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Assessment of Anticipatory Approach Using the Integration of GIS, and Remote Sensing Techniques for Flood Management in Alexandria City, Egypt

Mai Afifi[1,*], Rifaat Abdel Wahaab[1,2], Abdelkawi Khalifa[3], Ibrahim Moukhtar[1], Ezzat Elalfy[3]

[1]Holding Company for Water and Wastewater, Cairo, 11631, Egypt
[2]National Research Center, Cairo, 12622, Egypt
[3]Faculty of Engineering, Ain Sham University, Cairo, 11566, Egypt

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Abstract Alexandria city is the second largest city in Egypt; located on Mediterranean Sea. It experienced yearly extreme rainfall events. In 2015, it was hit by an extreme rainfall, causing a heavy impact flooding on the most urban areas of the city. This causes a huge negative impact on the social and economic activities. The responsible authorities did not prepare enough for this extreme event. This study aims to assist decision makers to prepare priority plans by developing flood susceptibility mapping for Alexandria city, using Geographic information system (GIS), remote sensing applications (RS), and integration with multi-criteria decision-making method. The analytic hierarchy process (AHP) techniques, and the list of significant urban flood factors are developed following a review of the related literature and a technical discussion with experts from the water sector. The required data for each factor were derived by remote sensing techniques. A quantitative analysis using the analytical hierarchy process (AHP) method was used to derive the final weights for each factor. A spatial data analysis was performed to identify different factors of the susceptibility map using the GIS system. Finally, the study has shown that the rainfall amount factor has the highest probability of flooding with a priority weight of 38%; this is because of its importance in the flood trigging, trailed by distance to stream with weight 26.3%, and the slope with weight 13.4%. Land cover-land use and elevation were the least important factors with priority weightings of 11.5%, 10.8% respectively. The developed susceptibility map classified the Alexandria city into zones regarding its likelihood risk of urban flooding to three grades, as high, moderate, and low. The purpose of this classification is to help decision-makers in preparedness for flood mitigation.

Keywords Flood Management, GIS, Remote Sensing, Rainfall

1. Introduction

Nowadays, the climate change is considered as a critical factor on the development of urban areas. The combination of the natural and human activities in the urban areas has high chance to increasethe concentration of the greenhouse gases [1]. Great uncertainty raised about the adaptation of the urban flood risk upon increasing of population and urban developing activities, so the development of new structure and unstructured measures, might enable the management of flood risk [2]. The increase of flood phenomena due to intensity and extreme of rainfall event and other hazard have been evident on climate change impact on urban area [3].

On October 25 and November 4 of 2015, Alexandria City and the neighboring region of Egypt experienced an unexpected severe rainfall event causing severe flooding. This extreme event flood has been described as "the worst flooding of Alexandria City over the past decades" [2]. As floods are considered the most common natural disasters worldwide, so the identification of the flood risks factor has been a crucial issue to mitigate its damage [4]. Such risks cannot be properly managed using only structure methods as the work of downstream on the promenade and the installation of high-capacity pumps, since these actions are short-term and limited impact, as they lack integrated dynamic modeling and flexible scenarios associated with variables on the ground to develop the best sustainable solutions.

Managing and assessing urban flooding is important for authorized government institutions, moreover, the main goal of the urban flood risk map is classifying the area regarding to its potential flood risk degree, and determine the area where it is required storm water project [5]. Flood risk map is a tool for assessment of flood vulnerability to understand a level of susceptibility to being harmed. GIS system is an effective environment used to analyze and determine the risk of flood prone areas. Moreover, the GIS approach allows analyzing of the multidimensional natural hazard such as floods [6]. An assessment of flood risk is necessary for understanding the area that can be affected by the disaster, as well as putting the appropriate plan for managing the flood event [7]. Otherwise, the analytical hierarchical process (AHP) is a qualitative approach for assessing the decision-making issue, [5] and the remote sensing techniques are applied for measuring and monitoring the aerial extent of flooded areas. It helps efficiently to save effort and provide quantifiable estimates of the amount of level and infrastructure affected. Geographic information system (GIS) considered as the main tools for developing flood risk assessment, using GIS system for visualization, simulation and analyzing the potential flood [8]. Integration between the remote sensing techniques and GIS system gets a quick estimated and calculation result for identification the most affected area, to improve the efficiently of flood disaster monitoring risk assessment [9].

Rainfall intensity is the most important parameter in determine determining flood hazard, the higher rainfall amount usually increases the chance of flood prone [6]. Rainfall indication has the highest likelihood as trigging factor [10]. Moreover, in GIS system, there are various methods that can be used to estimate the average rainfall over an area from point measurements, some of the commonly used methods are: average depth method, Thiessen method, Isohyetal method, Kriging, reciprocal distance method and Inverse Distance Weight (IDW) [11]. For forecasting rainfall, the Egyptian Meteorological Authority (EMA) uses many numerical Models: ETA, MM5, WRF & COSMO Models, creating daily report about weather conditions and forecast up to four days, another institution is the Nile Flood Forecasting Center at planning sector, water resources and irrigation using WRF Mode there are also different open-source data, as Global satellite mapping of precipitation.

The objectives of the present study are; (1) to clarify the occurrence and processes of flooding; (2) to collect all required data to be used in developing the model; (3) Analysis and discussion of the significant risk factors affecting the flood mitigation and resilience; (4) Set-up flood susceptibility mapping including; potential risk flood area as start of early warning system (5) Stating the conclusions showing the importance of using the integration of GIS system and remote sensing techniques with AHP method for identifying the urban flood risk. Consequently, the findings of this study are intended to support decision-makers, for selecting an appropriate solution and a mitigation action plan for each zone regarding its rate of risk.

Study area

Alexandria is the second capital of Egypt. The area of Alexandria is about 2,818 km^2 consisting of 19 districts and 128 neighborhoods, which is located between 31° 12' 56.30" N latitude and 29° 57' 18.97" E longitude, extending about 63 km along the coast of the Mediterranean sea, population of Alexandria Governorate is 5,160,793 with density of 1,900/km^2. Its low level on the Nile delta makes it highly vulnerable to rising sea levels. Figure 1 shows the study area location.

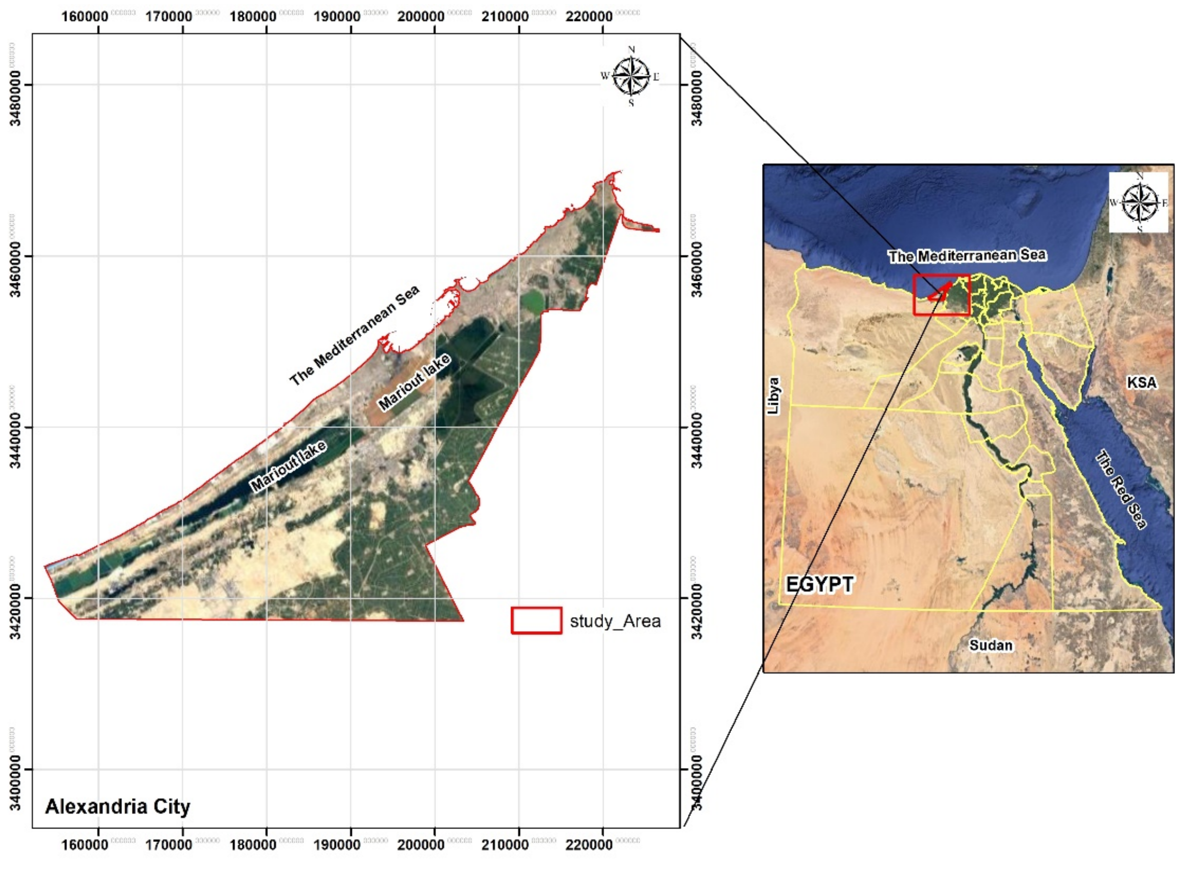
Alexandria is Egypt's largest seaport, serving approximately 80% of Egypt's imports and exports. The climate of the city of Alexandria is the Mediterranean climate, which is characterized by warmth and, dry in summer and mild, rainy in winter, where precipitation is concentrated from October to February yearly, with an average annual amount of precipitation approximately about 196 mm per year. Rainfall is disposed of through sewage systems, which is a combined drainage system. Based on the previous rainfall events, the inability of the sewage networks to absorb the amount of rain, which results in the accumulation of rainwater mixed with sewage in the streets [12].

Alexandria is characterized by the absence of a separate network for the collection of rainwater, where the rainwater is collected from the roofs and streets through catch basins, which in turn give the collected rainwater to the sewage network, and to the pumping and treatment stations. Rainwater increases the load on pumping and treatment stations. Alexandria governorate has a seasonal pump station that works only in case of increasing the loads and discharges on the pumping stations. It can distinguish the type of the urban flood, the subject of this case study, which it is pluvial flood, because it happens due to heavy rainfall directly on the urban area such that the runoff exceeds the capacity of the drainage systems.

2. Materials and Methods

In this study, the integration of the Analytic hierarchy process (AHP), remote sensing techniques and geographic information system were applied to develop a flood susceptibility mapping to assist decision makers to prepare priority plans, the study methodology accomplished in this research is illustrated in the following chart as shown in Figure 2.

Firstly, identifying and selecting the main factors affecting urban flooding in the study area, by studying literature review on the urban flood hazard assessment, and analyzing the results for five case studies in this regards, whereas they are in the Bangkok in Thailand [6], Dammam in Saudi Arabia [10], Bhubaneswar in India [7], Greece in Athens [5] and Bitlis in Turkey [13]. Table 1 shows the main factor for each case study and its weight, as the result of the analysis, five main and common factors used in the urban flood risk assessment are the rainfall amount, the elevation, the slope, distance from the stream, and land use- land cover (LULC).



(source: the researchers)

Figure 1. Alexandria city Location

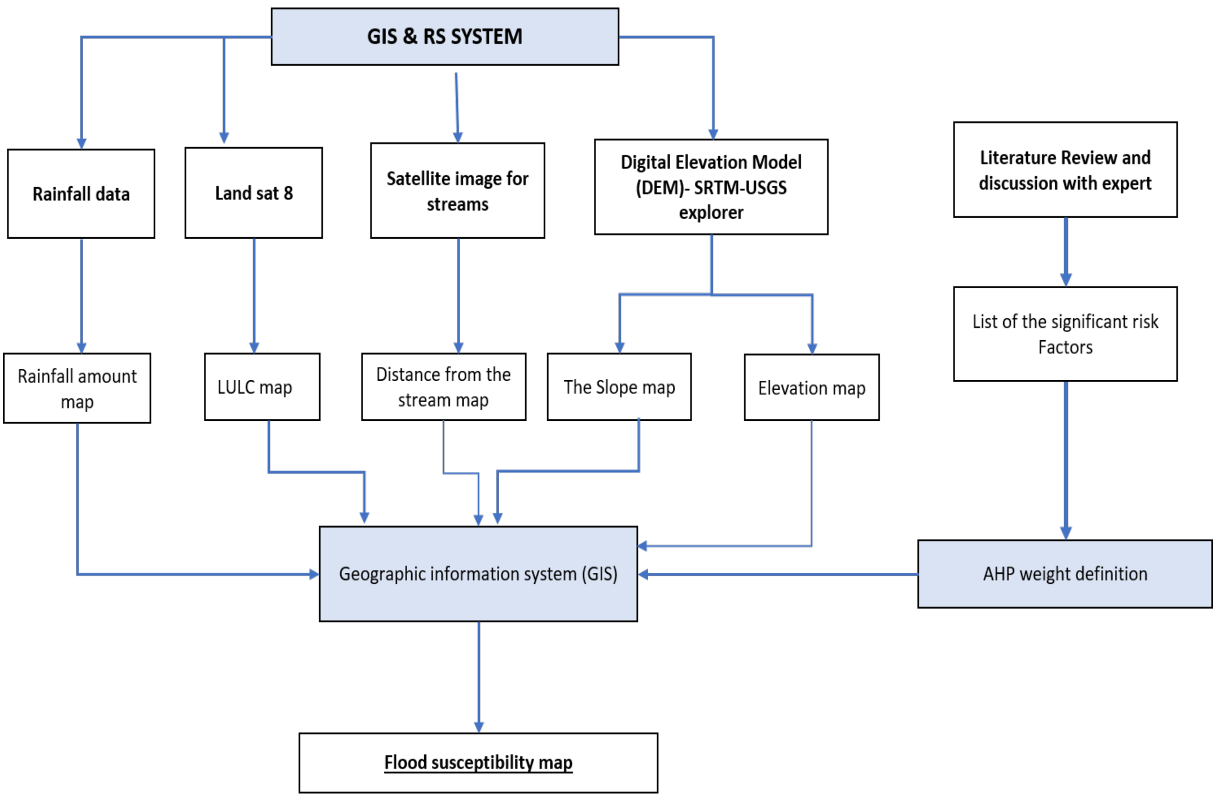


Figure 2. Study methodology flowchart (source: the researchers)

Table 1. The factors and weights for the case studies from literature

Case study	Factors/weights
Bangkok in Thailand	Rainfall amount (0.4), River density (0.25), slope (0.15), Elevation (0.1), soil permeability (0.06), Land use (0.04)
Dammam in Saud Arabia	Rainfall amount (0.32), Land use (0.19), slope (0.18), Elevation (0.168), soil type (0.06)
Bhubaneswar in India	Flow accumulation (0.4), distance from channel (0.25), slope (0.15), Elevation (0.1), soil permeability (0.06), Land use (0.04)
Greece in Athens	Slope (0.21), Elevation (0.06), distance from open channel (0.22), distance from covered channel (0.26), Hydro-lithology (0.1), Land cover (0.283),
Bitlis in Turkey	Rainfall amount (0.23), distance to stream (0.34), slope (0.13), Land use (0.11), soil (0.06), Geological structure (0.06), Elevation(0.03), Aspect(0.03), population(0.02)

Secondly, for weight calculation of each factor, the analytic hierarchy process (AHP) techniques, multi criteria analysis using excel sheet template [14] has been applied with five factors to get the final weight for each factor.

The AHP process was implemented by the pair-wise comparison matrix for calculating the final weight for each factor. The input data is developed by comparing the importance of each factor with others, reference to the literature review case studies and conducting technical discussion with water experts from Alexandria sanitation company, faculty of engineering at Alexandria university, and local governorate.

The importance between one factor and another is estimated regarding to a numerical scale from 1 to 9. The weights of each factor calculated after they are compared regarding to their importance, the correlation between numbers and significance is as the following: 1 = the same influence, 3 = moderate importance, 7 = Strong importance, 9 = of great importance [15].

Equations of the AHP process which are used:

Normalization of all factor weights through the following "(1),":

$$\sum_{i=1}^{n} W = 1 \quad (1)$$

Estimation of the consistency ratio (CR) to check consistency of eigenvector matrix after calculating the weight values, as the following "(2)," this ratio is used to avoid creating any ancillary judgments in the matrix, and when CR< 0.1 an acceptable level of consistency has been achieved,

$$CR = \frac{CI}{RI} \quad (2)$$

Whereas,

RI: is the random Index created by Saaty (1977) that is consistent according to the order of the matrix and CI: the index of consistency estimated by: "(3),":

$$CR = \frac{\lambda\, max - n}{n-1} \quad (3)$$

whereas,

λ max: is the highest value in the eigenvalue matrix, and,

n: is the arrangement of the matrix.

In this research, the CR value is less than 0.1, to get corresponding matrices with an acceptable grade of consistency. The factor for the urban flood assessment was estimated using the weighted linear combining process, based on the following mathematical formula (4),

$$\mathrm{H} = \sum_{i=1}^{n} WiXi \quad (4)$$

where H is hazard degree, n is the number of the factors, Wi is the weight of the factor i and Xi is the rating of the factor i. The influence of uncertainty of the adopted factor weights on the flood hazard assessment was examined.

Thirdly, developing of different raster layers for each factor in the GIS environment, the rainfall amount map, the elevation map, the slope map, the distance from stream map, the Land use –Land cover map, all maps need to be in the same projections system and the same spatial resolution. In order to combine the data set, they must be on a common scale, so each layer is reclassified and organized in GIS system into five grade from 0 to 4, which 1 indicates the least prone to flood hazard and 4 indicates that the area has a high potential to flood hazard

Finally, all classified factor maps and their weights will be inserted in GIS system using spatial analysis overlay weighted tools, next the susceptibility map is developed, classified the Alexandria city to three level regarding its potential urban flood risk degree as high, moderate, low. In addition, the classification of areas in terms of level of risk is the main step in assessing flood risks and identifying appropriate mitigation measures to minimize its negative impacts.

The data used in this study can be differentiated as static and dynamic data, characteristics and dimensions of the land use, slope, distance to stream and elevation maps are considered as static data, as they are not changing during simulations. Moreover, the rainfall amount data characteristics can change over time; then the models should therefore be updated regularly in the future. On the other hand, the forecasted or measured rainfall, discharges and water levels were considered as a dynamic data.

2.1. Rainfall Amount Map

Table 1 shows that the rainfall amount is the most important parameter in determining flood hazard. The higher rainfall amount usually increases a chance of flood prone area where other parameters may be related, the spatial distribution of rainfall and its intensity are known to have a substantial influence upon the modeling of flooding events. A large part of the rainfall-runoff modeling errors can be explained by uncertainties on rainfall estimates. The shape, timing and peak of rainfall event are significantly influenced by spatial and temporal variability across the catchment.

These values are obtained based on the annual mean precipitation of the study area, downloaded the annual amount of rainfall data from the climatic research unit – university of East Anglia, inserted the data, produced the rainfall amount layer in GIS environment using IDW surface tools. Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a location dependent variable, the reclassified rainfall amount map is developed showing that the higher annual amount of rainfall reaches 157 mm/year, and the lower is 72.2 mm/year. Figure 3 shows the reclassified rainfall amount map.

2.2. The Elevation Map

The elevation is considered as the main factor for flood risk assessment, in which the lower elevation has more chance of flood, the elevation map for Alexandria city was created using the available data of the DEM (Digital Elevation Model) from the shuttle radar topography mission (SRTM) from USGS explorer using ArcMap GIS software 10.8, and the elevation was reclassified to five grades from 127 m to lower than 12 m. Figure 4 shows the spatial distribution of the Elevation in Alexandria city, and it shows that most of Alexandria has elevation lower than 12 m.

2.3. The Slope Map

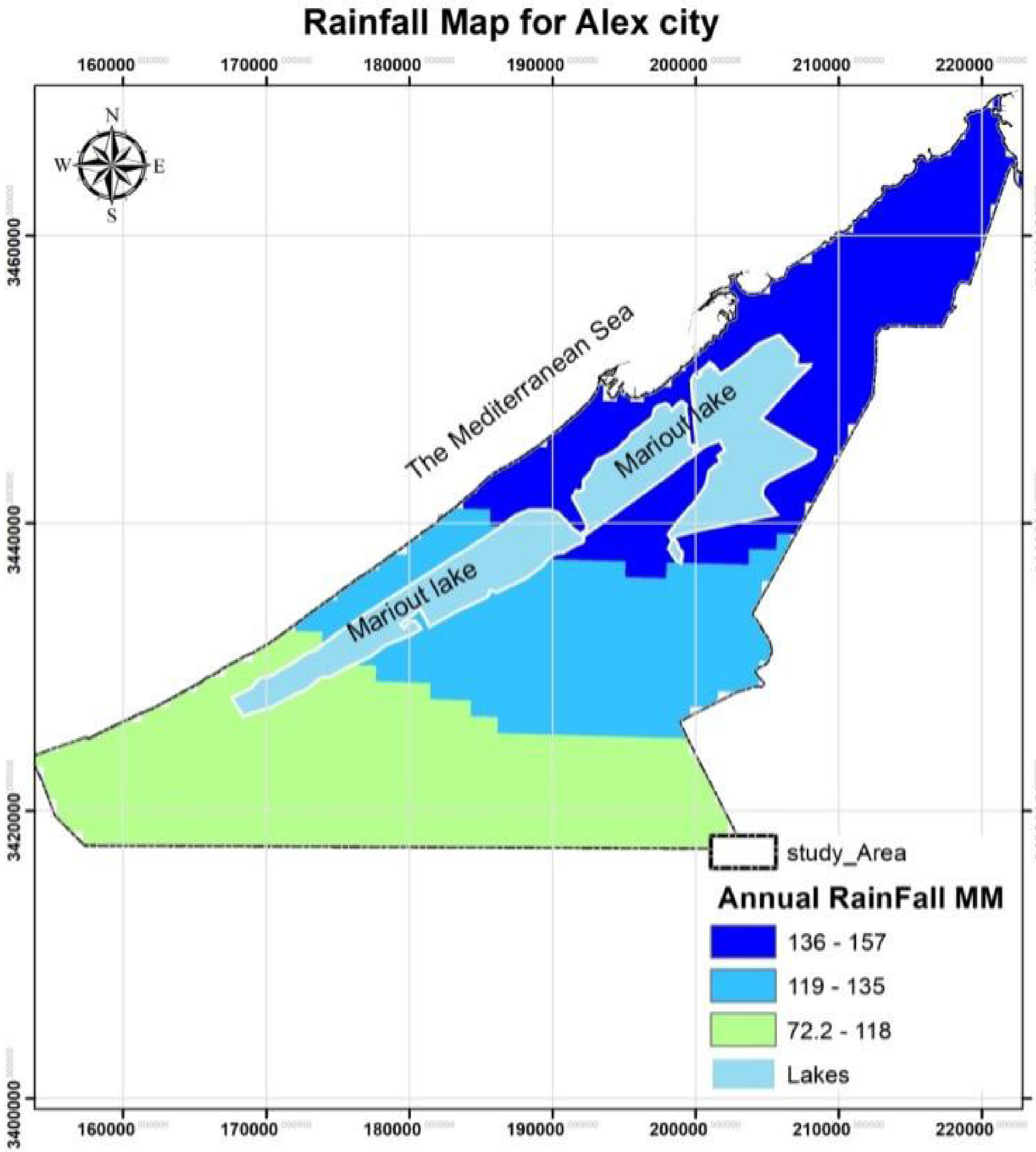
The slope layer was developed from the DEM (digital elevation model) through the shuttle radar topography mission (SRTM) from USGS explorer applied spatial analyst tools in Arc Map GIS software 10.8. Figure 5 shows the spatial distribution of the slope in Alexandria.

2.4. The Distance from the Stream Map

The distance from the stream map was created by digitizing satellite image and drawing the stream on the shapefile layer then using spatial analyst – Euclidean tool in ArcMap GIS software 10.8., in which the Euclidean tool estimates the distance from each cell in the stream raster to the closed source, moreover from the literature review, it is stated that the zones where are closed to the stream bed has the highest flood riskas shown in Figure 6.

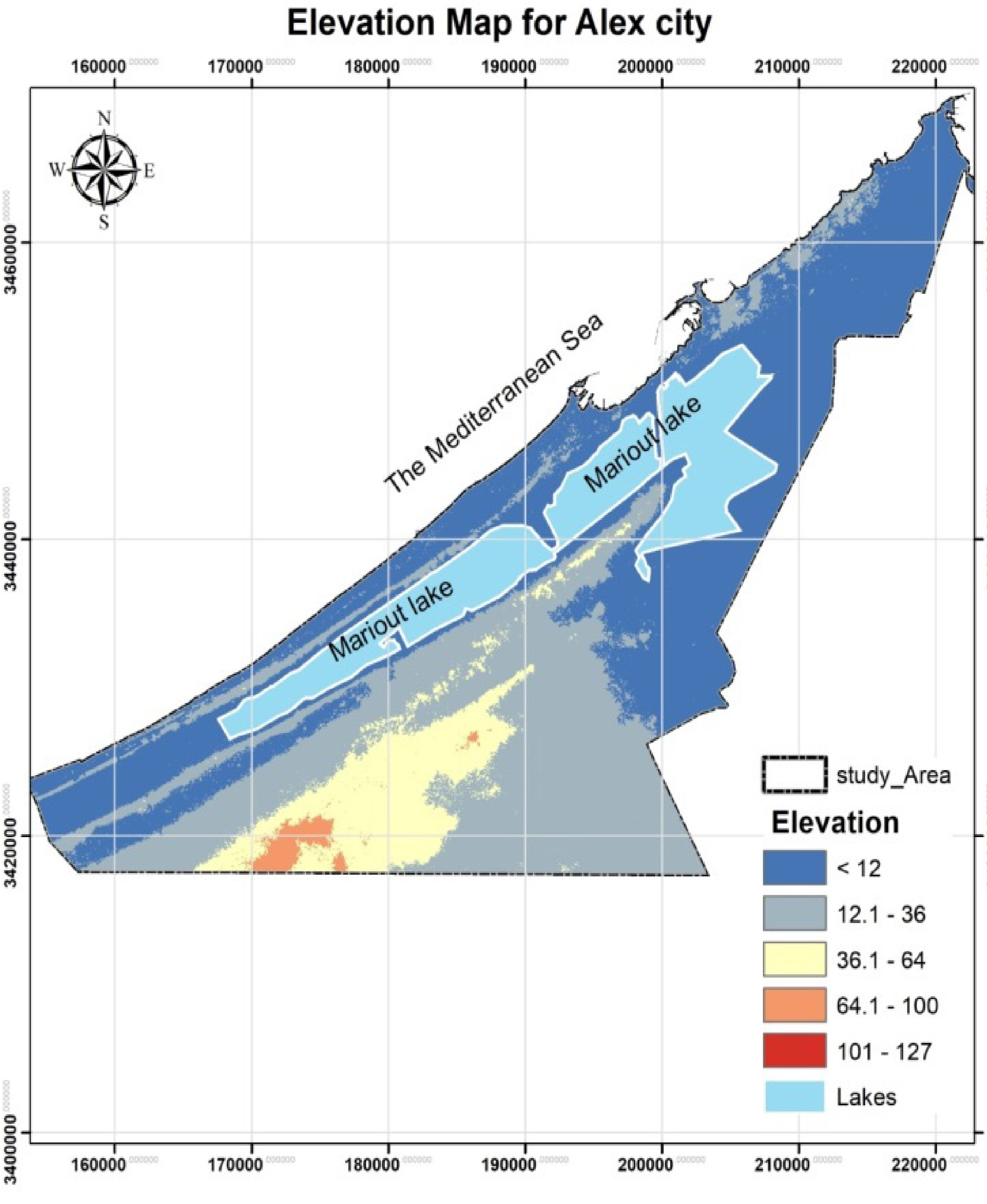
2.5. Land Use, Land Cover (LULC) Map

The average population in Alexandria city annually grows about 2-3%. As a result, Alexandria's urban area has increased by approximately 40% over the last 15 years. This caused an increasing of paved street and decreasing of the green or open areas [16]. LULC map was developed from Landsat-8, USGS-earth explorer, and the reclassification process was made by Arc map 10.8 system, accordingly the study area is classified as four categories, (Urban, Lake, Desert, and Agriculture area) as shown in Figure 7.



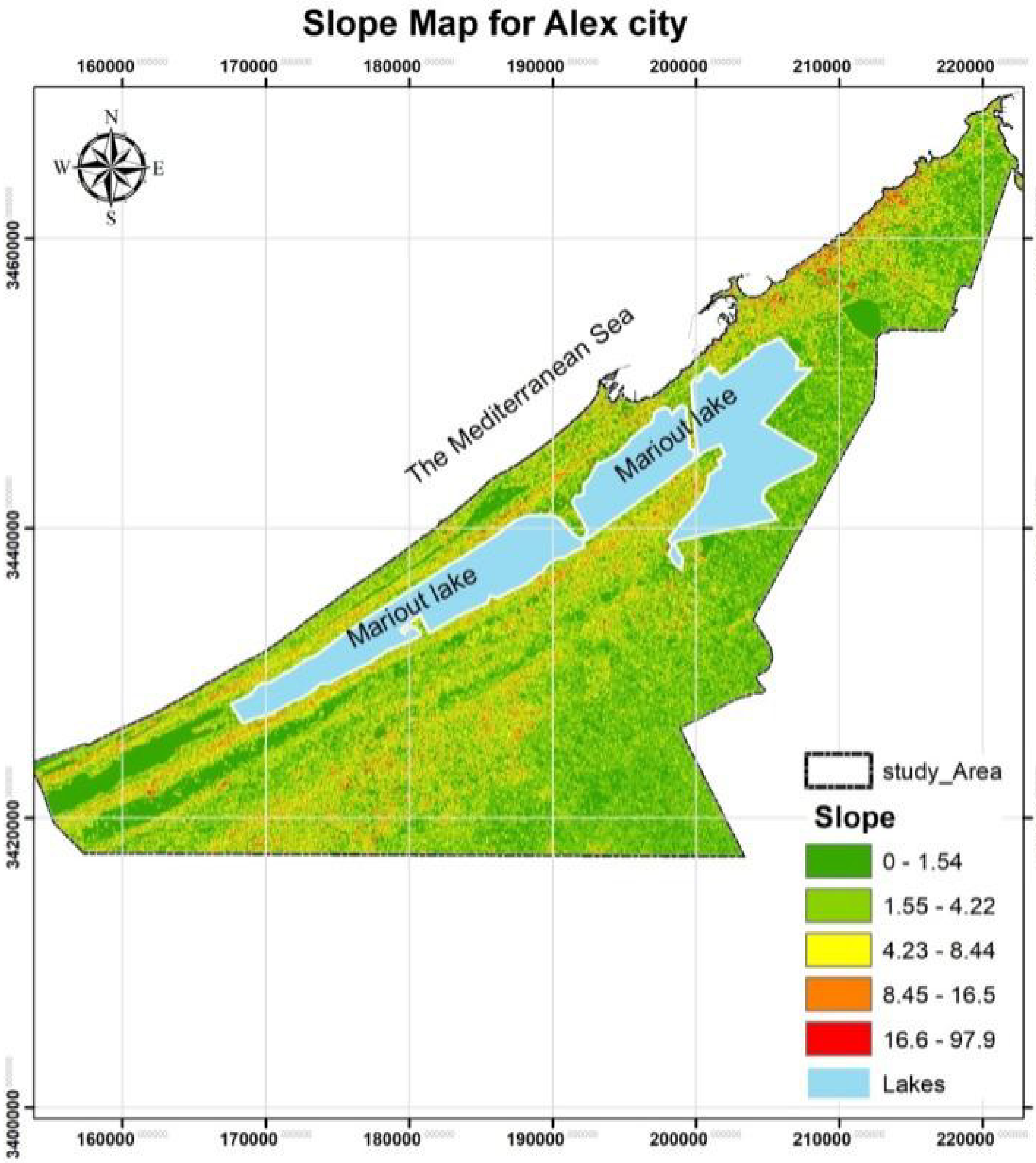
(Source: The Researchers)

Figure 3. The reclassified rainfall amount map of Alexandria city



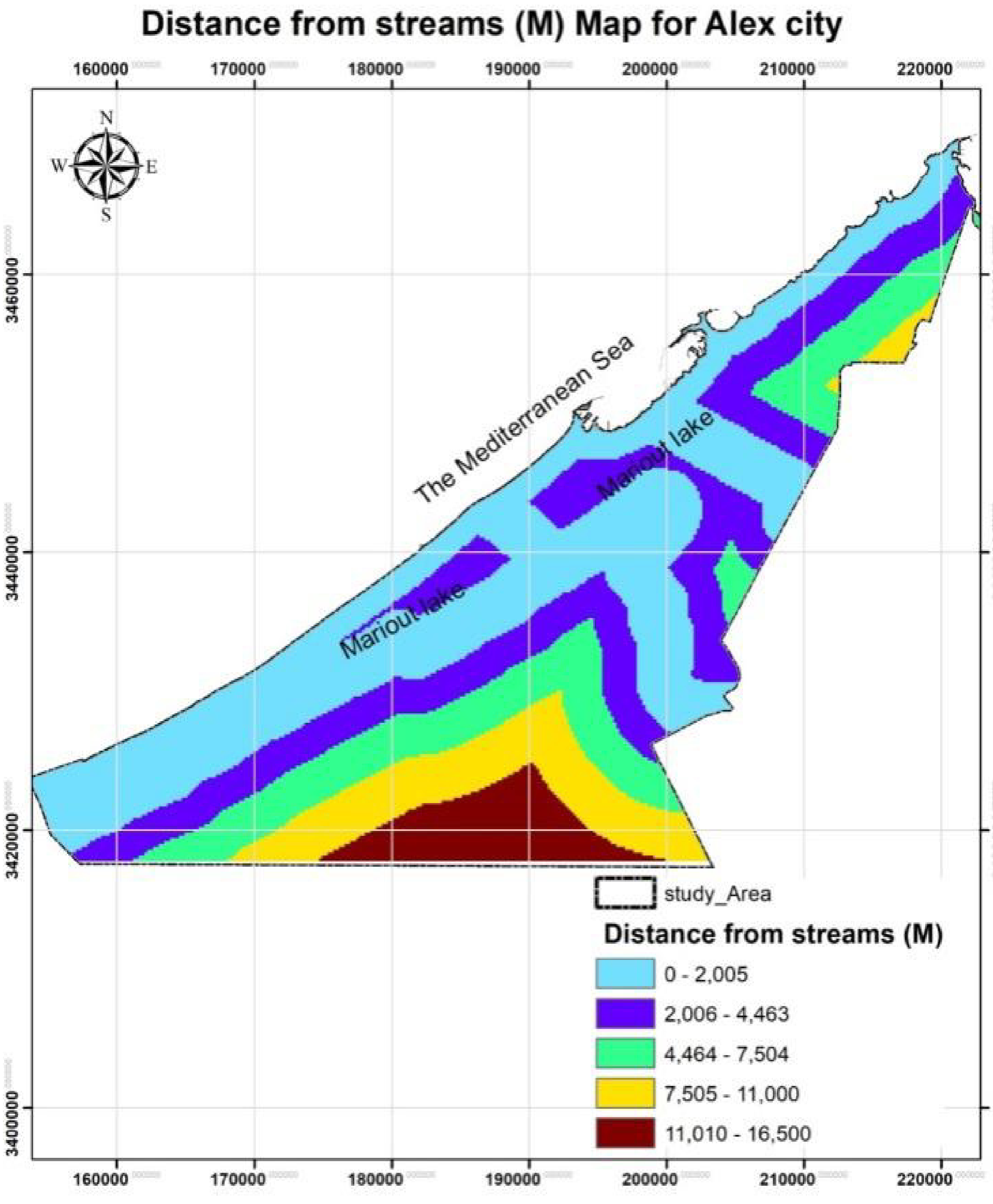
(Source: The Researchers)

Figure 4. Map of reclassified Elevation of Alexandria city



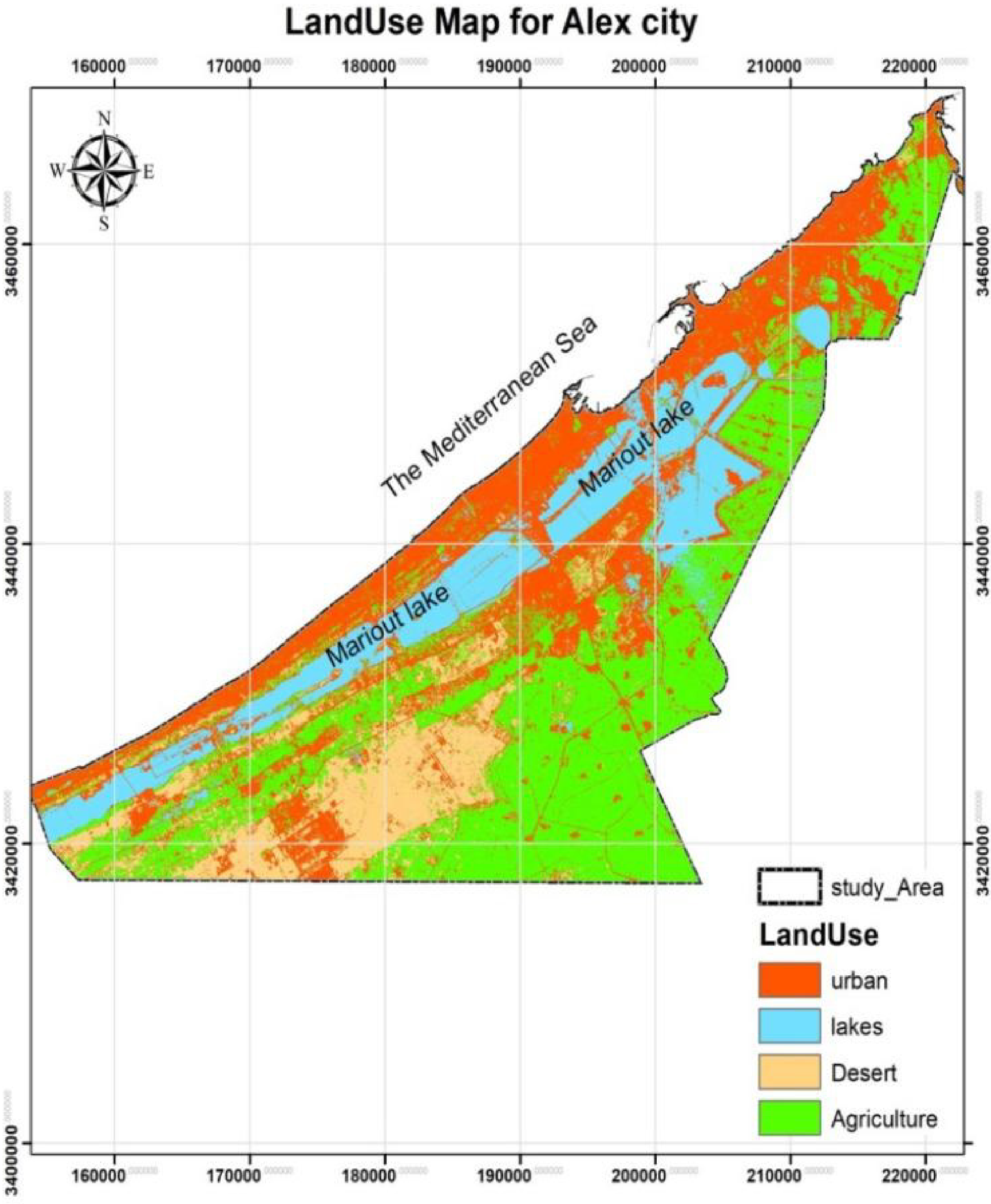
(Source: The Researchers)

Figure 5. Map of reclassified slopes of Alexandria city



(Source: The Researchers).

Figure 6. The reclassified distance from streams map of Alexandria city



(Source: The Researchers).

Figure 7. The reclassified Land use map of Alexandria city

3. Results and Discussion

A management system is required to develop an appropriate mitigation resilience plan to manage the risk of urban flooding, due to extreme rainfall and runoff that exceeds the capacity of the drainage system (storm flooding), and to inform responsible authorities of the time and spatial extent of the flood before, during and after it occurs. For Alexandria city, the Egyptian Meteorological Authority using its monitoring devices and data analysis programs, and the Forecasting Center of the Egyptian Ministry of Water Resources and Irrigation, have the responsibility to inform the implementing authorities on the time scale further ahead the undetermined spatial scale until the occurrence of the event, and here, the responsibility goes to the water and sanitation companies for dewatering the exceed water quantities from the street by traditional methods, using wastewater trucks, and water-raising pumps, losses and consuming time, effort, and money.

From the literature review, it is clear that the GIS application is considered as a crucial tool in the analysis of the flood event. In addition to specific data available, open source data have been provided as remote sensing techniques. For this purpose, applying these techniques in the city of Alexandria flood management effectively assists the responsible authorities in making an appropriate decisions. Prioritization of the risk zone is considered the main step in urban flood management.

Consequently, the purpose of the study is to develops a map of the flood risks in Alexandria to classify zones according to the degree of risk resulting from exposure to extreme rain, using the geographic information systems program (GIS) and remote sensing data integrated with analytical hierarchical process (AHP) to develop a shared vision planning and collaborative modelling. To manage the urban flood event before, during and after the event, it is needed to determine the hazard degree for each area, as well as develop the suitable and economic mitigation plan for this area according to its flood hazard degree. In this study, the main important factors affecting the urban flood in Alexandria will be identified, by analyzing different case studies concerning the urban flood plan, the AHP methodology is used to assess and estimate the weight of these major factors, along with the required data and maps obtained from remote sensing techniques, and the analysis of data were performed in the GIS tools.

The main selected five factors are the rainfall amount, distance to stream, slope, LULC, and the elevation selected as the most common influence factors that have affected on the urban flood. Pair wise matrix was used for comparing the weight of each factor reference to literature review cases study. Also, the discussion conducted with the expert is responsible for implementing, after the AHP method applied to obtain the weight of each factor, as it shows in the matrix Table 2 below.

Table 2. Weighting coefficients for each factor

Factors	**F1**	**F2**	**F3**	**F4**	**F5**	**Weights%**
F1	1.00	3.81	3.08	1.32	3.35	38
F2	0.26	1.00	0.72	0.47	1.05	10.8
F3	0.32	1.39	1.00	0.36	1.57	13.4
F4	0.76	2.14	2.78	1.00	1.57	26.3
F5	0.30	0.96	0.64	0.64	1.00	11.5

F1 = Rainfall amount, F2 = elevation, F3 = Slope, F4 = distance from streams, and F5 = land use/land cover

The selected five factors have been weighted as rainfall amount 38%, distance to stream 26.3%, slope 13.4%, LULC 11.5% and elevation 10.8, the consistency ratio for the matrix is 0.019, in which acceptable limit is less than or equal to 0.10 as a rule in the AHP process. Then reclassify each factor to five grades from 0 to 4 as shown in Table 3.

The rainfall amount is the first factor affecting risk of flooding which is a logical consequence as it is the main factor of flood, and the high amount of rainfall water reaches to the 157 mm/year caues drives high flood risk, however the low amount of rainfall water that it is lower than 72 mm /year causes low flood risk, and refer to the rainfall classified map. Figure 3 shows that the high amount of water concentered on the area near to stream as the Mediterranean sea and the Maroiut lake.

The second factor is the distance to stream, from the literature review [5],[7],[13] illustrating that the area that is near to the stream has experienced the high risk flooding rather than the area far from the stream, which seems thatit is logical approach, and regarding to the reclassified distance from streams map of Alexandria. Figure 6 shows that the areas ≤2006 m distance from the stream have a high flood risk potential, on the other hand the areas ≥ 4463 m distance far from the stream have the low flood risk potential.

The third factor is the slope. Figure 5 presents that most of the areas in the Alexandria have a slope ≤ 4.22 m, and the areas have a slope ≤ 1.54 m have a high flood risk potential, whereas the area with low slopes has more chances of flood risk potential than the areas with the high slopes [7].

The fourth factor is the land use-land cover (LULC), where this factor controls the infiltration rate of the rainfall amount from the surface area to the ground water, so the urban area is considered as the lower infiltration rate, so it has a high flood risk potential.

From Figure 7, the reclassified Land use map of Alexandria city shows that most of the urban areas in Alexandria are concentrated on waterbody plan, as the people prefer to live near to the water body such as the sea and lake, consquently it raised the flood risk potential.

Finally, the last ranked factor is the Elevation, where it affects the direction of flow and the flow depth., Since the water flows from high level to the lower level [18], so the areas with lower elevation have high flood risk potential [6]. Figure 4 shows that most of Alexandria has elevation <12m, and little area with the Elevation of >36 m.

The overlay weighted techniques were applied in GIS system, using all reclassified maps and its susceptibility class rating and weights as presented in Table 3. Accordingly the results have presented as the produced urban flood susceptibility map for Alexandria city, considering five main factors, and presented the city with three categories as high, moderate, and low urban flood risk potential as shown in Figure 8.

Table 3. Classes of the parameters and according to weights:

Flood Causative Criterion	Unit	Class	Susceptibility Class rating ranges and ratings	Susceptibility Class rating	Weight
Rainfall amount	mm/year	136-157	very high	4	38%
		119-135	high	3	
		108-118	moderate	2	
		92.9-107	low	1	
		<92.8	very low	0	
Elevation	m	< 12	very high	4	10.80%
		12.1–36	high	3	
		36.1–64	moderate	2	
		64.1–100	low	1	
		>100	very low	0	
Slope	%	<1.54	very high	4	13.40%
		1.55–4.22	high	3	
		4.23–8.44	moderate	2	
		8.45–16.5	low	1	
		> 16.6	very low	0	
Distance To streams	m	0-2005	very high	4	26.30%
		2006-4463	high	3	
		4464-7504	moderate	2	
		7505-11000	low	1	
		11000-16501	very low	0	
Land cover/ Land use (LCLU)	Type	Urban area	very high	4	11.50%
			high	3	
		Agriculture	moderate	2	
		desert	low	1	
		Lakes	very low	0	

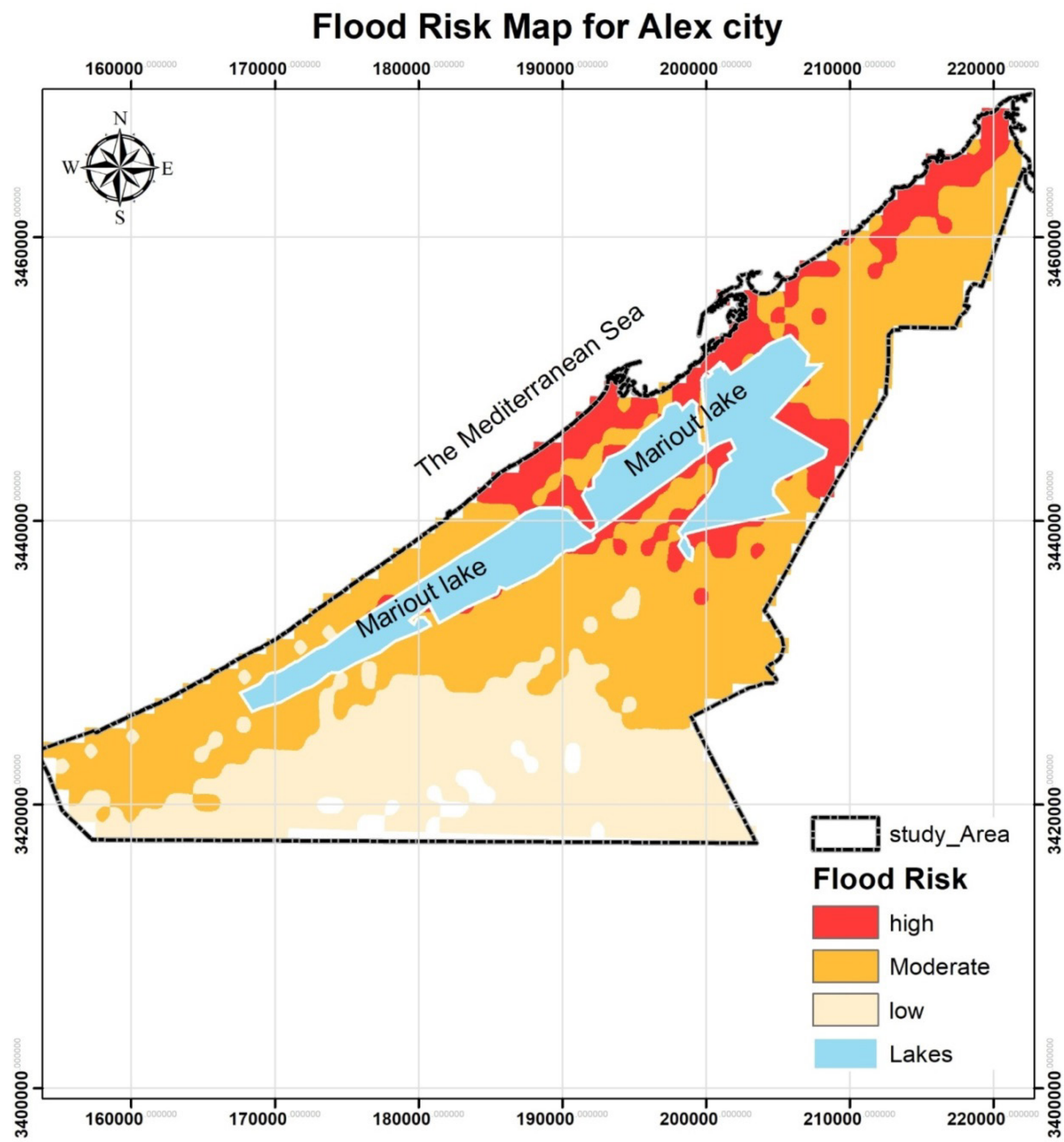


Figure 8. The urban flood Susceptibility map for Alexandria city (Source: The Researchers)

The produced susceptibility map for Alexandria presents the following results:

1. The high flood risk potential areas found on the urban and waterbodies plan locations with the annual rainfall amount > 136 mm/year, Elevation < 12 m, distance from stream < 2006 m, and slope< 1.55 %.
2. The moderate flood risk potential areas found on the agriculture area with the annual rainfall amount approximately from 119 to 135 mm/year, Elevation from 12 to 36 m, distance from stream from 2006 to 4463 m, and slope > 1.55 to 16.5 %.
3. The low flood risk potential areas found on the desert area with the annual rainfall amount approximately <119 mm/year, Elevation from > 36 m, distance from stream from > 4463 m, and slope > 16.5 %.

Comparing the results of the Urban Flood Susceptibility Map with the Alexandria Flood that occurred in 2015, it revealed that the sites presenting a high risk of flooding are El- montaza, El-Ramal, Bab Shariq, Mina Elbasel, Gomerk, Ameria neighborhood in the city of Alexandria, although these are the areas most affected by the 2015 floods. Therefore, the applications of GIS with remote sensing data integration with the AHP process are effectively integrated to anticipate and manage flooding, which it could apply with the responsible authorities with regard to the effective and economic management of flood phenomena.

4. Conclusions

A comprehensive study of floods in Alexandria and the provision of a dynamic simulation system (Dynamic Simulation Model) is carried out to determine the places and levels of floods and thus the optimal ways to deal with them with multiple possibilities and scenarios according to the different technical and environmental conditions of each case. The dynamic flood simulation system relies on state-of-the-art geographic information systems, remote sensing techniques and instantaneous satellite connectivity (GIS and Remote Sensing) as well as linking and integrating with all spatial data from Land cover-land use maps, lakes, drainage maps, elevation, slope map, to produce dynamic flood maps, "at-risk areas", best solutions for recovery and proposed scenarios in the short, medium and long terms, as well as strategies for dealing with cases regarding its risk degree.

The main purpose of the assessment and management of the flood is to identify risk areas, assess the severity of risk, investigate how to community perceives such risk, define what would be an appropriate mitigation measure that can minimize its negative impacts, produce a plan for implementation of mitigation measures, implement the measures accordingly and monitor their effectiveness. With instantiated models and specialist GIS flood mapping techniques it is possible to explore the generation of floods and evaluate effects of different measures in response to any extreme event.

In this research, the flood risk susceptibility map for Alexandria city was developed, applying the AHP process, GIS application and remote sensing techniques to anticipate, managing the high-risk floodplain area as priority plans and implementing appropriate and effective mitigation plans for that area. The city is classified into zones regarding to the flood risk, which would effectively help the responsible implemented authority for priorities its mitigation plans and preparedness activities economically and timely manner; as well as visualized data using GIS techniques is the first step to determine the all aspects regarding getting the most appropriate solution and mitigation action for each area, avoiding economic damage and losses live especially in poor areas, In addition, using the flood susceptibility map with the implemented authorities will improve their services, prepare its instruments and avoid any water prone area in the street and improve information and communication with regards to (potential) flooding.

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