



# **Urban land suitability analysis using geospatial techniques and combined weighting approach in Gabes zone, Southeastern Tunisia**

Dhekra Souissi, Lahcen Zouhri, Abdelaziz Sebei, Adel Zghibi, Mahmoud Dlala,  
Mohamed Ghanmi

## **► To cite this version:**

Dhekra Souissi, Lahcen Zouhri, Abdelaziz Sebei, Adel Zghibi, Mahmoud Dlala, et al.. Urban land suitability analysis using geospatial techniques and combined weighting approach in Gabes zone, Southeastern Tunisia. *Geomatics, Natural Hazards and Risk*, 2023, 14 (1), <10.1080/19475705.2023.2278278>. <hal-04297035>

**HAL Id: hal-04297035**

**<https://normandie-univ.hal.science/hal-04297035v1>**

Submitted on 21 Nov 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization



## Urban land suitability analysis using geospatial techniques and combined weighting approach in Gabes zone, Southeastern Tunisia

Dhekra Souissi, Lahcen Zouhri, Abdelaziz Sebei, Adel Zghibi, Mahmoud Dlala & Mohamed Ghanmi

**To cite this article:** Dhekra Souissi, Lahcen Zouhri, Abdelaziz Sebei, Adel Zghibi, Mahmoud Dlala & Mohamed Ghanmi (2023) Urban land suitability analysis using geospatial techniques and combined weighting approach in Gabes zone, Southeastern Tunisia, *Geomatics, Natural Hazards and Risk*, 14:1, 2278278, DOI: [10.1080/19475705.2023.2278278](https://doi.org/10.1080/19475705.2023.2278278)

**To link to this article:** <https://doi.org/10.1080/19475705.2023.2278278>



© 2023 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



Published online: 19 Nov 2023.



Submit your article to this journal [↗](#)



View related articles [↗](#)



View Crossmark data [↗](#)



# Urban land suitability analysis using geospatial techniques and combined weighting approach in Gabes zone, Southeastern Tunisia

Dhekra Souissi<sup>a</sup> , Lahcen Zouhri<sup>b</sup> , Abdelaziz Sebei<sup>a</sup> , Adel Zghibi<sup>c</sup> , Mahmoud Dlala<sup>a</sup> and Mohamed Ghanmi<sup>a</sup>

<sup>a</sup>LR01ES06 Laboratoire des Ressources Minérales et Environnement, Département de Géologie, Faculté des Sciences de Tunis, Université de Tunis El Manar, Tunis, Tunisie; <sup>b</sup>AGHYLE, SFR Condorcet FR CNRS 3417, Institut Polytechnique UniLaSalle Beauvais 19, Beauvais, France; <sup>c</sup>College of Science and Engineering, Hamad Bin Khalifa University, Doha, Qatar

## ABSTRACT

Urban Land Suitability analysis is necessary in any development project in order to ensure rational urban planning and sustainable development. In this study, a novel approach based on GIS and Combined Weighting method were used to construct a reasonable assessment model and calculate the Urban Land Suitability Index (ULSI) of Gabes area (Southeastern Tunisia). Seven conditional factors were selected: flooding susceptibility, Lithology, Topography, Seismotectonic, Water table depth, Swelling soils, Soils Aggressivity and the thematic layers were prepared in ArcMap\_GIS. The resultant model following combination of the geo-spatial (GIS) and geostatistical (CRITIC-ANP) modeling show that this region is subdivided into four analyzed zones in terms of geo-hazard susceptibility and foundation excavation: flooding risk area; settlement risk zone; collapse risk area and subsidence risk zone. The ULSI is equal to 3.5. The accuracy degree of the achieved model was validated by ROC-AUC curve, it's is around 78.4%. The ULS model developed enable assured a the assessed thorough and can well reflect an urban land suitability. The results achieved in this study assured planners, engineers, decision-makers and authorities assured a good risk prediction and management plan, could, thus, be facilitate decision-making and can serve as a guideline for all future urban planning projects in this region.

## ARTICLE HISTORY

Received 19 June 2023

Accepted 28 October 2023

## KEYWORDS

Urban land suitability; combined weighting; SIG; ROC-AUC; Gabes

## 1. Introduction

The cities of rapid urban and demographic growth require the development of new infrastructure and housing over vast areas. To improve the live and welfare, the land

**CONTACT** Adel Zghibi [azghibi@hbku.edu.qa](mailto:azghibi@hbku.edu.qa)

© 2023 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

suitability studies in urban space is crucial (Li et al. 2019). In order to reach a sustainable urban growth has to take into consideration both the geotechnical, geological, hydrological, environmental and hydrogeological factors of the developed area (Tan et al. 2021). However, this concept should focus on the study of the interaction between socio-economic, geotechnical, geological and environmental processes in urbanized sites, the resulting impact and the forecast of changes of this process under the influence of engineering and economic activities with the aim of ensuring sustainable development (Culshaw and Price 2011). Urban land suitability analysis and assessment is a decision process that allows effective land use planning and management (Fawad et al. 2022, Sotiropoulou and Vavatsikos 2023). Hence, it is important to make a detailed analysis and assessment of these process of the urban environment, before and during the foundation. These careful investigation and evaluation supply apposite information about the natural environment characteristics and examines the principal geotechnical problems, engineering activities (underground mining, slope excavation) as well as natural susceptibility hazards (flooding's, water erosion, slope instability...) (Fuchu et al. 1994). In order to help the specialists' identified risks and possible solutions, Fernandez et al. 1982; Rodríguez et al. 2013 have mentioned two important factors when studying any natural and anthropogenic phenomena in experimental science: (i) the choice of scientific models and (ii) selection of data.

Several studies have evaluated the urban land suitability such as: Li and Li (2014) integrating the FEC model (Fuzzy Comprehensive Evaluation Model) to identified and examined the foundation hazard for a suggested subway station at Ningbo, whereas El May et al. (2015) utilized conventionnel data's and incorporated the MCDM-SIG for identified the risk potential zones in Tunis area (Northern of Tunisia); Liu et al. (2019) used the TOPSIS model conventional to assess a proposed subsurface railroad station in central of China. In 2017, Gong et al. have utilized Random Field (RF) for determine the characteristics and statistics of the property geotechnical; Peng and Peng in 2018 have combined of the geospatial (GIS) and geo-statistical modelling to assessment the urban zone in Changzhou; Dehghanbanadaki et al. (2019) have utilized the Artificial Neural Networks driven by a Back Propagation Algorithm (ANN-BP) and Particle Swarm Optimization Technic (ANN-PSO) in order to estimate the Unconfined Compression Strength (UCS) soil of the Pontian region of the state of Johor in Malaysia; Zhou et al. in 2019 using the Multi-Objective Linear Weighting method and the Analytic Hierarchy Process (AHP) at Nantong; in 2020 Sarkar and Mondal have selected nine conditioning factors (slope, elevation, rainfall, drainage density, land use-land cover, TWI, population density, road density and household density) and integrated the MCDA-FR-GIS model to delineate the flood hazard vulnerability zones of the Kulik river basin; Saha et al. in 2020, have assessed the flood risk in Raiganj Sub-division, (Eastern India) using the Frequency ratio, Entropy index, Weight of evidence-information Value models and the spatial modeling (RS, GIS); in 2021, Dou et al. have applied a 3D-UGSE setting and evaluated quantitatively and qualitatively of geological urban zone of Qianjiang city; Sarkar et al. in 2021 combined the spatial (RS and GIS) and statistical (Requency Ratio and Entropy Model) modeling to identified the flood hazard zones in the Patna

district; Shahri and Moud in 2022 have used a Hybrid Block-Based Neural Network Prototype (HBNN) with the aim of elaboration of Landslide susceptibility model in Guilan province (North of Iran); Saikh and Mondal in 2023, used six Machine Learning Algorithms (Machine learning-based Artificial Neural Network (ANN), Support Vector Machine (SVM), Random Forest (RF), Reduced Error Pruning Tree (REPTree), Logistic Regression (LR)) coupled of geographical information system technique to identified the flood susceptibility zone and make a more accurate prediction of flood susceptibilities in the Pagla river basin; Anteneh et al. 2023 used the Multicriteria Decision-Making (MCDM) analysis integrated with AHP and Remote Sensing and GIS in order to identify, quantify and allocate the proper suitable site for Urban Green Space development in Debre Markos City (Ethiopia). The research elaborate by Dutta et al. in 2023 aims to identified the various flood-prone zones in the Dakshin Dinajpur district, based on the bivariate methods like Shannon's Entropy Index (SEI) and Weight of Evidence (WofE-IV) models have been used in conjunction with remote sensing and GIS; Sutradhar and Mondal (2023), were carried a morphometric analysis and sub-watershed prioritizing in order to identified and assess the susceptibility to flooding of the Ajay river basin's; Sotiropoulou and Vavatsikos in 2023, used the PROMETHEE II multicriteria method and k Nearest Neighbor Machine Learning Models into a GIS platform with the aim of supporting land use suitability analysis. Alam et al. 2023 have introduced GIS-based Multi-Criteria Decision-Making (MCDM) and CRITIC techniques for identified the settlement suitability zone in the lower Ganga riparian zone. Many evaluation models, we allow ameliorated the geological suitability assessment modeling for Urban space planning such as: The Fuzzy Comprehensive Evaluation (FuzzyCE), the conventional TOPSIS model... So far, In Tunisia the urban space land use suitability assessment and analysis are performed by the classical methods due to technical and material limitations.

Hence, the present research aimed to construct a more reasonable spatial planning prototype and determined a closeness suitability index based on GIS-ANP-CRITIC method. The accuracy percent of the elaborated method is determined by the Receiver Operating Characteristic (ROC) curve technique based on the soil bearing capacity map. The Land suitability for urban planning mapping technique based on the identification, classification, assessment and analysis of characteristics linked to non-consolidated deposits, climate, hydrologic and geomorphology (Zuquette et al. 2004). In this context, a geoscientific database can be provided for engineers, planners and decision makers in order to respond to many geological, hydrological and geotechnical in order to ensure the rational land use planning and urban development (Anon 1996). With the increasing expansion of urban areas in Gabes (Southern East part of Tunisia), urban planning and development is being constrained by flooding, collapse and sinkholes risks. To achieve balance between the physical environments with urban development, a comprehensive, regional Urban Land Suitability study is urgently needed in order to fix these problems and support territorial and urban planning. It is for this reason that field and laboratory studies of engineering properties of foundation materials are needed for: (i) study the physical environment; (ii) study geologic and hydrological hazards (iii) perform recommendations for urban planning.

The primary objective of the present research is to elaborate a hydro-geotechnical micro-zonation model in order to determine the land use suitability of Gabes region using the GIS-MCDM and CRITIC-ANP model, which can utilize as an important data base for the local government, policymakers and planners for implementing territory planning and development. The secondary objective is to calculate and evaluated the Urban Land Suitability index. Given that the study zone is already densely populated especially in the coastal area, the proposed micro-zoning model should be used to verify the adequacy of the urban zones and to establish the necessary additional precautions for the foundation and planning projects.

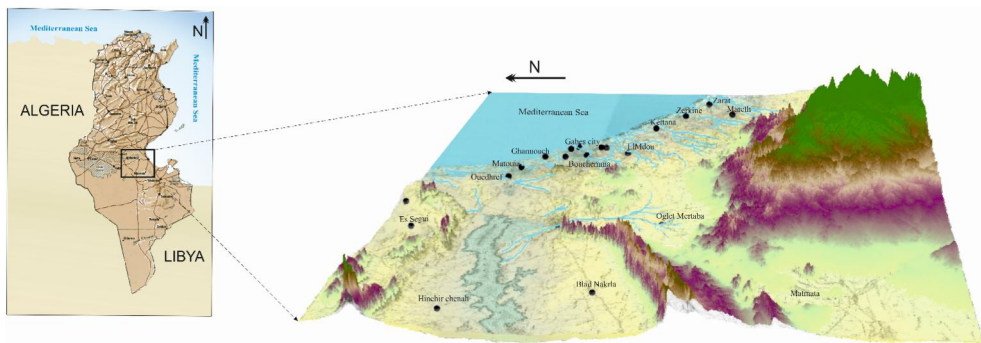
The political, social, economic, physical and cultural drivers of smart cities show that, the cities provide services to support the population's well-being (Eric et al. 2012). The concept of the engineering geology allows not only providing a new technology development but also ensuring willingness to the engineering geologists to collaborate with all specialists and to present geo-objectives, which an already acquired in the minds of geologists, planners, engineers, developers and decision makers.

The geological urban space suitability for urban planning mapping technique based on the identification, classification, assessment, processing and analysis of characteristics linked to non-consolidated deposits, climate, water, hydrologic and geomorphology (Zuquette et al. 2004). In this context, a geoscientific database can be provided for engineers, planners and decision makers in order to respond to many geological, hydrological and geotechnical in order to ensure the rational land use planning and urban development (Anon 1996). With the increasing expansion of urban areas in Gabes (Southern East part of Tunisia), urban planning and development is being constrained by flooding, collapse and sinkholes risks. To achieve balance between the physical environments with urban development, a comprehensive, regional Urban Land Suitability study is urgently needed in order to fix these problems and support territorial and urban planning. It is for this reason that field and laboratory studies of engineering properties of foundation materials are needed for: (i) study the physical environment; (ii) study geologic and hydrological hazards (iii) perform recommendations for urban planning. The purpose of the current study is to elaborate a typical hydro-geotechnical micro-zonation prototype in order to determine the land use suitability. Given that the study zone is already densely populated especially in the coastal area, the proposed micro-zoning model should be used to verify the adequacy of the urban zones and to establish the necessary additional precautions for the foundation and planning projects.

The political, social, economic, physical and cultural drivers of smart cities show that, the cities provide services to support the population's well-being. The concept of the engineering geology allows not only providing a new technology development but also ensuring willingness to the engineering geologists to collaborate with all specialists and to present geo-objectives, which an already acquired in the minds of geologists, planners, engineers, developers and decision makers (Eric et al. 2012).

## 2. Description of the study area

The study area is situated in Tunisia's South East, it covers an area in order of 3275,7 km<sup>2</sup>. Geographically, Gabes region is located between  $X_1 = 550\ 000$ ,  $X$



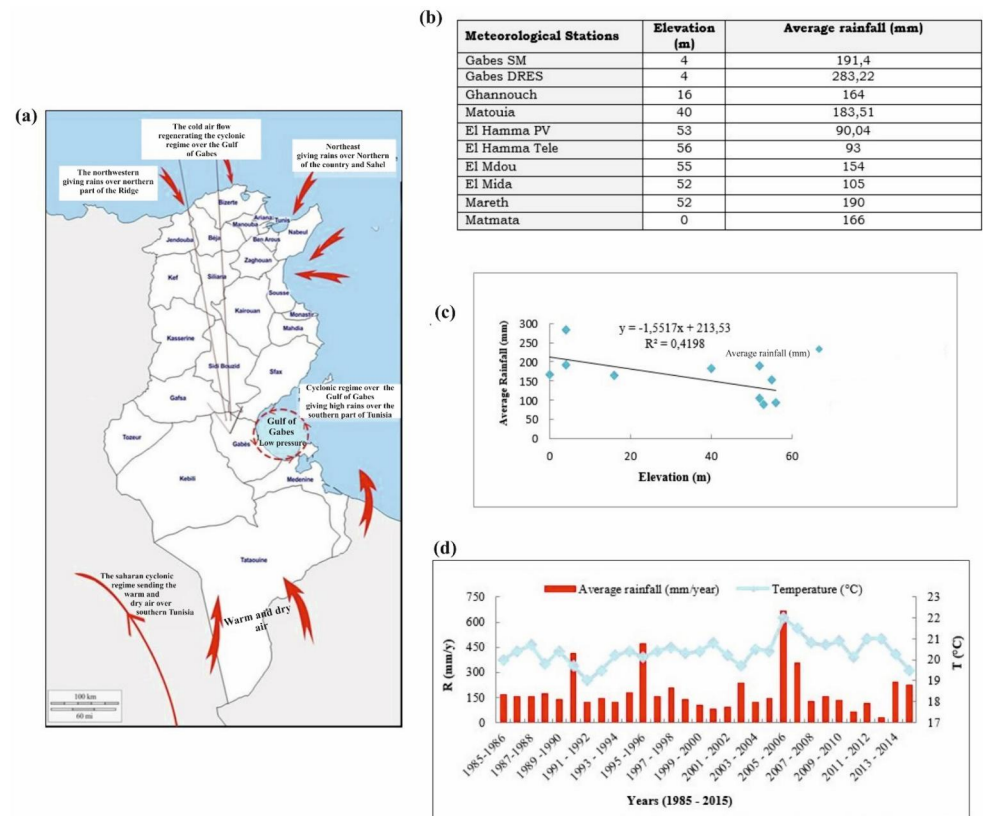
**Figure 1.** Geographic location map of Gabes area.

2 = 620 000 and Y1 = 3 700 000, Y 2 = 3 770 000 (UTM geographic projection system). This zone is limited in the North by Dj. Es. Semaia, Dj. Haidoudi and Dj. Zemlet El Beidha, El Hamma fault to the West, the Gabes Gulf in the East, and Dj. Ragouba, Dj. Monncef, Dj. Sidi Saleh and Matmata region in the South part of the zone ([Figure 1](#)).

This area has undergone climate changes. It is submissive to the influences of both winds coming respectively from the Mediterranean Sea (East) and from the desert (South). The mostly frequent winds blow from the East part (Mediterranean Sea) towards the West and from the South (Sahara) to the North (Figure 2a). The analysis of the data of rainfall in the study area during 30 years has shown an average value of the order 162 mm/year (DGRE 2015) (Figure 2b, c, d). In Gabes, the mean temperature varied between 12 °C and 28 °C (Souissi et al. 2018) (Figure 2d). However, the climate of this zone is an arid climate with a hot dry summer season and a cool and moist winter season. Rainfall is highly variable and uneven distribution leading to intensive flash floods. Topographically, it is characterized by a mild elevation (0 m to 660 m) and slopes range from 0% to 36%.

From a hydrology point of view, the drainage network is dense. It is composed by nine non-perennial wadies. These drainage systems flow into the Sabkhas or into the sea (Souissi et al. 2018). According to the research of Souissi et al. 2019, the elevation, land use/land cover and impermeable litho-facies are the main parameters, which tend to favor surface water runoff and thereafter increase the flood hazard in this region. Results of this work show that the plain zone of the Gabes area is classified as the highest flood hazard potential zone (15% of the total area). The wadis have a torrential character because to irregular rainfall and high evapotranspiration. The area of Gabes represents a site of specific interest in terms of regional geological and geotechnical problems. The hydro-lithostratigraphic column shows that the geological formations in this zone range from Triassic to Quaternary (Figure 3). The investigation area is characterized by lateral litho-stratigraphic variations (Mekrazi 1975). The Cretaceous series flush in the anticlines at the North and south part of the Gabes area is represented by gypsums, clay, dolomite, anhydrite, marl and limestone layers (Mhamdi et al. 2013). The Tertiary is distinguished by Mio-Pliocene deposits made mostly of gypsums clay and sand. The Quaternary is represented by three terraces, compounds by clay with a scab of silty and gypsum sediments, quaternary sediments and alluviums (Ben Hamouda et al. 2013).





**Figure 2.** (a) The movement of air masses resulting precipitation over Tunisia (Ben Baccar 1982 modified), (b) distribution of average rainfall as a function of altitude in different climatological stations (1985 - 2015), (c) Correlation between average rainfall and altitudes for different climatological stations, (d) evolution of temperature and rainfall.

Period	Age	Lithology	Formation	Thickness (m)	Hydrogeological Units		
					Permeability	Lithology	Aquifer
Quaternary	Actual–Pleistocene	Fine sands and conglomerates	-	-	Permeable		GWP
Neogene	Pliocene	Sandy clays, sands and conglomerates	Séguí	95	Permeable to semi-Permeable		Substratum
	Miocene	Sands fine to coarse	Ouedref	195	Permeable		GWP
Late Cretaceous	Campanian	White marly limestone and marls	Abiod	140	Semi-permeable to impermeable		Substratum
	Santonian–lower Coniacian	Limestone and coquina marls, dolostone, alternation of marls, limestones and gypsum	Aleg	135	Semi-permeable to impermeable		GWP
				105	Permeable		Substratum
	Turonian–upper Cenomanian	Dolomitic limestone	Guettar	25	Permeable		GWP
Early Cretaceous	Cenomanian–upper Albian		Zebbag	98	Impermeable		Substratum
	Aptian–Albian		Orbata	110	Semi-permeable		GWP
	Barremian	upper Barremian –lower Aptian	Sidi Aich	70	Permeable		GWP
		Lower Barremian	Bou Hedma	440	Semi permeable a impermeable		Substratum
		Valanginian – Hauterivian	Boudinar		Permeable		GWP

GWP: Groundwater Potentiality

**Figure 3.** Succession of the hydro-lithostratigraphic potentially aquiferous formations.



The Mio-Plio-Quaternary aquifer of Gabes area is a multilayered aquifer system (Ben Alaya et al. 2014). The aquifer potential formations (the Continental intercalary, Upper Cretaceous deep aquifer, Upper Miocene intermediate aquifer and Mio-Plio-Quaternary aquifer) are separated by impermeable formations of clayey and marly nature. In 2015, the renewable water resources in the region were estimated to 17.1 Mm<sup>3</sup>/year with annual exploitation in the order of 23.9 Mm<sup>3</sup>/year (DGRE 2015). The water resources in this zone continued to decrease progressively. Indeed, this increase of the exploitation rate between 1985 (11.25 Mm<sup>3</sup>/year) and 2015 (23.9 Mm<sup>3</sup>/year) being caused by drought, increase of the water needs, the expansion population and the agricultural and industrial activities development, irregularity of the precipitation (Souissi et al. 2018) (Figure 4). During last years, intensive exploitation of the aquifer induced declining water levels and the salinity of the shallow groundwater increased progressively heading from the West to the East (the coast) (Table 1).

3. Database and methods

3.1. Database

Multi-factor evaluation for land suitability of Gabes urban zone is defined as a multi and interdisciplinary activity. It focuses on the judicious use of land with a greater comprehension of the problems related of the soil type, hydrological, geological, hydrogeological. for dealing with risks in the current and future civil engineering

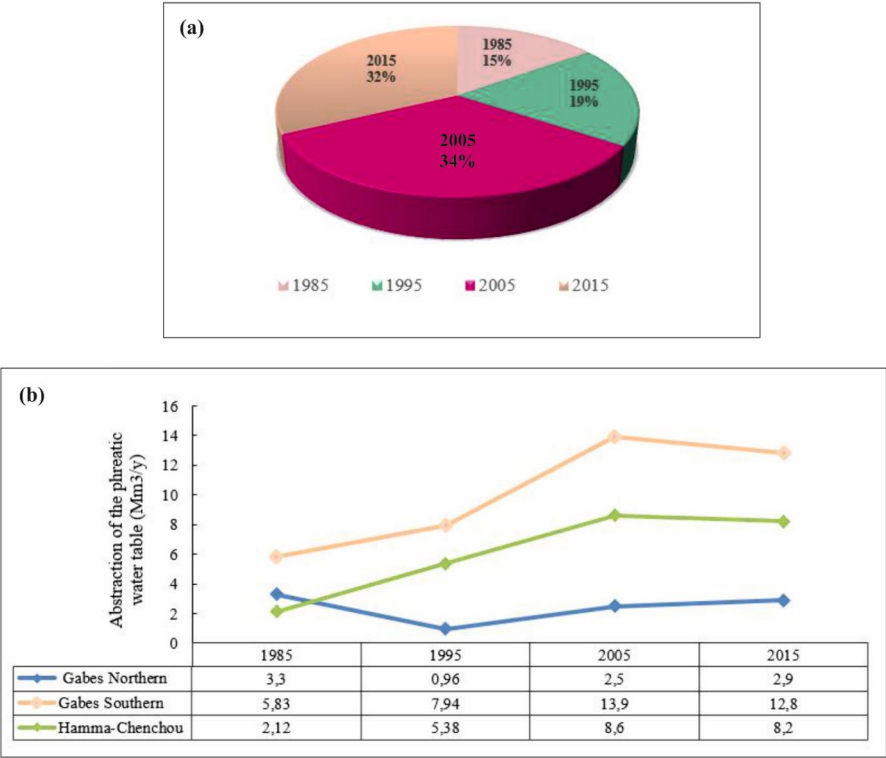


Figure 4. Exploitation of the phreatic water table (Souissi et al. 2018).

**Table 1.** Mineralization of the phreatic water table (CRDA 2015).

Dry tailings (mg/l)	1985	1990	1995	2000	2005	2010	2015
Northern Gabes water table	3.5-7	3.5-7	3.5-7	3-7	3-8	3-8	3 à 8
Southern Gabes water table	2.5-6	3.5-7	3.5-7	2.5-8	2.5-10	2.5-10	2.5 à 10
Hamma-Chenchou water table	5-7	3.5-7	3.5-7	3-6	3.5-10	3-7	3 à 7

works (Moeinaddini et al. 2010). Multiple data were used in the study, including flooding, Lithology, Topography, Seismotectonic, Water table depth, Swelling of soils, Soils Aggressivity, collected from different sources.

Multi-factor evaluation for land suitability of Gabes urban zone is defined as a multi and interdisciplinary activity. It focuses on the judicious use of land with a greater comprehension of the problems related of the soil type, hydrological, geological, hydrogeological ... for dealing with risks in the current and future civil engineering works (Moeinaddini et al. 2010; Zhou et al. 2019). In the present study the authors have selected seven factors including flooding, Lithology, Topography, Seismotectonic, Water table depth, Swelling of soils, Soils Aggressivity. The selection of factors is based on the historical data of naturel and anthropogenic events, previous work, field work and depend to local hydrogeological, hydrological and morphological characteristics (Figure 5).

### 3.2. Methods

The suitability urban area mapping was conducted in accordance the steps presented in Figure 6. The purpose of this research is to produce an Urban Land Suitability prototype of the Gabes zone, showing suitable risk sites in this region using a GIS-ANP- CRITIC model. Recently, the rapid development of computer and geostatistical technologies has enabled it possible to conduct systematic analysis of complex MCDM problems (Souissi et al. 2022). The use of geo-informatic technology (GIS) has generated a huge amount of information, which makes Multiple Criteria Decision Analysis useful in supporting and solving various decision making, environmental, ecological and socio-economic problems (Xu and Yang 2001; Sabokbar 2005). The integration of Geographic information system based MCDM-ANP is important in the preparation of the Urban Land suitability prototype due to the need of using a spatial big data and integrating the conventional data with the policy-makers' decisions (Dunčková et al. 2019). The ANP allows the decision maker to include all the factors real or intangible that have a significant influence on making a best decision (Tuzkaya et al. 2008). The prototype elaborate has been validate by AUC-ROC curve and bearing capacity map model. This technic is resting on the following stages:

The weights of the Urban Land Suitability Index (ULSI) include three types: subjective, objective and combination weights. In the present research, the objective weights were computed by the improved CRITIC model, the subjective weights are computed by the geostatistical model 'ANP' and integrating the coefficient of variation method. The weight estimation of ULSI, we allow to obtaining reasonable and reliable evaluation results. The elaboration of Game Theory (GT) based Combined Weighting (CW) prototype is resting on the following stages:

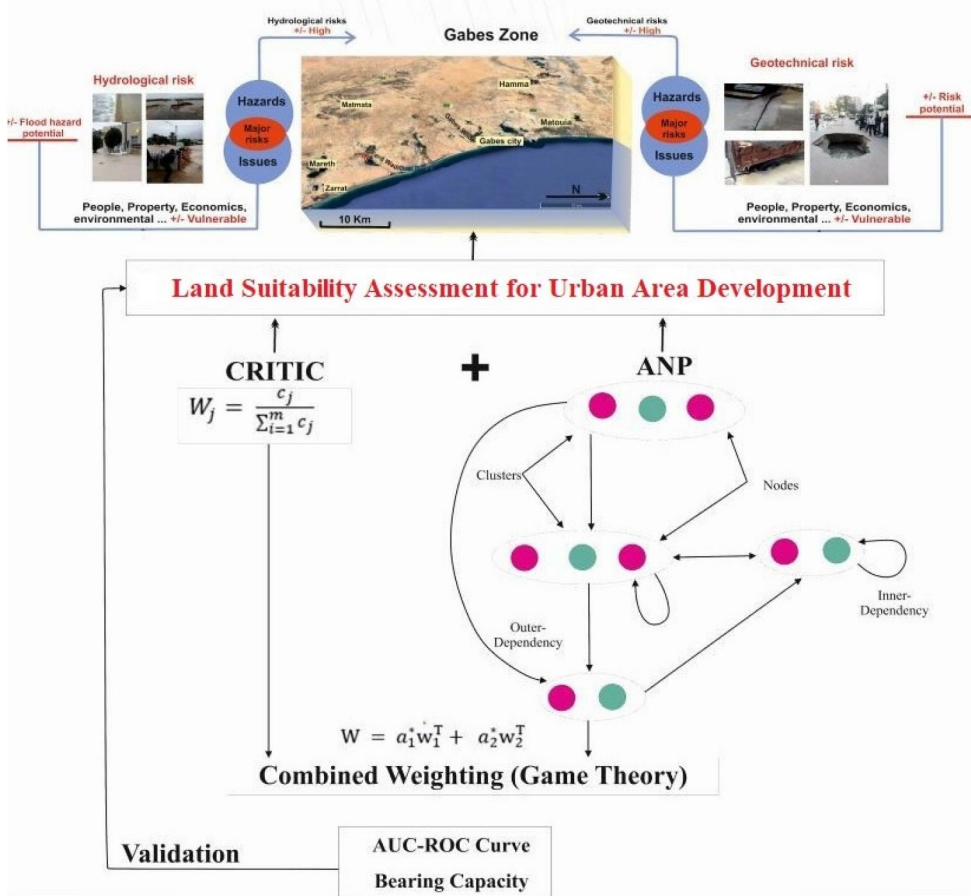


Figure 5. Schematic representation of the methodology adopted.

### 3.2.1. Calculation of subjective weights of decision criteria

The supermatrix approach, what is known as the Analytic Network Process (ANP) (Promentilla et al. 2006). This method is a decision-making method developed by Thomas Saaty and Turner (1996) for the non-independent hierarchical structures. It has become a very interesting approach for a more and easier understanding of a complex decision-making problem, because it overcoming the restraints of the linear hierarchical frameworks (Saaty 2001; Souissi et al. 2022). This method is characterized by a hierarchical structure more difficult and more complex than the Analytical hierarchical process. Saaty's Analytical Network Process includes and measures all qualitative and quantitatively measurable criteria and standardize each into a numerical scale.

According to Saaty's and Turner (1996) the ANP calculation includes four steps.

### 3.2.2. Develop a decision network structure model

The decision prototype is portrayed as a directed network. The decision-making model is achieved after a decision of the decision makers and shareholders (Promentilla et al. 2006).

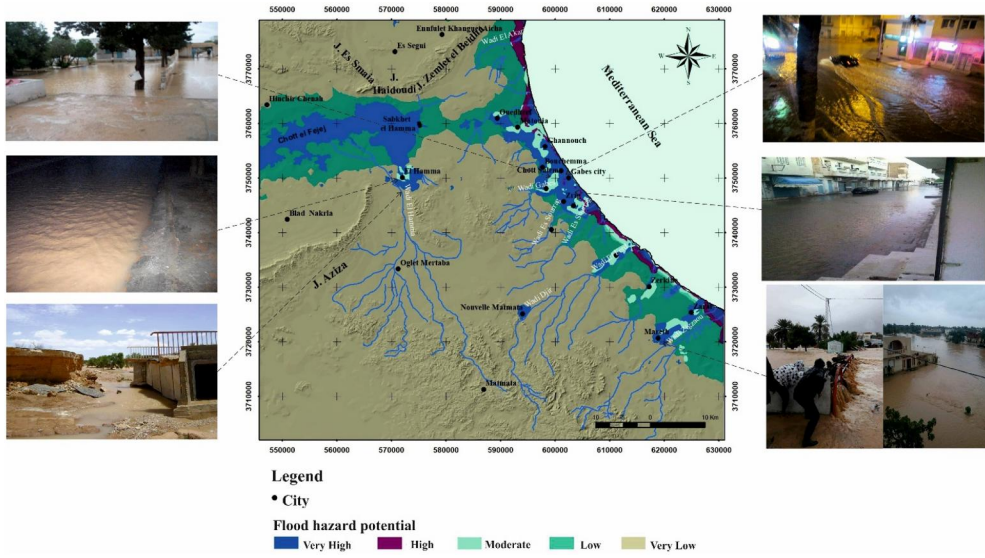


Figure 6. Flood hazard prototype (Souissi et al. 2019).

### 3.2.3. Construction of the supermatrix

Determined the Pairwise Comparison (PWC) between the parameters interdepending in the decision-making system. The dominance inter-relationships can be interpreted the must influencing of one parameter compared to the other factors.

$$A = \begin{bmatrix} x_1(k_1) & x_2(k_2) & \cdots & x_n(k_n) \\ \vdots & \vdots & & \vdots \\ x_1(k_m) & x_2(k_m) & \cdots & x_n(k_m) \end{bmatrix} \quad (1)$$

$$= x_1(k_1)_n \times_m (k = 1, 2, \dots, n; m = 1, 2, \dots, m)$$

### 3.2.4. Estimation of the weighted supermatrix

There are different algorithms to calculate these weights. In Saaty (1980) recommended the Analytical Hierarchical Process eigenvector approach because this is the unique solution which had enabled to obtain the ranking and the relative dominance, measure of the judgment consistency by the computation of the consistency index and consistency ratio.

$$AW = \lambda_{\max} W \quad (2)$$

$$CI = \frac{\lambda_{\max} - 1}{n - 1} \quad (3)$$

$$CR = \frac{CI}{RI} < 1 \quad (4)$$

### 3.2.5. Estimation of the limit supermatrix and achieve the final dominance weights

The transformation and processing of the non-weighted supermatrix to a weighted and normalized stochastic matrix whose the column sum is the order of 1. Then, computation the dominance weight vectors of the stochastic matrix (Saaty and Turner 1996; Promentilla et al. 2006).

### 3.2.6. Estimation of the objective weights of decision criteria

The CRITIC method (CRiteria importance Through Intercriteria Correlation) is a correlation method, it was proposed by Diakoulaki et al. (1995) to attribute objective weights of multi-influencing factors based on their importance they reflect... For every factor 'x<sub>ij</sub>' function of membership and 'r<sub>ij</sub>' which translates any the values of factor 'x<sub>j</sub>' into scale [0, 1].

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \quad (5)$$

$$r_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \quad (6)$$

The preliminary matrix is transformed into a matrix with generic elements r<sub>ij</sub>. each vector has a Standard Deviation (SD) (Vujičić et al. 2017).

$$C_j = \sigma_j \sum_{i=1}^m (1 - r_{ij}) \quad (7)$$

The equation of the objective criteria weights is estimated by Standardization of the values C<sub>j</sub> using the improved CRITIC method is as follows:

$$W_j = \frac{c_j}{\sum_{i=1}^m c_j} \quad (8)$$

### 3.2.7. Combined weighting according Game theory

The Combination Weight method (CW) based on the Game Theory (GT) according the Nash equilibrium model is a method of strategic multicriteria decision making. The GT is a mathematical model involving dispute and collaborations between intelligent, rational decision makers (Rogers 1991). This model allows to determines the agreement between objective and subjective weights (Zhu and Li 2014), and then it is decreases of the subjective aleatory and took account of the biased of objective datums. This model is based on the stages of the Combination Weighting method (CW) following:

Step (1): The subjective and objective weights of the ULS prototype are achieved by assigned weights by the objective and subjective weight computation models, CRITIC and ANP respectively.

$$W = a_1 w_1^T + a_2 w_2^T \quad (9)$$

Step (2): The two linear combination coefficients  $a_1$  and  $a_2$  in Equation 9 are enhanced according to the game aggregation theory. This allows us to obtain the best weights.

$$\min \left\| \sum_{k=1}^n a_k w_k^T - W_k \right\|_2 \quad (k = 1, 2, \dots, L) \quad (10)$$

Step (3): According to the differentiation property of the matrix, the linear equations of the optimal first-order derivative condition in Equation 10 is follows:

$$\begin{bmatrix} a_2 w_2^T & a_2 w_2^T \\ a_2 w_2^T & a_2 w_2^T \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} w_1 w_1^T \\ w_2 w_2^T \end{bmatrix} \quad (11)$$

Step (4): Calculation of the optimized combination coefficients  $a_1$  and  $a_2$  using Equation 11, and then normalized following the equation 12:

$$\begin{cases} a_1 * w_1 w_1^T + a_2 * w_1 w_2^T = w_1 w_1^T \\ a_1 * w_2 w_1^T + a_2 * w_1 w_2^T = w_2 w_2^T \end{cases} \quad (12)$$

Step (5): The overall weight 'W' using the Combination Weighting (CW) is obtained by the following equation number 13:

$$W = a_1^* w_1^T + a_2^* w_2^T \quad (13)$$

### 3.2.8. Validation

The theoretical methods (ANP, CRTIC and Nash equilibrium model) are subjective method, suffers from uncertainty rate (Banuelas and Antony 2004). Therefore, the validation of the urban land suitability prototype generated by GIS based on MCDM-ANP-CRTIC-Nash model is a principal stage to determine the reliability degree of the calculated model (Das 2020). There are several models of validation such as: Monte Carlo simulation, Confidence Interval, Receiver Operating Characteristic (ROC) curve... In this research, the spatial effectiveness of of the calculate model was evaluated by ROC-AUC (Abedi Gheshlaghi and Feizizadeh 2021) based on the soil bearing capacity map. Receiver Operating Characteristic (ROC-AUC) is the curve of the probability of correctly predicted (true positive) on the X axis and the probability of wrongly predicted event response (false positive) on the Y axis (Abedi Gheshlaghi and Feizizadeh 2021) based on the soil bearing capacity map. Receiver Operating Characteristic (ROC-AUC) is the curve of the probability of correctly predicted (true positive) on the X axis and the probability of wrongly predicted event response (false positive) on the Y axis (Mao et al. 2022). AUC is the area under ROC curve.



$$TPR = \frac{TP}{TP + FN} \quad (14)$$

$$FPR = \frac{FP}{FP + TN} \quad (15)$$

Where TPR: True Positive Rate, TP: True Positive; FN: False Negative; FPR: False Positive Rate; FP: False Positive; TN: True Negative

This AUC-ROC curve algorithm is a simple and useful technique based on sciences data base through which we can accurately assess the prediction rate and effectiveness and accuracy of the theoretical prototype (Sarkar and Mondal 2020, Saha et al. 2021, 2022, Sarkar et al. 2022). According Long et al. and Yariyan et al. in 2020, the AUC value closing to 1 indicates better performance, when the  $AUC > 0.7$ , is represents while good model.

Based on AUC-ROC curve, The AUC value is cis classified into five classes as: 0.9–1 (Excellent), 0.8–0.9 (Very good), 0.7–0.8 (Good), 0.6–0.7 (Moderate), and 0.5–0.6 Poor) (Dutta et al. 2023). The level of authenticity of the predicted Urban Land suitability model is determined based on these AUC values.

AUC is the area under ROC curve. It used to evaluate the prediction rate and effectiveness and accuracy of the theoretical prototype. According Long et al. in 2020, the AUC value closing to 1 indicates better performance, when the  $AUC > 0.7$ , is represents while good model.

The bearing capacity allows to analysis of the geotechnical units for foundation works (Díaz-Díaz et al. 2017; Alencar et al. 2021). Thus, in detrital deposits the bearing capacity is checked by the  $N_{SPT}$ . It allows of determined the foundation type and identified the potential geotechnical risks.

## 4. Results

### 4.1. Parameters used for urban land development suitability analysis

There are no guidelines or a literature review for selecting major geotechnical, hydrological and geologic criterions, that influence the adequacy of the geological urban zone to building's foundations. The general condition of the study area should be considered (nature, climate, population, geomorphology, geology...) and the data availability. In addition, in a spatial multi-criteria analysis study, we should also make sure that selected factors are accessible, non- uniform, measurable. In the present study, seven controlling factors were identified for spatial planning for the purpose of assessing the degree of suitability of foundation which are as follows: (1) Flooding susceptibility, (2) Lithology, (3) Topography, (4) Seismotectonics, (5) Water table depth, (6) Swelling potential of soils and (7) Soils agessivity. All these datasets were treated and developed in raster layers format and classified in five classes.

#### 4.1.1. Flooding susceptibility

Flooding is a hydro-environmental problem, which can restrict urban development (Fuchu et al. 1994; Bourenane and Bouhadad 2021). However, detail and careful

mapping, carried by Souissi et al. 2019, based in coupling the statistical (MCDM-AHP) and spatial (GIS) modelling shows that around 15% of the total area are flood-prone with a flood hazard index of 6.30. About seventy four percent and a half of the observed flood zones are mostly characterized in a moderate to a very high inundation risk potential. The plain zone is characterized by high urbanization, of a very high flood hazard potential, high rainfall intensity, low elevation and slope, a semi permeable to impermeable soil type, and a distance between the wadis is very close.

The study realized by Souissi et al. 2019, presents a flood hazard potentiality mapping and assessment method in the region of Gabes based on the combination of the geospatial (GIS-MCDM) and geostatistical modelling (AHP) and sensitivity analysis. Eight factors have been used in the flood modeling: elevation, land use/land cover, lithology, rainfall intensity, drainage density, distance from the drainage network, slope, and groundwater depth. The results obtained shows that the most prominent flood influencing factor is the elevation (22.5%), around 15% (890 km<sup>2</sup>) of the total area of Gabes zone is flooded with a very high to moderate flood risk potential. The flood hazard index is equal 6.30. The very high flood risk zone is characterized by the lowest elevation and slope, an urbanized zone, the distance from the streams is very near, an impermeable to semi permeable soil type and high rainfall intensity.

#### 4.1.2. Lithology

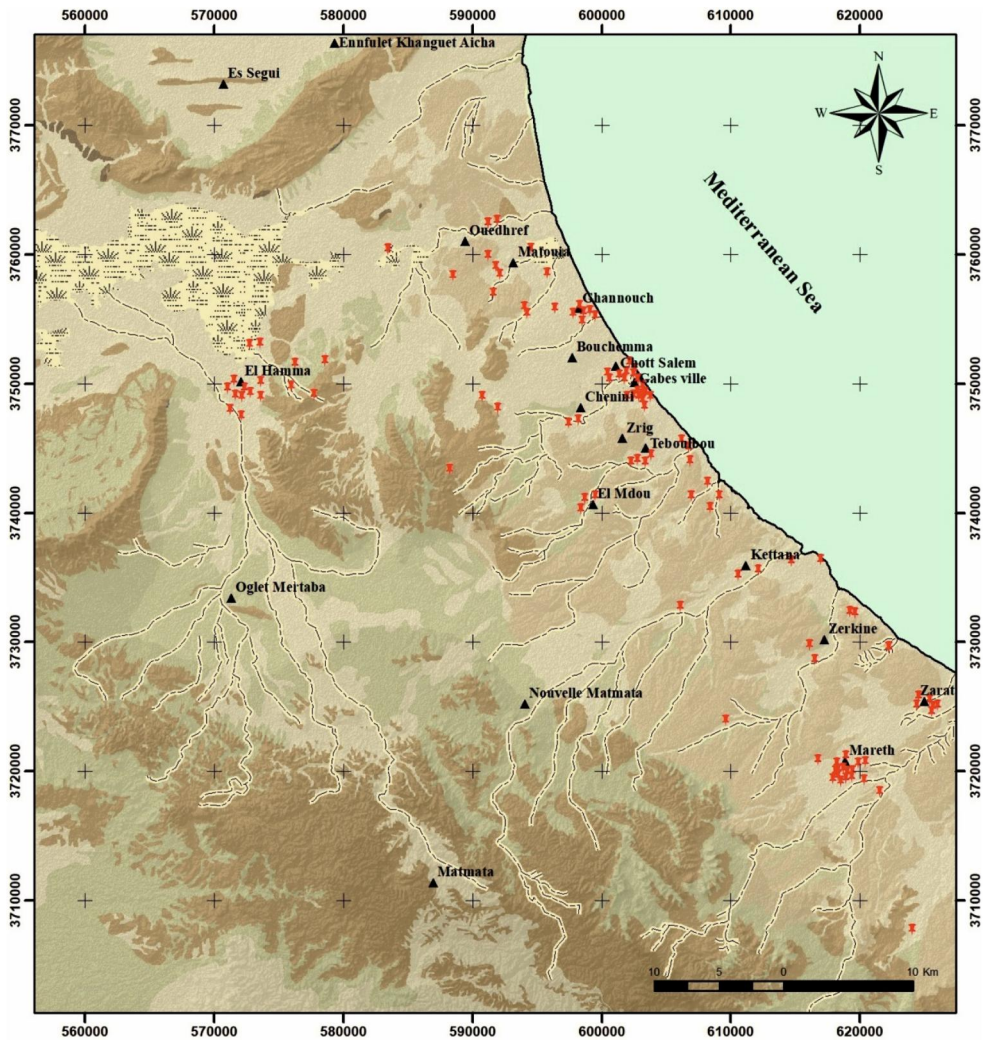
The lithological layer (Figure 7) is prepared based on the geological map and the relevant data of 136 boreholes geotechnical. Two lithological units were identified (Figure 7):

The plain zone is occupied by: (i) recent alluvial sediments are trained by muddy, clay, sand. (ii) The marine deposits and sebkhas deposits are consist of silts, muddy, and evaporates (iii) the formations of Holocene are made of the shelly sands, (iiii) the formations of the Pleistocene age, formed by: backfills, gravel, clay, sand, muddy, silts, Aeolian sand gypsum and tuff. (iiiii)The layer of sandy clays, gypsum clays, sands, conglomerates and sandstones, of the Mio-Pliocene age. These levels are classified in the category of loose soils and heterogeneous. For this unit lithological, its heterogeneous nature, relatively high compressibility and low to very low allowable bearing capacity allows to classify these soils as a problematic soil, have a high potential to collapse if have been wetted. Subsequently, it is strongly recommended to take compaction and pre-wetting measures during the design, to take into consideration both soil heterogeneity and the possibility of irregular collapse caused by wetting due to infiltration of the runoff or drainage water.

The reliefs are occupied by limestone and of alternating of marl and limestone. These levels are considered homogeneous compact formations, and the most suitable for construction, because that should be no problem related to materials, thus the ground water level is profound.

#### 4.1.3. Topography

The topography is a conditioning parameter which has a direct influence in the geological, hydrological and geotechnical risk analysis (Gritzner et al. 2001). The altitude was prepared using the DEM\_30 m. In Gabes zone, it's varied among 0 and 650 m



### Legend

- Recent alluvial depots, marine deposits and sebkhas deposits, silts, evaporates and aeolian sand
- Backfills, gravel, sandy soil, muddy soil, silts, clay, Tuff, gypsum (Heterogeneous rock)
- Heterogeneous and loess soils
- Heterogeneous and compact Formation
- Homogeneous and high compact soil Formation

**Figure 7.** Lithology map of the study area.

above sea level (Figure 8). Three units geomorphological were identified: high residual massif, plains, and the coastal zone (Figure 8). The coastal zone consists of foreshores and fluviomarine plains. The inside plain area is typified by moderate to lowly altitudes varying betwixt 0 and 100 m, is covered by Alluvium, Sebkhas soils, silt, eoliens deposits, loose soils and Heterogeneous and Sandy soil. The high residual

massif is formed by Homogeneous and compact formation and Heterogeneous and compact rocks (Figure 8) with altitudes reaching 650 m. the slopes are varying between 0 and 36% (Tables 2 and 3).

#### 4.1.4. Seismotectonic

Seismotectonic mapping represents a basic tool for all planning activity and territory management (Kolati et al. 2012). Despite the general stability of Tunisia, the Southeastern part is one of the moderately active areas from a seismic point of view. Between 1881 and 2012 there have been 37 earthquakes greater than 5,2 Ms on the Richter scale in the last 131 years earthquake (Dj. Haidoudi and the region of Mareth), caused extensive damage and life loss. A considerable amount of geological,

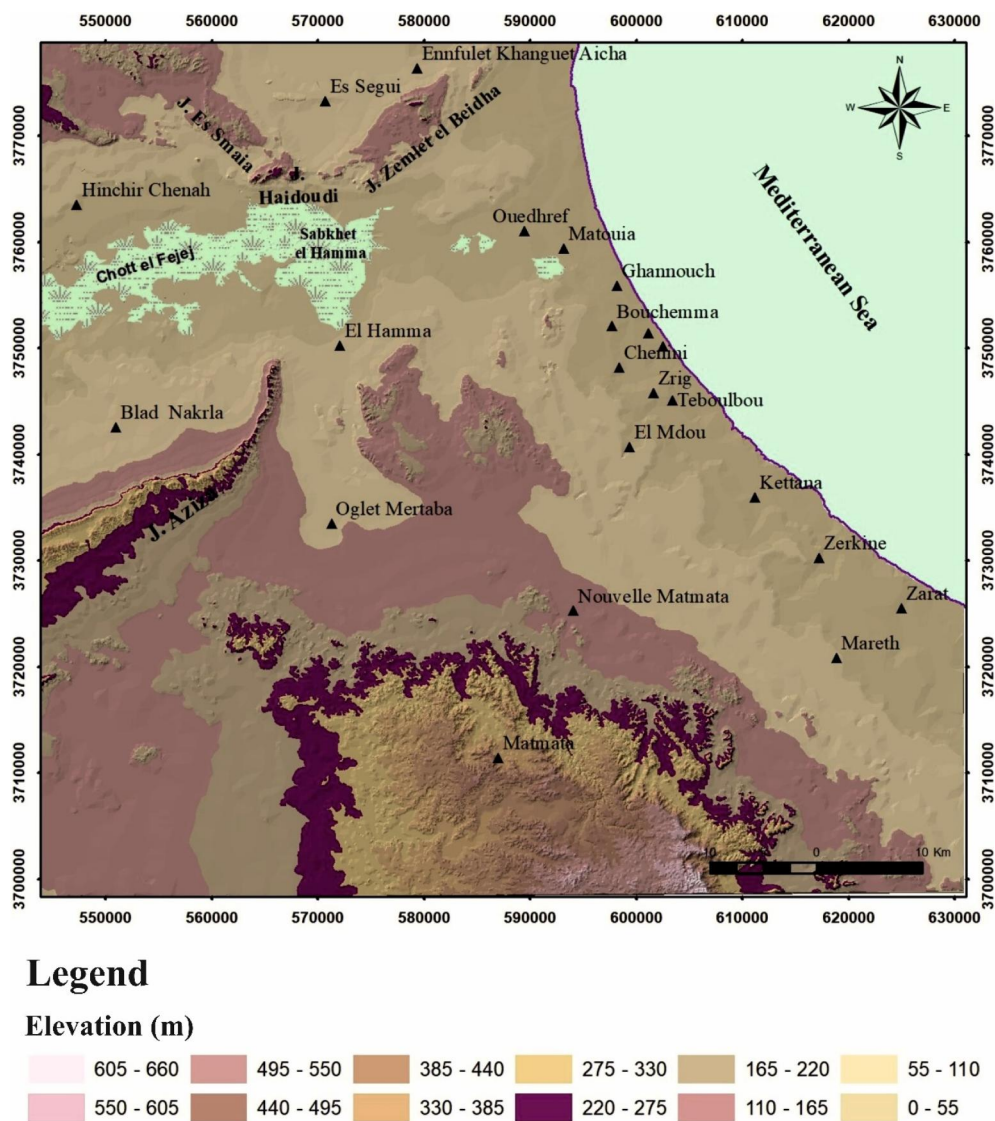


Figure 8. Topographic map of the study area.



**Table 2.** Scale of Saaty (2008).

Degree of Importance	Definition	Interpretation
1	Equal importance	Two factor making equal importance to the aim
3	Moderate importance	Moderate importance of factor over the other factor
5	Much more important	Strong importance
7	Very much important	Very strong importance
9	Extremely important	Extreme importance
2, 4, 6 and 8	Intermediate values	These are needful when comprise between two adjacent judgment is necessary
1/1, 1/2 ... to 1/9	Reciprocals	Reciprocals

geomorphological, geotechnical, seismological and geophysical investigations was collected and processed in order to thoroughly characterize the Gabes basin using complementary techniques with different resolution levels. However, a Geographic Information System platform was used to manage the collected data. The epicenter data was obtained from the earthquake data published by National Institute of Meteorology in 2013 of Gabes area and its surroundings. [Figure 4](#) also shows faults distribution, epicenters and magnitudes of past earthquakes occurred in the Gabes region. These earthquakes occurred with magnitudes varying between 3.1 and 5.20 Ms and a focusation depth which does not exceed 15 km. Tunisia appears to be a particular example in the field of intra-continental seismicity. It is characterized by the epicenters of intra-continental earthquakes with a depth varying between 10 and 15 km. In the study region, the earthquakes are concentrated in the city of Gabes and in the Gulf presenting the same direction as the regional fault of Gafsa, i.e. from SE to NW.

Note that the Gabes city has been affected by 6 earthquakes during 131 years ([Figure 9](#)):

- The seismic activities in this region have magnitudes between 3.1 Ms (1995) and 4.4 Ms (1881).
- The Gulf of Gabes was affected by earthquakes of magnitude between 3.00 Ms (1997) and 5.20 Ms (1990).
- In the Southeast of the study region and more precisely in Mareth, the earthquakes have small magnitudes (3.12 Ms and 3.75 Ms).
- In the western part, the region of El Hamma was hit by small magnitude earthquakes varying between 3.00 Ms and 3.70 Ms.

Analysis of instrumental, historical seismicity and recent to quaternary deformation data (Dlala 1995; Ahmadi et al. 2013) show that this region is currently subjected to a compressive regime of NW-SE direction.

The seismotectonic results obtained are compatible with seismotectonic data from North Africa (Meghraoui et al. 1986; Philip et al. 1986; Dlala 1992) and fit into the convergent geodynamic context of South Africa and Eurasia (Dlala 1992).

#### 4.1.5. Groundwater table depth

This factor is one of the most significant and important parameters that is impact on the stability of building foundation excavations (Dearman 1991). The water table depth map was elaborated based on the values of static levels groundwater published

**Table 3.** Details of the data's.

Data Name	Type	Source	Resolution
Rainfall	Climate data	GDWR	10 m
Temperature	Climate data	NIM	10 m
Groundwater depth	Hydrogeological data	GDWR	10 m
Abstraction of the phreatic water table	Hydrogeological data	GDWR	10 m
Flood hazard index		DOI: 10.1080/10106049.2019.1566405	10 m
Geology	Lithostratigraphy	NIM	10 m
Elevation	Topographic	SRTM	30 m
Slope	Topographic	SRTM	30 m
Magnitudes	seismotectonic data	NIM	10 m
Swelling of soil data	Geotechnical data	CGGS	-
Percent of gypsum	Geotechnical data	CGGS	-
[SO <sub>4</sub> <sup>2-</sup> ]	Geotechnical data	CGGS	-
Allowable bearing capacity	Geotechnical data	CGGS	10 m

**NIM:** National Institute of Meteorology, **GDWR:** General Department of water Resources, **CGGS:** Company of Geological and Geotechnical Studies.

by the General Directorate of Water Resources (GDWR) in 2015. Thus, the [Figure 10](#) shows that the underlying zones to the shallow foundations where the static level varying between 0 and 5 m occupying the plain. These zones are characterized by an urban extension and high concentration of people. A second areas where static level varying between 5–10 m. The third zones are characterized groundwater depth deeper than 10 m.

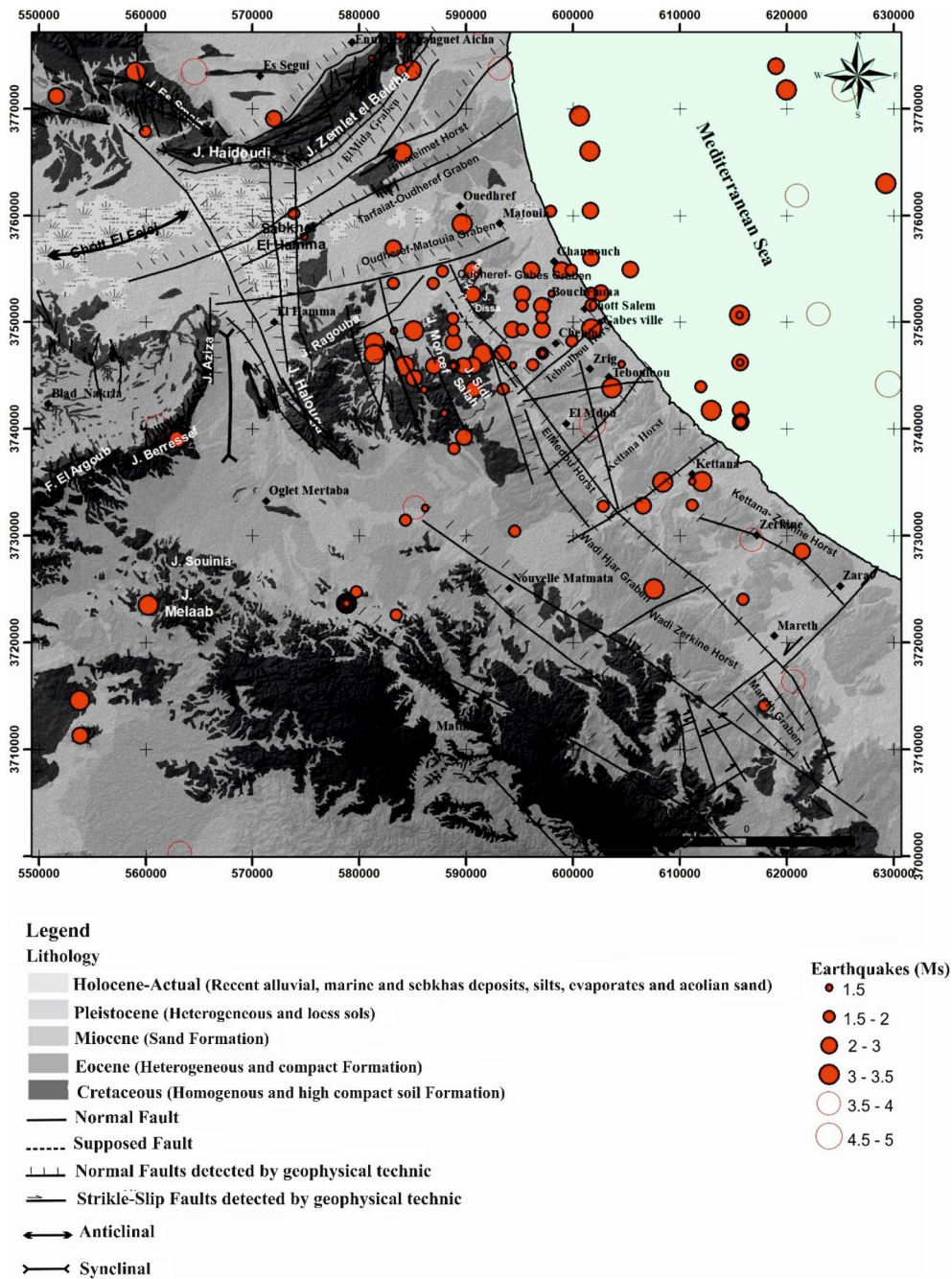
#### 4.1.6. Swelling potential of soils

The swelling of soils is a significant factor in geotechnical studies, due of its influence the buildings stability (Tadios 2013). The swelling potential map in this region was determined through soil specimens' analysis taken from test core drillings of the first meters. After determining the clay rate (%) and plasticity index (%) of the soils samples, these values were evaluated by using standards ([Tables 4, 5](#)). The local phenomenon swelling is related to clays, muddy and silts containing smectites, or in residual non-consolidated material. This process can be produced in three ways: the low, medium and high swelling potential classes. The plasticity diagram published by Casagrand in 1932 ([Figure 11](#)) shows that the soil samples from the cities of Sobkhas, Sidi Boulbaba, Gabes (Bab bhar, El Manzel, Jara, Kornich), Omar Ibn el Khat tab Avenue, Erriadh City, et El Amel City are characterized by a high swelling potential that may cause cracks in the constructions in the case of humidification and drying of these materials.

#### 4.1.7. Soils agressivity

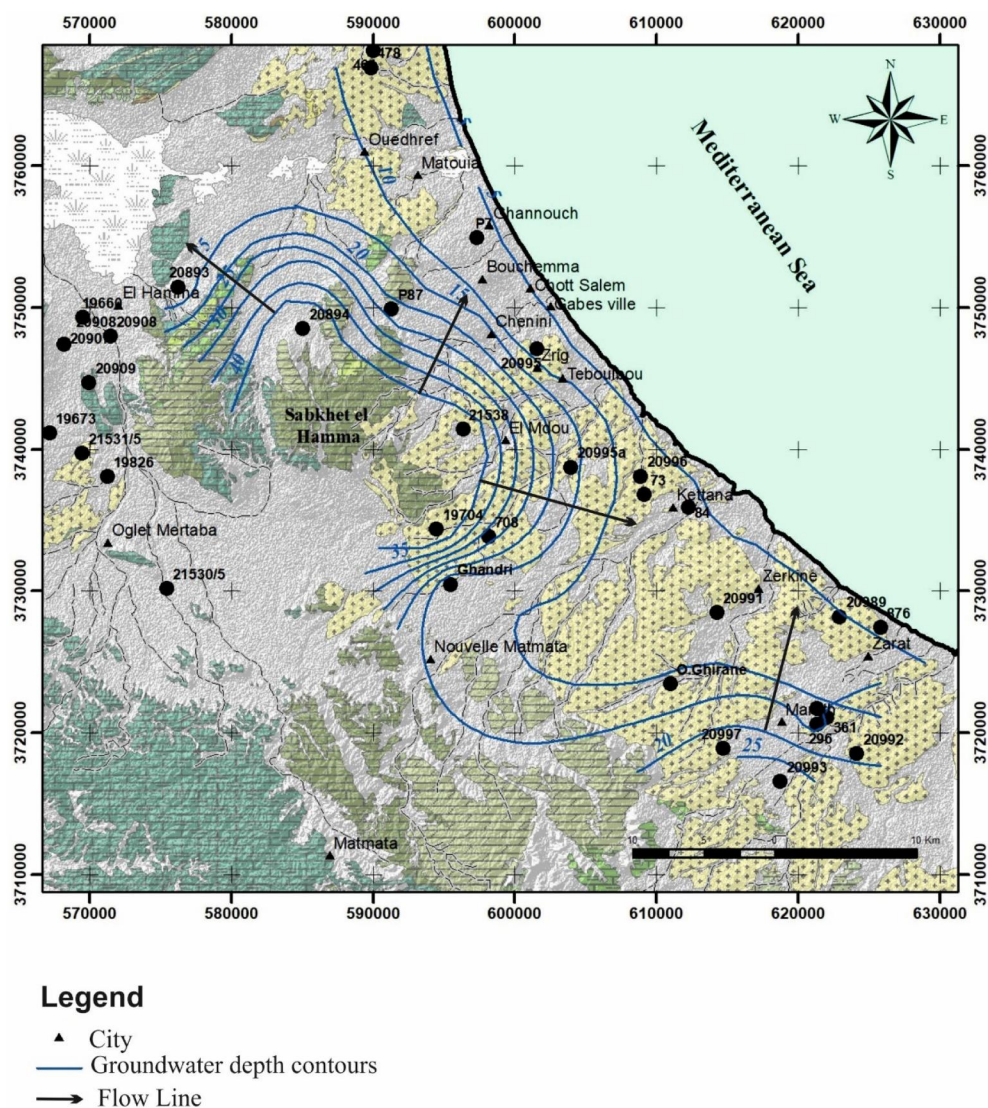
Gypsum (CaSO<sub>4</sub>2H<sub>2</sub>O) is readily soluble in water (Cooper 2008). It is present in the bedrock, either as massive beds or as large beds (Mekrazi 1975). It can be associated with sulphate-rich groundwater that can be noxious to concrete (Marteau 1993; Thierry et al. 2009). Hence, the dissolution of gypsiferous beds can leave a weak resistance of residue, which also produces poor ground conditions for buildings, bridges and roads construction (Wei et al. 2020). In order to prevent the damage associated with subsidence and collapse a result of the dissolution of gypsum, it is strongly recommended you take precautions of dealing with the safety problems arise in gypsiferous soil. The investigation on the gypsiferous soils is accomplished in order to elaborate the soil aggressivity map. A chemical analysis of the representative water and soil samples of different test pits of the Gabes area was performed. Then, an





**Figure 9.** Gabes zone categorization based on the seismotectonic layer (faults exported works from De ligneris et al. 1951, in Mekrazi 1975, Ben Baccar 1982, Mhamdi et al. 2013, Gharbi et al. 2013, 2014, 2015, seismological datas (NMI 2013).

evaluation and classification of the obtained results were performed according to the of soils aggressivity classification standards (Tables 6, 7). The mapping also revealed the subsidence risk potential areas.



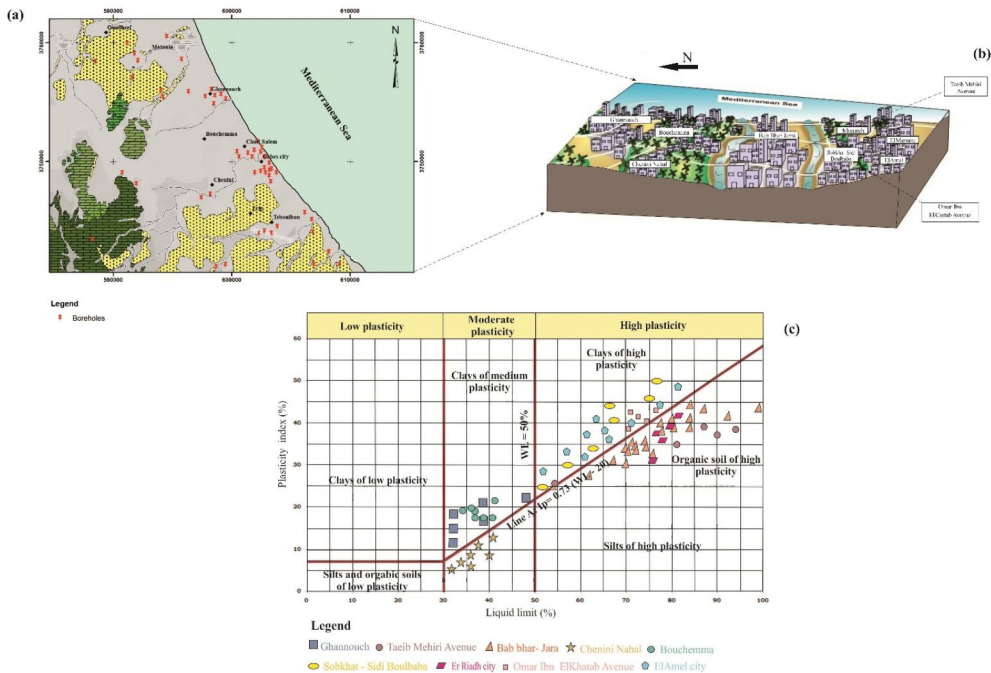
**Figure 10.** Water table level (2015) map of the Gabes area.

From the point of view of geo-mechanicals, soils aggressivity susceptibility map is classified in three classes:

Very strongly aggressive soils (A4): represents areas that are with high proportion of gypsum in soil ( $10\% < \text{gypsum} < 50\%$ ) and a high concentration of sulphate  $[\text{SO}_4^{2-}]$  in water that exceeds 3000 mg/l.

Strongly aggressive soils (A3): represents areas, which have  $[\text{SO}_4^{2-}]$  equals 3000 mg/l and a high gypsum content.

Moderately aggressive soils (A2): environments, which are characterized by  $[\text{SO}_4^{2-}]$  varying between 600 and 3000 mg/l in water and the gypsum content is less than 10% (Figure 12).



**Figure 11.** (a) Gabes city, (b) Block diagram: Swelling potential layer in urban zone (Gabes city), (c) plasticity diagram.

**Table 4.** Plasticity index of the soils (Magnan 1997).

Liquid limit (%)	Classification
0-20	Non-swelling
20-35	Low swelling
35-50	Medium swelling
50-70	High swelling
70-90	Very high swelling
> 90	critical swelling

**Table 5.** Classification proposed by dakshanamurthy and raman for swelling soils (1973).

Plasticity index	Plasticity degree
$0 < PI < 5$	Non-plastic
$5 < PI < 30$	Low plastic
$30 < PI < 50$	Plastic
$50 < PI$	High to very plastic

## 5. Discussions

### 5.1. Elaboration of urban land suitability assessment model

#### 5.1.1. Prediction of urban land suitability

Urban development and planning are dependent on the geologic environment. The geotechnical, geological, hydrological and environmental problems may be restrictive criterions on the process of planning (Turkmen and Taga 2005). They should be identified, evaluated and considered in the planning process for rational urban

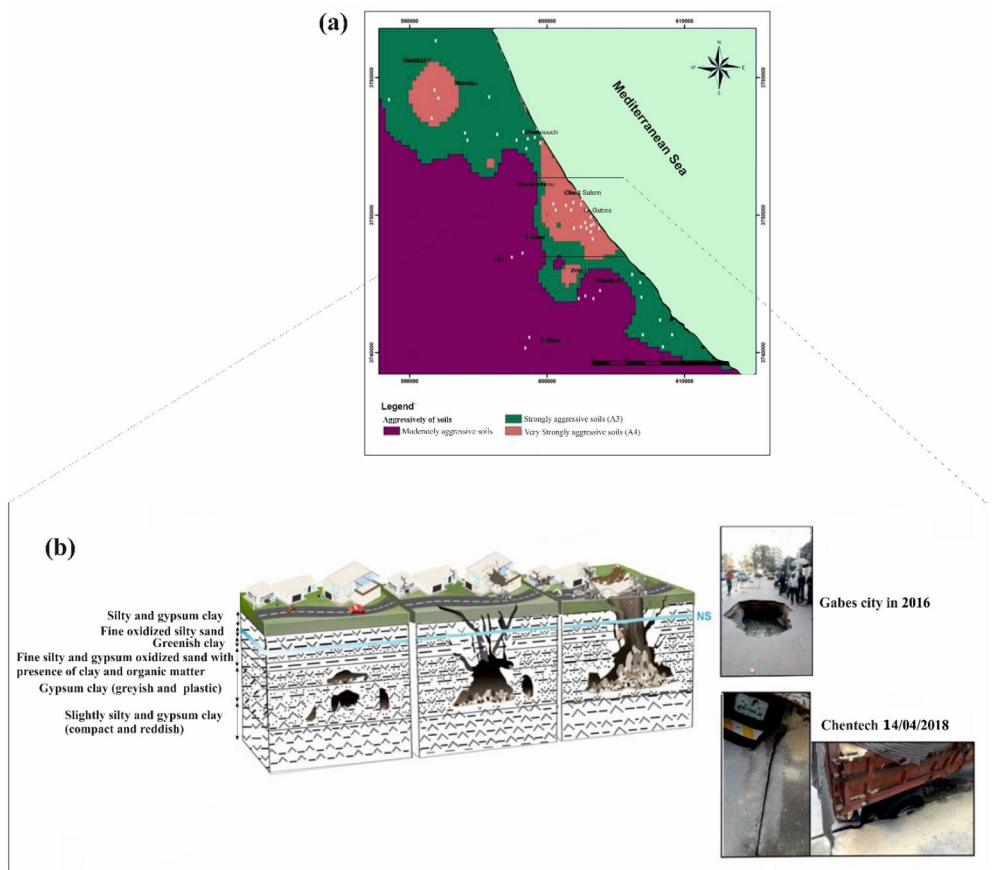


**Table 6.** Classification of aggressively environments (norme NF EN 206-1 Standard of the NF P 18-011, 2009 documentation file).

Limit values for chemical attack of the surface water and the groundwater			
Chemical characteristics	Sub-classification		
	XA1	XA2	XA3
SO <sub>4</sub> <sup>2-</sup> (mg/l)	200 to 600	600 à 3000	3000 to 6000
pH	5.5 to 6.5	4.5 to 5.5	4 to 4.5
CO <sub>2</sub> (mg/l)	15 to 40	40 to 100	of 100 up to saturation
NH <sub>4</sub> <sup>+</sup> (mg/l)	15 to 30	30 to 60	60 to 100
Mg <sup>2+</sup> (mg/l)	300 to 1000	1000 to 3000	of 3000 up to saturation

**Table 7.** Recommendations booklets (standard NF P 18-011, classification of aggressively environments 2009).

Agressevily class	Symbol	Protection level
Low agressivity	A <sub>1</sub>	1
Moderatet agressivity	A <sub>2</sub>	2
High agressivity	A <sub>3</sub>	2
Very high agressivity	A <sub>4</sub>	3



**Figure 12.** (a) Aggressively soil of the Gabes area, (b) the subsidence risk model.

development. Many planners do not understand this geo-information, for this reason, it is strongly recommended that professionals provide a detailed Urban Land Suitability map, which are easily used and can be considered in the urban planning process. From this map, hydrological, geological and geotechnical hazard mapping (Figure 13) was generated, which shows zones according to the danger levels and the high hazards. A geological urban area suitability potential model is the best technique to represent the geologic setting for engineering detailed (Dearman and Matula 1976). It is a type of hydro-geotechnical and geological model, which gives a very detailed performance of all risks that damaged land-use planning, construction, design and maintenance as applied to civil engineering in Gabes zone.

However, Gabes zone is especially a good example undergoing urban expansion where is being expanded. The planners and decision planners and decision makers need a Urban Land Suitability prototype showing a hydro-geotechnical micro-zoning in order to guarantees rational urban extension. The applied process consists in superposition of multi-thematic layers based on GIS. The result of the combination the influencing criterions shows that the Gabes area has been classified into four areas based on the risk potential and foundation adequacy for urban spaces (Figure 13):

**Area I:** This zone is characterized by Neogene and Quaternary detrital materials, which cover a vast surface. This is a floodplain characterized by the potential of flood hazard ranging from a moderate to a very high (Souissi et al. 2019). From spatial point of view, high flood susceptibility zones are the Residential areas (Gabes city and its surroundings, Mareth and El Hamma cities), the zones surrounding streams zones. Morphologically, it is characterized by low to very low elevations and slopes concentrating the runoff waters. It is marked by high concentration of streams Network and a low distance between the drainage Network. In this zone, the groundwater level depth is very low (0 and <5 m). However, the substantial surface and subsurface water flows generates instability of the buildings and soils. Hence, it is recommended to build artificial levees along the channel, this drainage system was designed to collect and redirect runoff water in order to improve the overall stability of the soils and buildings and reduce the magnitude of flood damage.

**Area II:** This is an area with a minor extension from surface point of view, but it is characterized by a high demographic and urban density. This area be part of the high flood hazard potential zone and a low groundwater level. It is formed by quaternary and alluvial deposits from the geotechnical perspective, clay soils present a very high liquidity ( $50 < WL < 100\%$ ) that can generate geotechnical problems. These features are present in the sector of: Sobkhat - Sidi boubaba, Bab bhar, Jara regions, El Amel city, Omar Ibn el Khattab and Taeib el Mehiri Avenues in Gabes city and these surroundings.

**Area III:** The chemical analysis carried out on solid and liquid samples show that Ghannouch and El Hamma region are characterized by highly aggressive environments with an aggressiveness degree A3. The soils of Gabes and Bouchemma cities and the Southern Gabes are very strongly aggressive with an aggressivity degree A4. Indeed, these sectors have a very high subsidence risk potential. Consequently, the constructions in this zone must take the necessary precautions to adapt the foundations of the works to the conditions of the site. Hence, it is strongly recommended that: you:

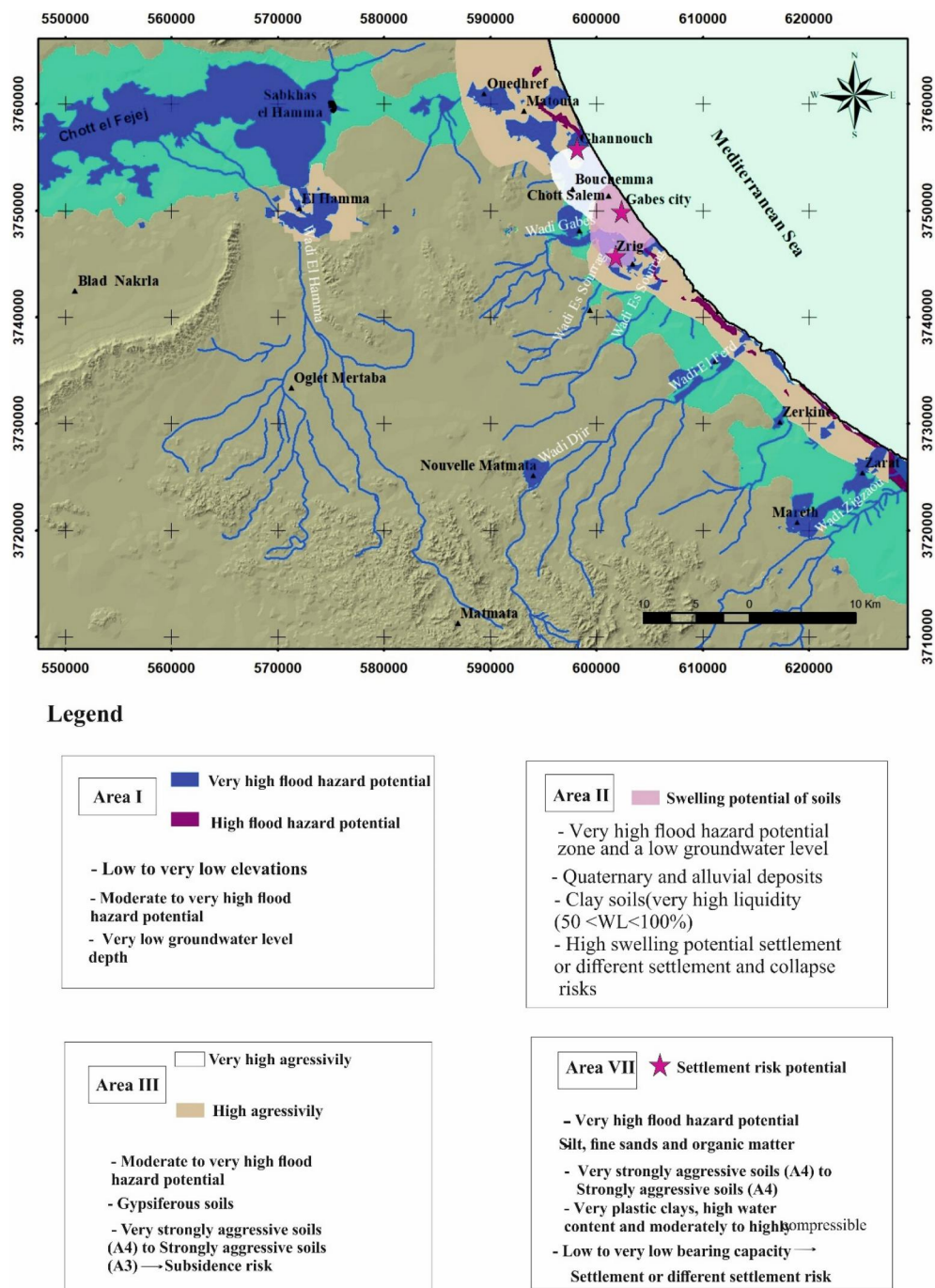


Figure 13. Urban land suitability model.

- Installation of a draining circuit or a Geomembrane in order to prevent groundwater containing sulphates from rising into buildings as well as to guarantee the stability of building ground.



- Using the high resistance cements of the sulfate (HSC)
- Increase in the cover concrete section (+ 2 cm) in order to prevent contact between the sulfate groundwater and the concrete reinforcement

**Area IV:** The soils of Ghannouch, Bab Bhar cities and Taeib Mehiri Avenue are marked by the presence of silt, fine sands and organic matter. In this region, the clays are very plastic. The deposits covering El Amel City are very plastic clays with a high-water content, moderately to highly compressible. These deposits have poor geotechnical characteristics where they demonstrate a very high plasticity and low to very low bearing capacity that can generate geotechnical problems. The risk of settlement or different settlement is highly probable in this zone.

### 5.1.2. Weighted calculation

The modern Geoscience can contribute specially to finding solutions concerning the use land use in urban environments (Huggenberger and Epting 2011). In decision-making setting, a factor would involve classes and norms by which one factor could be judged as more influenced than another one would. The subjective and objective weights were computed using the ANP et CRITIC methods. According, the Game Theory Combined Weighting (GTCW) Model the weight coefficients for the combined weights have been defined to be 0.02 and 0.30. Thereafter, combination weights have been achieved incorporation the weight coefficients into Equation 13. The results of the combination weights process are presented in Table 8, Flood, Swelling Potential of soils, lithology and Soil Agressivity, have important impact on the Land suitability in urban zone of Gabes, followed by topography, while the groundwater table and seismotectonic have the least influence. The Land Suitability was primarily influenced hydrological and geotechnical engineering attributes, complying with the soil bearing capacity results.

In this present study, seven significant parameters contribute in analysis of the urban land suitability areas. The geospatial modeling method and MCDM-ANP-CRITIC-Combined Weighting model was adopted to develop the ULS model and calculate the ULS index (ULSI) in the Gabes region by:

$$\begin{aligned} \text{ULSI} &= \text{FH}_w \text{FH}_r + \text{LG}_w \text{LG}_r + \text{SS}_w \text{SS}_r + \text{AS}_w \text{ASG}_r + \text{WT}_w \text{WT}_r + \text{TP}_w \text{TP}_r + \text{ST}_w \text{ST}_r \\ \text{ULSI} &= 0.31\text{FH}_r + 0.191\text{LG}_r + 0.137\text{SS}_r + 0.131\text{ASG}_r + 0.10\text{WT}_r + 0.10\text{TP}_r + 0.02\text{ST}_r \\ \text{ULSI} &= 3.5 \end{aligned}$$

Where is the FH is the Flood Hazard index, LG is the Lithology index, SS is the Swelling Potential of soils index, AS is the Agressivity index, WT is the Water Table index, TP is the Topography index, and ST is the Seismotectonic index.

### 5.2. Validation of results

In this research, were used the ROC-AUC validation method for ULSI assessment based on the soil bearing capacity map. The bearing capacity map is prepared following a review and assessment of a 136 boreholes relevant data. In this study, the

**Table 8.** Weighted calculation.

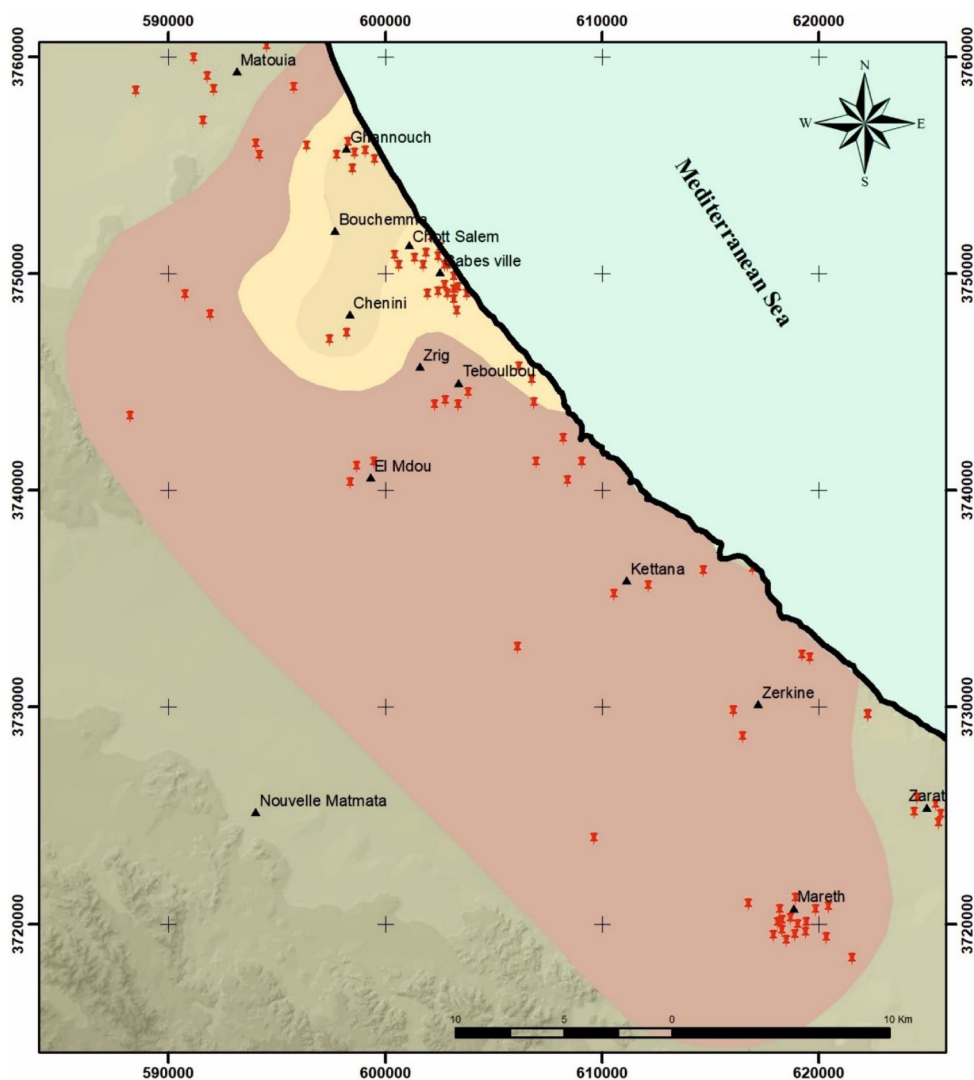
Factor	Domain of effect	Weight of effect	Subjective weights	Objective weights	Combination weights	ULS
Flood	Very High	1	0.30	0.32	0.31	Very low
	High	2				Low
	Moderate	6				Moderate
	Low	7				High
	Very low	9				Very High
Lithology	Alluvium + Sebkhas soils + silt + eoliens deposits	1	0.20	0.22	0.191	Very low
	loose soils and Heterogeneous	2				Low
	Sandy soil	4				Moderate
	Heterogeneous and compact formation	6				High
	Homogeneous and compact formation	9				Very High
Swelling Potential of soils	High swelling	1	0.13	0.144	0.137	Very low
	Medium swelling	2				Moderate
	Low swelling	6				High
	No swelling	9				Very High
Agressivity	Very high aggressively of soils	1	0.12	0.143	0.131	Very low
	High aggressively of soils	2				Low
	Low aggressively of soils	9				High
Water Table	0–5 m	1	0.11	0.095	0.10	Very low
	5–10	2				Low
	10–15	4				Moderate
	15–20	6				High
	20–>20	9				Very High
Topography	0–40	1	0.11	0.095	0.10	Very low
	40–80	2				Low
	80–120	4				Moderate
	120–160	6				High
	>160	9				Very High
Seismotectonic	High seismotectonic	1	0.03	0.01	0.02	Low
	Medium seismotectonic	4				Moderate
	Low seismotectonic	9				Very High

bearing capacity map was classified in four categories good, moderate, poor and worst soil conditions (Figure 14).

The validation was based on predicting and proving that high risk potential is located within lowly bearing capacity zones that corresponds to the lowly ULSI and then poor soil conditions for the foundations. The value of an area under ROC curve is about 78.4%, which suggests the total ULSI pixels was good-ranked by the ULSI prototype. The results of comparison processes show that there is a high similarity and compatibility between these two maps with the appearance a new area (Zerkine, Teboulbou, Mareth and Kettana) identified new risk sites to shallow foundations.

However, for greater accuracy we need a geophysical investigation (Resistivity tomography) for these zones, in order to test these soils and make sure these zones do not present risks. Therefore, the results of this study are precise, specific and important they can avoid most practical errors in developing for future projects of urban extension (Figure 15).

Thus, in order to prevent any disasters in the future, it is necessary that in the risk areas either should be rebuilt or reinforce the buildings by: increasing the bearing capacity of soil foundation, stabilization using cement or calcium hydroxide, using

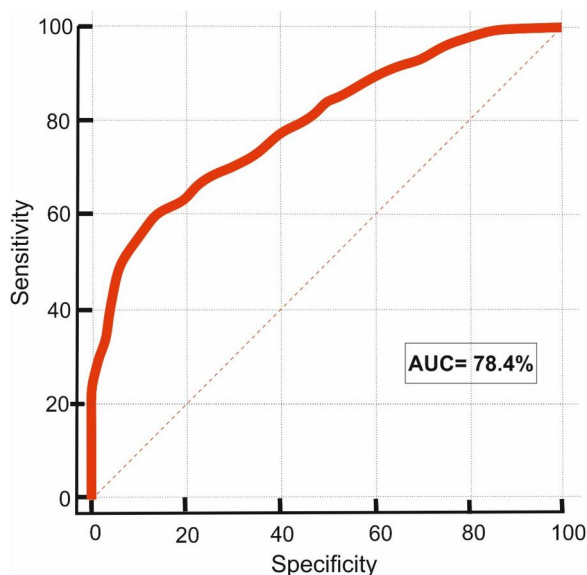


Legend

Bearing capacity depth		Soils conditions		Fondation depth
7 - 9 m	----->	Worst	----->	Deep foundation
5 - 7 m	----->	Bad	----->	Deep foundation
4 - 5 m	----->	Acceptable	----->	Shallow foundation
1 - 3 m	----->	Good	----->	Shallow foundation

Figure 14. The allowable bearing capacity map of the study zone.

the deep foundation, using hydro-isolation against the aggressivity properties of groundwater, installation of a draining circuit and a Geomembrane, a reinforced concrete general raft in case of settlement or differential settlement, Injection of a rigid polyurethane foam (PUR) in case of differential settlement.



**Figure 15.** Validation of urban land suitability model based on area under curve (ROC-AUC).

## 6. Compare the results with the previous study

In the present study, the geo-statistical (GIS-MCDM-ANP-CRITIC) measure for Urban Land Suitability analysis in Gabes zone (Tunisia) require the integration of seven significant variables reflecting on topography, Soil, climate, landscape, land use, and environment for the multi-criteria evaluation of the ULS. These include: Flooding susceptibility, Lithology, Topography, Seismotectonic, Water table depth, swelling potential of soils and the soils aggressively. This evaluation shows that the used model for analyzing Urban Land Suitability of Gabes zone is acceptable (AUC= 78.4%). The Urban Land Suitability map highlighted that this zone is divided in four areas depending on the risk potential and foundation suitability for residential areas. Alam et al. 2023 have used a novel approach to elaborat site suitability models for human settlement with the help of the AHP-CRITIC-MCDM method combined with GIS. Twelve significant factors have selected in the multi-criteria evaluation (elevation, slope, precipitation, temperature, distance to road and river, groundwater, soil texture, LULC, FVI, river shifting zone, and population density). The results of this study shows the lower Ganga plains (India) is spatially quantified into five categories, from unsuitable to high-suitable and the floods are considered main risk which affects the region. In this study, the results obtained are validate by ROC curve, the ROC values of the theoretical predicted model are high, show the perfection of the calculated model by MCDM-AHP- CRITIC method. The CRITIC is an objective weighting model where factors weights are determined by the standard deviation of the criterion and its correlation coefficients between all pairs of factors (Wei et al. 2020; Wu et al. 2020). The objective factor weights are more reliable than subjective factor weights and considered with of the lack of decision-makers' judgements (Wang et al. 2012). In 2023, the research work realised by Sotiropoulou and Vavatsikos, to elaborated a land use suitability mapping using PROMETHEE II and k Nearest Neighbor Machine

Learning Models. The results can be used by spatial planners, investment developers and decision makers to predict the the degree of suitability for future development projects and can be combined with economic feasibility and environmental impact assessment analyses to help decision-makers make comprehensive spatial decisions for sustainable investments.

## 7. Conclusion

In the past few years, the researchers and the civil engineering experts have made a lot of efforts in evaluating urban environment in order to ensure the adaptation of the foundations to the characteristics of the sites. The geotechnical, geological, seismotectonic and hydrological risks assessment in the urban environment, may help in construction buildings and other civil engineering structures, will adapt the foundations of the structures to the geotechnical characteristics of the land, and subsequently then will reduce the probability of loss of life and property.

The creation of a land use plan should take into account the contributions of multidisciplinary scientists, the studies geological, geophysical, geo-environmental and geotechnical carried and the conventional tools used. In the present study, the creation of an Urban Land Suitability map requires a multi-criteria evaluation of foundation conditions of Urban Land Suitability investigation. Variety of methods has been used to establish engineering-geological models. In recent time, with the development of mathematical and statistical methods, some quantitative evaluation methods have been introduced to Urban Land Suitability prototype, such as the ANP et CRITIC methods. In this research, in order to determine the urban problem, a GIS-based MCDM with seven parameters (Flooding susceptibility, Lithology, Topography, Seismotectonic, Water table depth, swelling potential of soils and the soils aggressively) were investigated. The combination of the MCDM-ANP-CRITIC- Combined Weighting and Geographic Information System allows treating the spatial data and calculating the rating and the weight of the relative importance of each class to each conditional factor. An MCDM- ANP-CRITIC- Combined Weighting is a powerful tool that has been proved useful in resolving complex problems. The analysis of the Urban land suitability model has revealed the challenges and prospects of land use analysis for urban extension in Gabes region.

The Urban Land Suitability map highlighted that this region is divided in four areas depending on the risk potential and foundation suitability for residential areas. For this particular case study, it is the first time to proceed to the identification of current land use situations in the Gabes area using a GIS, combined with a multi-criteria decision analysis approach for the existing conditions analysis by integrating seven factors of geo-socio-economic influences. Consequently, the spatial multicriteria evaluation of land use planning conditions presented in this research is advantageous. It allows relatively savings in the process of building foundations, in a simple, relatively fast and progressive way of evaluation data manipulation, rapid data updating and the possibility of producing various new scenarios for the areas of land use. The results obtained in this research provided valuable information and presented an optimal base for the urban extension for planners, policy and decision makers,

municipalities and for individual builders. It allows preventing potential damages due to natural conditions underestimation. In order to improve the accuracy and the reliability of case study, a geophysical study is strongly recommended.

Finally, the process of evaluating Urban Land Suitability conditions using SMCDM-ANP-CRITIC- Combined Weighting can be used in general in any territory while respecting the particularities of each zone (climatic, hydrological, geological, geotechnical). The drawback of the methodology presented in this manuscript require geological and geotechnical investigations as well as a big database.

The goal of the present research is to use a novel approach such as the geostatistical modeling (GIS- MCDM-ANP-CRITIC) to assess the Land Suitability Urban area in Gabes region, to achieve adequate and sustainable development. Urban land suitability analysis and assessment is a decision process that allows effective land use planning and management. The present study took different physical, socio-economic variables that have had an impact on Urban Land. Seven parameters (Flooding susceptibility, Lithology, Topography, Seismotectonic, Water table depth, swelling potential of soils and the soils aggressively) were investigated. Authentication of the outcome obtained using training data and validation datasets showed that the success rate of the GIS-MCDM-ANP-CRTIC model is 87,4% ( $AUC > 0.7$ ) shows that the used model for analyzing Urban Land Suitability of Gabes zone is acceptable. The Urban Land Suitability map highlighted that this region is divided in four areas depending on the risk potential and foundation suitability for residential areas.

The Gabes cities are demarcated as the area having very low adequation for urban land planning. For this particular case study, it is the first time to proceed to the identification of current land use situations in the Gabes area using a GIS, combined with a multi-criteria decision analysis approach for the existing conditions analysis.

The results obtained in this research provided valuable information and presented an optimal base for the urban extension for planners, policy and decision makers, municipalities and for individual builders. It allows preventing potential damages due to natural conditions underestimation. In order to improve the accuracy and the reliability of case study, a geophysical study is strongly recommended.

Finally, the process of evaluating Urban Land Suitability conditions using SMCDM-ANP-CRITIC- Combined Weighting can be used in general in any territory while respecting the particularities of each zone (climatic, hydrological, geological, geotechnical).

## Acknowledgements

The authors would like to thank the Tunis El Manar University for their logistical support and interest in this work. We appreciate Mrs. Mariem Saadi for their language assistance. Open Access funding provided by Qatar National Library. The findings herein reflect the work and are solely the responsibility of the authors.

## Authors' contributions

Conceptualisation: Dhekra Souissi, Lahcen Zouhri, Abdelaziz Sebei and Adel Zghibi; Data curation: Dhekra Souissi, Abdelaziz Sebei and Adel Zghibi; Formal analysis: Dhekra Souissi,



Lahcen Zouhri, Abdelaziz Sebei and Adel Zghibi; Investigation: Dhekra Souissi; Methodology: Dhekra Souissi, Lahcen Zouhri, Abdelaziz Sebei and Adel Zghibi; Software: Dhekra Souissi; Supervision: Lahcen Zouhri, Abdelaziz Sebei, Mahmoud Dlala and Mohamed Ghanmi; Validation: Dhekra Souissi, Lahcen Zouhri and Abdelaziz Sebei; Writing –original draft: Dhekra Souissi; Writing – review and editing: Lahcen Zouhri, Abdelaziz Sebei, Adel Zghibi, Mahmoud Dlala and Mohamed Ghanmi.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

Dhekra Souissi  <http://orcid.org/0000-0003-2807-1954>  
 Lahcen Zouhri  <http://orcid.org/0000-0003-4370-676X>  
 Abdelaziz Sebei  <http://orcid.org/0000-0002-8263-9590>  
 Adel Zghibi  <http://orcid.org/0000-0001-6821-4708>  
 Mohamed Ghanmi  <http://orcid.org/0000-0001-9475-1400>

## Data availability

Data are available upon request on the first author.

## References

- Abedi Gheshlaghi H, Feizizadeh B. 2021. GIS-based ensemble modelling of fuzzy system and bivariate statistics as a tool to improve the accuracy of landslide susceptibility mapping. *Nat Hazards*. 107(2):1981–2014. doi:[10.1007/s11069-021-04673-1](https://doi.org/10.1007/s11069-021-04673-1).
- Ahmadi R, Mercier E, Ouali J. 2013. Growth-strata geometry in fault-propagation folds: a case study from the Gafsa basin, southern Tunisian Atlas. *Swiss J Geosci*. 106(1):91–107. doi:[10.1007/s00015-013-0122-z](https://doi.org/10.1007/s00015-013-0122-z).
- Alam N, Saha S, Gupta S, Chatterjee A. 2023. Settlement suitability analysis of a riverine flood-plain in the perspective of GIS-based multicriteria decision analysis. *Environ Sci Pollut Res Int*. 30(24):66002–66020. doi:[10.1007/s11356-023-26985-4](https://doi.org/10.1007/s11356-023-26985-4).
- Alencar A, Galindo R, Melentijevic S. 2021. Influence of the groundwater level on the bearing capacity of shallow foundations on the rock mass. *Bull Eng Geol Environ*. 80(9):6769–6779. doi:[10.1007/s10064-021-02368-2](https://doi.org/10.1007/s10064-021-02368-2).
- Anon. 1996. Geological aspects of land-use planning. *Atlas of Urban Geology* 8. United Nations, New York.
- Anteneh MB, Damte DS, Abate SG, Gedefaw AA. 2023. Geospatial assessment of urban green space using multi-criteria decision analysis in Debre Markos City, Ethiopia. *Environ Syst Res*. 12:7(2023). doi:[10.1186/s40068-023-00291-x](https://doi.org/10.1186/s40068-023-00291-x).
- Banuelas R, Antony J. 2004. Modified analytic hierarchy process to incorporate uncertainty and managerial aspects. *Int J Prod Res*. 42(18):3851–3872. doi:[10.1080/00207540410001699183](https://doi.org/10.1080/00207540410001699183).
- Ben Alaya M, Saidi R, Zemni T, Zargouni F. 2014. Suitability assessment of deep groundwater for drinking and irrigation use in the Djefara aquifers (Northern Gabes, south-eastern Tunisia). *Environ Earth Sci*. 71(8):3387–3421. doi:[10.1007/s12665-013-2729-9](https://doi.org/10.1007/s12665-013-2729-9).
- Ben Baccar B. 1982. Contribution à l'étude hydrogéologique de l'aquifère multicouche de Gabès-Sud. Thèse. Doct, 3<sup>ème</sup> cycle Univ. Paris Sud (Orsay), 115 p, 1 annexe.

- Ben Hamouda MF, Mamou A, Bejaoui J, Froehlich K. 2013. Hydrochemical and Isotopic Study of Groundwater in the North Djeffara Aquifer, Gulf of Gabès, Southern Tunisia. *IJG*. 04(08):1–10. doi:[10.4236/ijg.2013.48A001](https://doi.org/10.4236/ijg.2013.48A001).
- Bourenane H, Bouhadad Y. 2021. Spatial analysis, assessment and mapping of flood hazard in the alluvial plains of Boumerzoug and Rhumel (city of Constantine, north-eastern Algeria): application to development and urban planning projects. *Bull Eng Geol Environ*. 80(2): 1137–1155. doi:[10.1007/s10064-020-01980-y](https://doi.org/10.1007/s10064-020-01980-y).
- Cooper AH. 2008. The classification, recording, databasing and use of information about building damage caused by subsidence and landslides. *QJEGH*. 41(3):409–424. doi:[10.1144/1470-9236/07-223](https://doi.org/10.1144/1470-9236/07-223).
- Culshaw MG, Price SJ. 2011. The contribution of urban geology to the development, regeneration and conservation of cities. The 2010 Hans Cloos lecture. *Bull Eng Geol Environ*. 70(3):333–376. doi:[10.1007/s10064-011-0377-4](https://doi.org/10.1007/s10064-011-0377-4).
- Dakshanamurthy VE, Raman V. 1973. A simple method of identifying an expansive soil. *Soils and Foundations, Japanese Society of Soil Mechanics and Foundation Engineering*. 13n°(1): 97–104. DananhuTousuquan island arcXinjiangNW ChinaJournal of African Earth Sciences. doi:[10.1016/j.jafrearsci.2016.12.011](https://doi.org/10.1016/j.jafrearsci.2016.12.011).
- Das. 2020. 14th IAPR International Workshop, Wuhan, China, July 26-29, 2020, Proceedings. Volume 12116 of Lecture Notes in Computer Science, Springer, 2020.
- Dearman WR, Matula M. 1976. Environmental aspects of engineering geological mapping. *Bull IAEG*. 13(1):141–146. doi:[10.1007/BF02634779](https://doi.org/10.1007/BF02634779).
- Dearman WR. 1991. Engineering geological mapping. Oxford: Butterworth-Heinemann.
- Dehghanbanadaki A, Sotoudeh MA, Golpazir I, Keshtkarbaeemoghadam A, Ilbeigi M. 2019. Prediction of geotechnical properties of treated fibrous peat by artificial neural networks. *Bull Eng Geol Environ*. 78(3):1345–1358. doi:[10.1007/s10064-017-1213-2](https://doi.org/10.1007/s10064-017-1213-2).
- DGRE. 2015. *Annuaire d'exploitation de la nappe profonde 1950–2015*. Ministère de l'Agriculture, Tunis
- Diakoulaki D, Mavrotas G, Papayannakis L. 1995. Determining objective weights in multiple criteria problems: the CRITIC method. *Comput Oper Res*. 22(7):763–770. doi:[10.1016/0305-0548\(94\)00059-H](https://doi.org/10.1016/0305-0548(94)00059-H).
- Díaz-Díaz LM, Pando L, Arias D, López-Fernández C. 2017. Geotechnical map of a coastal and industrialized urban area (Avilés, NW Spain). *J Maps*. 13(2):777–786. doi:[10.1080/17445647.2017.1381195](https://doi.org/10.1080/17445647.2017.1381195).
- Dlala M. 1992. Seismotectonic study in Northern Tunisia. *Tectonophysics*. 209(1-4):171–174. doi:[10.1016/0040-1951\(92\)90020-7](https://doi.org/10.1016/0040-1951(92)90020-7).
- Dlala M. 1995. [ Evolution géodynamique et tectonique superposée en Tunisie: implication sur la tectonique récente et la sismicité ]. [PhD Thesis]. University of Tunis, Tunisia.
- Dou F, Xing H, Li X, Yuan F, Zhitang L, Li X, Ge W. 2022. 3D Geological Suitability Evaluation for Urban Underground Space Development Based on Combined Weighting and Improved TOPSIS. *Nat Resour Res*. 31(1):693–711. doi:[10.1007/s11053-021-10004-9](https://doi.org/10.1007/s11053-021-10004-9).
- Dunčková L, Bednarik M, Krčmář D, Marschalko M, Tornyai R. 2019. GIS-based multicriteria evaluation of foundation conditions. *Bull Eng Geol Environ*. 78(4):2903–2917. doi:[10.1007/s10064-018-1283-9](https://doi.org/10.1007/s10064-018-1283-9).
- Dutta M, Saha S, Saikh NI, Sarkar D, Mondal P. 2023. Application of bivariate approaches for flood susceptibility mapping: a district level study in Eastern India. *Hydro. Research*. 6:108–121. doi:[10.1016/j.hydres.2023.02.004](https://doi.org/10.1016/j.hydres.2023.02.004).
- El May M, Souissi D, Ben Said H, Dlala M. 2015. Geotechnical characterization of the quaternary alluvial deposits in Tunis City (Tunisia). *J African Earth Sci*. 108(2015):89–100. doi:[10.1016/j.jafrearsci.2015.05.003](https://doi.org/10.1016/j.jafrearsci.2015.05.003).
- Eric D, Baker JL, Hoornweg D, Tiwari A. 2012. Urban Risk Assessments: understanding Disaster and Climate Risk in Cities. Urban Development Series. Washington DC: world Bank. License: creative Commons Attribution CC BY 3.0. doi:[10.1596/978-0-8213-8962-1](https://doi.org/10.1596/978-0-8213-8962-1).

- Fawad M, Ullah F, Irshad M, Shah W, Mahmood Q, Ahmad I. 2022. Marble waste site suitability assessment using the GIS-based AHP model. *Environ Sci Pollut Res Int.* 29(19): 28386–28401. doi:[10.1007/s11356-021-18373-7](https://doi.org/10.1007/s11356-021-18373-7).
- Fernandez JA, Pinto JLP, Lopez FF. 1982. Geoscientific map of the natural environment of the Province of Almeria. In: proceedings of the 4th Congress of the International Association of Engineering Geology, New Delhi. A.A. Balkema, Rotterdam, 1: p. 47–56.
- Fuchu D, Yuhai L, Sijing W. 1994. Urban geology: a case study of Tongchuan city, Shaanxi Province, China. *Eng Geol.* 38:164–175.
- Gharbi M, Bellier O, Masrouhi A, Espurt N. 2014. Recent spatial and temporal changes in the stress regime along the southern Tunisian Atlas front and the Gulf of Gabes: new insights from fault kinematics analysis and seismic profiles. *Tectonophysics.* 626:120–136. doi:[10.1016/j.tecto.2014.04.003](https://doi.org/10.1016/j.tecto.2014.04.003).
- Gharbi M, Espurt N, Masrouhi A, Bellier O, Amari EA. 2015. Style of Atlasic tectonic deformation and geodynamic evolution of the southern Tethyan margin, Tunisia. *Mar. Pet. Geology.* 66(4):801–816.
- Gharbi M, Masrouhi A, Espurt N, Bellier O, Amari EA, Ben Youssef M, Ghanmi M. 2013. New tectono-sedimentary evidences for Aptian to Santonian extension of the Cretaceous rifting in the Northern Chotts range (Southern Tunisia). *J. Afr. Earth Sci.* 79:58–73. doi:[10.1016/j.jafrearsci.2012.09.017](https://doi.org/10.1016/j.jafrearsci.2012.09.017).
- Gritzner ML, Marcus WA, Aspinall R, Custer SG. 2001. Assessing landslide potential using GIS, soil wetness modelling and topographic attributes, Payette River, Idaho. *Geomorphology.* 37(1-2):149–165. doi:[10.1016/S0169-555X\(00\)00068-4](https://doi.org/10.1016/S0169-555X(00)00068-4).
- Huggenberger P, Epting J. 2011. *Urban Geology. Process-Oriented Concepts for Adaptive and Integrated Resource Management.* Springer Science & Business Media.
- Kolat C, Ulusay R, Suzen ML. 2012. Development of geotechnical microzonation model for Yenisehir (Bursa, Turkey) located at a seismically active region. *Eng Geol.* 127:36–53. doi:[10.1016/j.enggeo.2011.12.014](https://doi.org/10.1016/j.enggeo.2011.12.014).
- Li K, Shang Y, He W, Lin D, Hasan M, Wang K. 2019. 2019. An engineering site suitability index (ESSI) for the evaluation of geological situations based on a multi-factor interaction matrix. *Bull Eng Geol Environ.* 78(1):569–577. doi:[10.1007/s10064-017-1122-4](https://doi.org/10.1007/s10064-017-1122-4).
- Li XP, Li YN. 2014. Research on risk assessment system for water inrush in the karst tunnel construction based on GIS: case study on the diversion tunnel groups of the Jinping II Hydropower Station. *Tunn Undergr Space Technol.* 40:182–191. doi:[10.1016/j.tust.2013.10.005](https://doi.org/10.1016/j.tust.2013.10.005).
- Liu, Dong, Qi, Xiaochen, Li, Mo, Zhu, Weifeng, Zhang, Liangliang, Abrar Faiz, Muhammad, Khan, Muhammad Imran, Li, Tianxiao, Cui, Song, QiangFu,. 2019. A resilience evaluation method for a combined regional agricultural water and soil resource system based on Weighted Mahalanobis distance and a Gray-TOPSIS model. *J. Clean. Prod.* 229, 667–679. doi:[10.1016/j.jclepro.2019.04.406](https://doi.org/10.1016/j.jclepro.2019.04.406).
- Magnan J-P. 1997. Description, identification et classification des sols Techniques de l'ingénieur. Paris. 1(C208):C208.1–C208.16.
- Marteau P. 1993. *Mémento Roches et Minéraux industriels Gypse et Anhydrite.* Editions du BRGM.
- Mao Z, Shi S, Li H, Zhong J, Sun J. 2022. Landslide susceptibility assessment using triangular fuzzy number-analytic hierarchy processing (TFN-AHP), contributing weight (CW) and random forest weighted frequency ratio (RF weighted FR) at the Pengyang county. *Northwest China Environ Earth Sci.* 81(3):86. doi: [10.1007/s12665-022-10300-4](https://doi.org/10.1007/s12665-022-10300-4).
- Meghraoui M, Cisternas A, Philip H. 1986. Seismotectonics of the lower Chéiff basin: structural background of the El Asnam (Algeria) earthquake. *Tectonics.* 5(6):809–836. doi:[10.1029/TC005i006p00809](https://doi.org/10.1029/TC005i006p00809).
- Mekrazi AF. 1975. [ Contribution à l'étude géologique et hydrogéologique de la région de Gabès Nord ]. [PhD Thesis]. University of Bordeaux.
- Mhamdi A, Dhahri F, Gouasmia M, Soussi M, Inoubli N, Ben Dhia H. 2013. Groundwater investigation in the southern part of Gabes using resistivity sounding, southern Tunisia. *Arab J Geosci.* 6(2):601–614. doi:[10.1007/s12517-011-0375-7](https://doi.org/10.1007/s12517-011-0375-7).

- Moeinaddini M, Khorasani N, Danehkar A, Darvishsefat AA, Zienalyan M. 2010. Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: karaj). *Waste Manag.* 30(5):912–920. doi:[10.1016/j.wasman.2010.01.015](https://doi.org/10.1016/j.wasman.2010.01.015).
- Peng J, Peng FL. 2018. A GIS-based evaluation method of underground space resources for urban spatial planning: part 1 methodology. *Tunn. Undergr. Space Technol.* 74:82–95. doi:[10.1016/j.tust.2018.01.002](https://doi.org/10.1016/j.tust.2018.01.002).
- Philip H, Andrieux J, Dlala M, Chihi L, Ben Ayed N. 1986. Evolution tectonique mio-plio-quaternaire du fossé de Kasserine (Tunisie centrale): implications sur l'évolution géodynamique récente de la Tunisie. *Bull Soc Geol Fr.* II(4):559–568. doi:[10.2113/gssgfbull.II.4.559](https://doi.org/10.2113/gssgfbull.II.4.559).
- Promentilla MAB, Furuichi T, Ishii K, Tanikawa N. 2006. Evaluation of remedial countermeasures using the analytic network process. *Waste Manag.* 26(12):1410–1421. doi:[10.1016/j.wasman.2005.11.020](https://doi.org/10.1016/j.wasman.2005.11.020).
- Rodríguez F, Bocher E, Chancibault K. 2013. Terrain representation impact on periurban catchment morphological properties. *J Hydrol.* 485:54–67. doi:[10.1016/j.jhydrol.2012.11.023](https://doi.org/10.1016/j.jhydrol.2012.11.023).
- Rogers KB. 1991. The Relationship of Grouping Practices to the Education of the Gifted and Talented Learner: research-Based Decision Making Series.
- Saaty TL, Turner DS. 1996. Prediction of the 1996 super bowl. Proceedings of the Fourth International Symposium on the Analytic Hierarchy Process Simon Fraser University, Burnaby, B.C., Canada, July 12–15
- Saaty TL, Vargas LG. 2000. Models, Methods, Concepts and Applications of the Analytic Hierarchy Process. Kluwer Academic Publishers, Boston,
- Saaty TL. 1980. The Analytic Hierarchy Process: planning, Priority Setting, Resource Allocation. McGraw-Hill International Book Company, New York, USA.
- Saaty TL. 2001. Decision making with dependence and feedback: the analytic network process. 1st ed. Pittsburgh: RWS Publications.
- Saaty TL. 2008. Decision making with the analytic hierarchy process. *Int J Serv Sci.* 1:83–98.
- Sabokbar HF. 2005. Siting commercial services units with using the AHP method (case study of Torghabeh in Mashhad, Iran). *Geogr Res.* 51:125–138.
- Saha S, Sarkar D, Mondal P. 2022. Efficiency exploration of frequency ratio, entropy and weights of evidence-information value models in flood vulnerability assessment: a study of raiganj subdivision, Eastern India. *Stoch Environ Res Risk Assess.* 36(6):1721–1742. doi:[10.1007/s00477-021-02115-9](https://doi.org/10.1007/s00477-021-02115-9).
- Saikh NI, Mondal P. 2023. Gis-based machine learning algorithm for flood susceptibility analysis in the Pagla river basin, Eastern India. *Nat Hazards Research.* doi:[10.1016/j.nhres.2023.05.004](https://doi.org/10.1016/j.nhres.2023.05.004).
- Sarkar D, Mondal P. 2020. Flood vulnerability mapping using frequency ratio (FR) model: a case study on Kulik river basin, Indo-Bangladesh Barind region. *Appl Water Sci.* 10(1):17. doi:[10.1007/s13201-019-1102-x](https://doi.org/10.1007/s13201-019-1102-x).
- Sarkar SS, Mondal P. 2022. GIS-based frequency ratio and Shannon's entropy techniques for flood vulnerability assessment in Patna district, Central Bihar, India. *IJEST.* 19:8911–8932.
- Sotiropoulou KF, Vavatsikos AP. 2023. A Decision-Making Framework for Spatial Multicriteria Suitability Analysis using PROMETHEE II and k Nearest Neighbor Machine Learning Models. *J Geovis Spat Anal.* 7(2):20. doi:[10.1007/s41651-023-00151-3](https://doi.org/10.1007/s41651-023-00151-3).
- Souissi D, Msaddek MH, Zouhri L, Chenini I, El May M, Dlala M. 2018. Mapping groundwater recharge potential zones in arid region using GIS and Landsat approaches, southeast Tunisia. *Hydrol Sci J.* 63(2):251–268. doi:[10.1080/02626667.2017.1414383](https://doi.org/10.1080/02626667.2017.1414383).
- Souissi D, Souie A, Sebei A, Mahfoudhi R, Zghibi A, Zouhri L, Amiri W, Ghanmi M. 2022. Flood Hazard mapping and assessment using fuzzy-analytic hierarchy process and GIS techniques in Takelsa, Northeast Tunisia. *Arab J Geosci.* 15(16):1405. doi:[10.1007/s12517-022-10541-4](https://doi.org/10.1007/s12517-022-10541-4).
- Souissi D, Zouhri L, Hammami S, Msaddek MH, Zghibi A, Dlala M. 2019. GIS-based MCDM - AHP modeling for flood susceptibility mapping of arid areas, southeastern Tunisia. *Geocarto Int.* 35(9):991–1017. doi:[10.1080/10106049.2019.1566405](https://doi.org/10.1080/10106049.2019.1566405).

- Sutradhar S and Mondal P. 2023. Prioritization of watersheds based on morphometric assessment in relation to flood management: a case study of Ajay river basin, Eastern India. *WEE*. 5:1–11. doi:[10.1016/j.wsee.2022.11.011](https://doi.org/10.1016/j.wsee.2022.11.011).
- Tadios SK. 2013. GIS-based Geotechnical Microzonation Mapping using Analytic Hierarchy Process: a case study in Shire-Endasilasie City, Tigray, Northern Ethiopia. *mejs*. 5(2):101–116. doi:[10.4314/mejs.v5i2.91493](https://doi.org/10.4314/mejs.v5i2.91493).
- Tan F, Wang J, Jiao YY, Ma BC, He LL. 2021. Suitability evaluation of underground space based on finite interval cloud model and genetic algorithm combination weighting. *Tunn. Undergr Space Technol*. 108:103743. doi:[10.1016/j.tust.2020.103743](https://doi.org/10.1016/j.tust.2020.103743).
- Thierry P, Leparmentier AMP, Lembezat C, Vanoudheusden E, Vernoux JF. 2009. 3D geological modelling at urban scale and mapping of ground movement susceptibility from gypsum dissolution: the Paris example (France). *Eng. Geol.* 105(1-2):51–64. doi:[10.1016/j.enggeo.2008.12.010](https://doi.org/10.1016/j.enggeo.2008.12.010).
- Turkmen S, Taga H. 2005. Engineering geological assessment of the Diyarbakir solid waste landfill site (SE Turkey). *Bull Eng Geol Environ*. 64(4):433–440. doi:[10.1007/s10064-005-0008-z](https://doi.org/10.1007/s10064-005-0008-z).
- Tuzkaya G, Onut S, Tuzkaya UR, Gulsun B. 2008. An analytic network process approach for locating undesirable facilities: an example from Istanbul, Turkey. *J Environ Manage*. 88(4): 970–983. doi:[10.1016/j.jenvman.2007.05.004](https://doi.org/10.1016/j.jenvman.2007.05.004).
- Vujičić MD, Papić MZ, Blagojević MD. 2017. Comparative analysis of objective techniques for criteria weighing in two MCDM methods on example of an air conditioner selection. *Tehnika*. 72(3):422–429.
- Wang YL, Tzeng GH. 2012. Brand marketing for creating brand value based on a MCDM model combining DEMATEL with ANP and VIKOR methods. *Expert Syst Appl*. 39(5): 5600–5615. doi: [10.1016/j.eswa.2011.11.057](https://doi.org/10.1016/j.eswa.2011.11.057).
- Wei L, Chai S, Guo Q, Wang P, Fang L. 2020. Mechanical properties and stabilizing mechanism of stabilized saline soils with four stabilizers. *Bull Eng Geol Environ*. 79(10):5341–5354. doi:[10.1007/s10064-020-01885-w](https://doi.org/10.1007/s10064-020-01885-w).
- Wu ZN, Shen YX, Wang HL, Wu MM. 2020. Urban flood disaster risk evaluation based on ontology and Bayesian network. *J Hydrol*. 583:124596. doi:[10.1016/j.jhydrol.2020.124596](https://doi.org/10.1016/j.jhydrol.2020.124596).
- Xu DL, Yang JB. 2001. Introduction to Multi-Criteria Decision Making and the Evidential Reasoning Approach. Working Paper Series No 0106:1-21 ISBN: 1-86115111-X.
- Zhou DK, Li XZ, Wang Q, Wang R, Wang TD, Gu Q, Xin YX. 2019. GIS-based urban underground space resources evaluation toward three-dimensional land planning: a case study in Nantong, China. *Unnelling and Underground Space Technology*. 84:1–10. doi:[10.1016/j.tust.2018.10.017](https://doi.org/10.1016/j.tust.2018.10.017).
- Zhu Y, Li L. 2014. A regional competitive water resources security evaluation model based on Nash equilibrium restrictions. *Water Policy*. 16(4):690–703. doi:[10.2166/wp.2014.081](https://doi.org/10.2166/wp.2014.081).
- Zuquette LV, Pejon OJ, Dos Santos Collares JQ. 2004. Engineering geological mapping developed in the Fortaleza Metropolitan Region, State of Ceara, Brazil. *Eng Geol*. 71(3-4):227–253. doi:[10.1016/S0013-7952\(03\)00136-4](https://doi.org/10.1016/S0013-7952(03)00136-4).