclined yet are broken, rocky, or rough (Riley et al., 1999; Sappington et al., 2007).

The analysis also showed that drainage density was not merely a morphometric property but acted as a direct indicator of surface dissection and of the likelihood of multiple crossings. In the agricultural and riverine areas, the canals, drains, and branches of the Tigris concentrated movement at a limited number of bridges and crossings, turning these sites into points of spatial control and obligatory passages. The finding is consistent with the morphometric basis of drainage density, which links high values to greater dissection and shorter distances between channels (Horton, 1945), but the present study extends that interpretation by showing its effect on the movement of forces and on the choice of avenues of approach.

5.2 Mobility and terrain accessibility

Land with very high and high trafficability covered 12,636.21 km², equivalent to 51.78% of the study area, while the low and very low classes covered 6,435.60 km², or 26.37%. The intermediate class accounts for 21.84% and is of particular interest, since it is the most sensitive to seasonal conditions, vehicle type, and changes in the state of roads and soil.

These proportions indicate that Salah Al-Din Governorate offers ample space for maneuver, but not space that is fully continuous, since it is cut by rivers, canals, hills, valleys, and loose sand. A large area of high capability does not therefore mean unconditional freedom of movement, because actual movement depends on how far the suitable areas connect with one another and on the location of crossings and roads. This is why least-cost path analysis showed that the optimal route may be longer than the straight line yet offer less resistance, because it avoids steep slopes, watercourses, and obstacles.

The result is in line with GIS route analysis studies, which stress that the shortest geometric distance is not necessarily the least-cost path, because spatial cost represents the sum of resistance accumulated along the route and not its length alone (de Smith et al., 2018; Malczewski & Rinner, 2015). This approach offers a more realistic account of movement than analysis based on distance or roads alone.

Natural obstacles received a weight of 30% and slope a weight of 25% in the movement cost model, so together they made up 55% of the total weight. The result reflects the experts' assessment of the importance of terrain control over movement, but it does not mean that roads, soil, and land cover are secondary factors: a relatively modest weight may be combined with a very high local effect, as in the case of a single bridge or crossing that controls movement across a wide area. The overall weight of a criterion must therefore be interpreted alongside its spatial distribution and the nature of the extreme values within it.

5.3 Visibility and key terrain

The visibility results showed that elevated positions do not necessarily offer equal command of the ground. The visible area from the observation points varied with location and with the orientation of the terrain, reaching about 97–98% at some open sites while falling sharply at positions masked behind escarpments or lying within valleys and depressions. This confirms that absolute elevation is not sufficient to identify key terrain, and that actual visibility, relative elevation, and access to the site matter more than the height value on its own.

Visibility accounted for 30% of the weight in the key terrain model, elevation for 25%, and slope for 20%, so the topographic and visual variables made up 75% of the model. Proximity to roads contributed 15%, while proximity to valleys, crossings, and vital installations together received 10%. This structure shows that key terrain was not defined on the basis of summits, but on the ability of a position to command and influence the axes of movement while remaining accessible and capable of being supported.

This conclusion is consistent with the concept of key terrain, which defines the value of a position by its capacity to give the side holding it a clear advantage in carrying out the mission, and not simply by its being higher than its surroundings (Department of the Army, 2019). It also agrees with applications of topographic analysis showing that the topographic position index is more useful than absolute elevation in distinguishing escarpments, valleys, and locally elevated sites (Weiss, 2001).

The results in the Makhoul and Hamrin hills show that the escarpments overlooking roads, valleys, and crossings have greater key value than some interior summits, since the former combine visibility with control over movement, whereas the latter may be too steep, hard to reach, or without command of any significant operational objective. The study thus offers a more discriminating treatment than classifications that equate elevation directly with military importance.

Reverse slopes, valleys, and river bluffs, by contrast, formed belts of dead ground that permit masked movement and concealment. Such areas gain importance in planning attacks and maneuvers, but they may also be routes dominated from the surrounding heights. Dead ground should therefore not be read as an absolute advantage, since its value depends on how far it connects with the avenues of approach, on the possibility of exiting from it, and on whether its entrances and exits are free from observation.

5.4 Natural obstacles and avenues of approach

The results confirmed that a natural obstacle does not always halt movement but reorganizes it spatially. Watercourses, escarpments, steep slopes, sandy deposits, and agricultural canals turned movement from a broad advance into a set of defined axes. The importance of this finding lies in the fact that obstacles are not measured by their area alone: a river may occupy a narrow strip on the map yet carry great operational weight, because it severs the connection between its two banks and ties movement to a limited number of bridges and crossings.

The obstacles and avenues of approach model achieved 87.8% agreement, an overall accuracy of 86.0%, and an RMSE of 16.8 m. These values indicate that the model represents the actual passages to a high degree, and that combining obstacles with slope and roads explained movement better than any single layer.

The results also showed that the sedimentary plain offered relatively broad avenues of approach but was more exposed to observation, whereas the foothills and valleys offered less exposed axes that were narrower and more closely governed by the terrain. In the riverine environment, the axes of movement were tied to the crossings, and the islands, banks, and canals became factors determining direction, speed, and flexibility.

This finding accords with the classical military treatment of obstacles and avenues of approach, in which obstacles are studied not in isolation but according to their capacity to prevent movement, slow it, or divert it into a direction that can be observed or controlled (Department of the Army, 2019). The study adds a quantitative dimension to that analysis by converting the degree of resistance into a continuous cost surface and generating routes that can be compared and verified.

5.5 Offensive and defensive suitability

Defensive suitability performed best among the models, with 90.0% agreement, an overall accuracy of 88.0%, and an RMSE as low as 15.1 m. The offensive suitability model followed, with 89.0% agreement, an overall accuracy of 87.0%, and an RMSE of 16.3 m. The relative advantage of the defensive model indicates that defensive positions were associated with stable geomorphological variables that can be represented spatially, such as escarpments, key terrain, fields of view, and natural obstacles.

Offensive positions, on the other hand, depend more on flexibility of movement, the continuity of the axis of approach, the speed of advance, and support, all of which are more variable over time. Even so, agreement of 89% shows that combining trafficability, roads, obstacles, and visibility succeeded in explaining most of the actual distribution of offensive positions.

The strong performance of the two composite models is explained by their combining several outputs with complementary functions. The movement model addressed accessibility, the visibility model determined the degree of exposure, the key terrain model revealed the positions of control, and the obstacle model identified constraints and passages; these elements were then merged within an offensive or defensive assessment. The study files confirm that the composite models raised explanatory power relative to the single models.

The higher accuracy of the composite model should not, however, be read as evidence that increasing the number of criteria always yields a better result, since combining layers that are too closely related may duplicate the effect of the same factor. This risk was reduced by distinguishing the functions of elevation, slope, TPI, and visibility, yet the possibility of correlation among some variables remains a source of uncertainty that will require future testing with correlation coefficients and sensitivity analysis.

Table 31. Comparison of the present findings with relevant terrain-analysis literature

Study aspect	Present study finding	Interpretation in previous literature	Degree of agreement
Low slopes and movement	High and very-high mobility covered 51.78%	Low slopes generally improve accessibility and manoeuvre	High
Rugged uplands	Makhoul and Hamrin restricted heavy movement	Rugged terrain reduces speed and channels movement	High
Elevated terrain	High value only when combined with viewshed and access	Key terrain depends on mission influence, not elevation alone	High
Drainage obstacles	Channels and rivers concentrated movement at crossings	Drainage dissection increases crossing cost and route control	High

Integrated modelling	Offensive and defensive models outperformed individual models	MCDA integration improves spatial decision support when criteria are complementary	High
Environmental variability	Agricultural and riverine zones produced lower accuracy	Dynamic land cover and water conditions reduce model transferability	High

Source: Present study; Department of the Army (2019); Guth (2011); Horton (1945); Malczewski and Rinner (2015); Riley et al. (1999).

5.6 Integrated suitability and decision support

The integrated map provided a spatial representation of the relationship between movement, visibility, control, obstacles, and access, but its use should be tied to the type of mission. High suitability for movement does not necessarily equal high defensive suitability, because open, level ground eases deployment yet increases exposure. Steep escarpments, likewise, may be excellent for observation but unsuitable for stationing heavy vehicles or for sustained support.

The main value of the model lies in its ability to compare alternatives and identify where the various functions agree and where they conflict. The results can be grouped into three operational patterns:

1. areas combining movement and access, which form axes suited to maneuver and supply;
2. areas combining visibility, protection, and obstacles, which form suitable defensive or observation positions;
3. areas of functional conflict, such as uplands that are good for visibility but poor for movement, or plains that are good for movement but highly exposed.

The third pattern represents the model's most valuable contribution, because it prevents decisions from being taken on the basis of a single indicator. It shows that a military decision requires the benefits of a position to be weighed against its costs, which is the central idea of multi-criteria analysis in GIS (Malczewski, 1999; Malczewski & Rinner, 2015).

The results also make clear that the final model is a decision-support tool rather than a substitute for the operational decision, since the geomorphological layers contain no real-time information on the disposition of forces, the threat, current weather, the state of bridges and roads, or security restrictions. The model should therefore be combined with up-to-date data when it is used in an actual situation.

5.7 Model accuracy and uncertainty

Mean spatial agreement across the models was 86.9%, mean overall accuracy 85.7%, and mean RMSE 17.3 m. These results are high for a regional model based on a 30 m cell, since the mean error is smaller than the width of a single cell and represents 57.67% of it.

These values support the validity of the model for regional analysis and for identifying belts and axes, but they do not automatically make it suitable for fine applications at the scale of a few meters, such as fixing the position of a small installation or a narrow crossing point. The final level of detail is bound to the accuracy of SRTM and of the thematic maps, so the boundaries between classes should be read as transitional zones rather than absolute lines.

The movement model recorded the lowest agreement at 81.3% and the highest RMSE at 22.5 m, while the defensive model produced the best results. The difference arises because movement is affected by rapidly changing variables such as soil moisture, the state of roads, water levels, crop cover, and tactical decisions, whereas defensive suitability rests more heavily on stable features such as escarpments, relative elevation, and visibility.

The thesis data show that the reasons for mismatch differed with the environment: on the open plains they were related to operational variables, in the hill environment to tactical considerations, in the semi-desert environment to sand movement, in the farmland to changes in vegetation cover and soil moisture, and in the riverine environment to changes in water levels and crossings.

Table 32. Principal sources of uncertainty

Environment or model component	Main source of uncertainty	Expected effect on results	Recommended improvement
Open plains	Operational decisions not represented in GIS	Actual routes may deviate from the lowest-cost route	Add scenario and mission constraints
Hilly terrain	DEM vertical and spatial resolution	Small ridges and channels may be generalized	Use higher-resolution DEM or UAV data

Semi-desert terrain	Sand movement and seasonal surface change	Mobility cost changes over time	Use multi-date imagery and field surface data
Agricultural terrain	Crop growth, irrigation, and soil moisture	Reduced visibility and changing trafficability	Introduce seasonal land-cover and soil-moisture layers
Riverine terrain	Water-level and crossing changes	Temporary barriers or new crossing opportunities	Integrate real-time hydrological and bridge-status data
Viewshed	Absence of detailed tree and building heights	Overestimation of visibility	Use DSM or LiDAR where available
AHP weights	Expert judgement and criterion dependence	Variation in suitability classes	Apply sensitivity and uncertainty analysis

Source: Present study and validation analysis.

A divergence between model and reality is a normal part of modeling and does not necessarily indicate a weak method, since a model reduces reality to a set of measurable variables while military operations are shaped by human, temporal, and informational factors that cannot all be represented in GIS. The strength of a model rests on the clarity of its assumptions and on stating the limits of its application, not on any claim of complete correspondence.

This view accords with Congalton and Green (2019) and Foody (2020), who stress that accuracy must be interpreted in light of the sampling design, the nature of the reference data, and the prevalence of the classes, and that a single value is not enough to judge the quality of a model. The study therefore used three complementary measures, SMR, OA, and RMSE, rather than relying on overall accuracy alone.

5.8 Transferability and limitations

One strength of the work is that the methodological framework can be transferred to other parts of Iraq, since the basis of the model rests on variables that are relatively easy to obtain, such as a DEM, slope, roads, drainage, and land cover. Transferring the weights and class thresholds directly to a different environment, however, may produce misleading results.

The verification results suggest that the model is most generalizable in environments similar to Salah Al-Din Governorate, such as floodplains, semi-desert land, and hills of moderate dissection, where movement, visibility, obstacles, and the road network govern the military value of the surface. Steep mountain environments, dense urban areas, marshlands, and coastal settings would require additional criteria and new weights.

The main limitations of the study are the following:

- reliance on a 30 m DEM, which may not represent small bluffs, canals, and minor rises;
- the absence of a digital surface model incorporating the height of buildings and trees;
- differences in the dates of some data sources;
- the dependence of part of the weighting on expert judgment;
- seasonal changes in the condition of roads, soil, and water;
- the omission of real-time information on weather, threat, or force disposition;
- the fact that the final digital areas of the integrated suitability classes were not extracted from the GIS layer in the accompanying copies.

These limitations do not diminish the value of the results, but they set the proper level at which to use them: the model is suited to regional planning, comparing alternatives, and identifying priority zones, yet it requires additional detailed and field data before any precise site-specific decision is taken.

5.9 Scientific contribution

The scientific contribution of the study lies in moving from conventional description of landforms to the construction of a spatial model that links geomorphological characteristics to military functions that can be measured and verified. This was achieved through:

- combining morphometric variables with environmental features and movement networks;
- separating trafficability, key terrain, visibility, and obstacles;
- building independent offensive and defensive models before final integration;
- using field data, routes, and reference positions for verification;
- measuring performance with several spatial and statistical indicators.

The results also show that the composite models achieved higher accuracy than most of the component models, which supports the study's premise that interpreting military terrain requires the integration of surface characteristics rather than reliance on a single topographic element. A mean overall accuracy of 85.7% with an RMSE of 17.3 m reflects the model's ability to explain most of the spatial variation in operational use within the limits of the available data.

The model thus offers a framework that can be developed further to support spatial planning, the assessment of movement axes, and the identification of areas of control and obstruction, provided its data are updated and it is recalibrated to suit the environment and the mission.

6. Conclusions

The study has shown that geomorphological characteristics are a decisive factor in determining the military suitability of land in Salah Al-Din Governorate, and that interpreting the operational value of the surface requires elevation, slope, dissection, the drainage network, soil, land cover, roads, and watercourses to be combined within an integrated spatial model rather than relying on any single variable.

The results showed that surfaces of low dissection make up 77.60% of the study area, yet trafficability was not uniform because of the influence of canals, drains, sandy deposits, and soil moisture, which confirms that topographic flatness alone does not reflect the operational efficiency of the ground. The movement model further showed that areas of high and very high capability occupied 51.78% of the study area, while areas of low capability amounted to 26.37% and were concentrated in the Makhoul and Hamrin hills and in the most dissected terrain.

The analysis of visibility and key terrain confirmed that the military value of a position depends on its field of view, its relative elevation, and its accessibility more than on absolute height, so the best positions were concentrated on the escarpments and heights overlooking roads and avenues of approach, while valleys, reverse slopes, and river bluffs played an important part in forming areas of dead ground and concealment.

The analysis of obstacles and avenues of approach showed that the Tigris, the canals, the steep slopes, and the drainage networks redirected movement toward particular passages and crossings, and least-cost path analysis demonstrated that the best operational routes are not the shortest in distance but those of least spatial resistance once all the influencing factors are combined.

The integrated model achieved high levels of accuracy: mean spatial agreement was 86.9% and mean overall accuracy 85.7%, while the mean spatial error was 17.3 m, less than the size of the spatial cell used (30 m). The defensive suitability model recorded the highest accuracy (90.0%), followed by the offensive suitability model (89.0%), which confirms that combining the component models gives a more realistic representation of military terrain than any single indicator.

The scientific contribution of the study lies in developing a geomorphological and spatial framework that integrates morphometric analysis with multi-criteria analysis inside a GIS environment in order to produce quantitative maps of movement, visibility, key terrain, obstacles, and military suitability. This framework is a suitable tool for supporting spatial planning and military decision-making at the regional level, and it can be applied in comparable areas once the weights are recalibrated to local geomorphological conditions.

Credit authorship contribution statement

Mohammed Nasseef Shuraiji: Conceptualization, methodology, data curation, investigation, formal analysis, software, visualization, validation, writing–original draft.

Prof. Dr. Ruqaya Ahmed Mohammed Amin: Conceptualization, supervision, methodology, validation, writing–review & editing.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Spatial datasets were obtained from relevant Iraqi governmental agencies and publicly available satellite imagery.

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