A GEOSPATIAL SOLUTION USING A TOPSIS APPROACH FOR PRIORITIZING URBAN PROJECTS IN LIBYA

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ABSTRACT: The world population is growing rapidly; consequently, urbanization has been in an increasing trend in many developing cities around the globe. This rapid growth in population and urbanization have also led to infrastructural development such as transportation systems, sewer, power utilities and many others. One major problem with rapid urbanization in developing/third-world countries is that developments in mega cities are hindered by ineffective planning before construction projects are initiated and mostly developments are random. Libya faces similar problems associated with rapid urbanization. To resolve this, an automating process via effective decision making tools is needed for development in Libyan cities. This study develops a geospatial solution based on GIS and TOPSIS for automating the process of selecting a city or a group of cities for development in Libya. To achieve this goal, fifteen GIS factors were prepared from various data sources including Landsat, MODIS, and ASTER. These factors are categorized into six groups of topography, land use and infrastructure, vegetation, demography, climate, and air quality. The suitability map produced based on the proposed methodology showed that the northern part of the study area, especially the areas surrounding Benghazi city and northern parts of Al Marj and Al Jabal al Akhdar cities, are most suitable. Support Vector Machine (SVM) model accurately classified 1178 samples which is equal to 78.5% of the total samples. The results produced Kappa statistic of 0.67 and average success rate of 0.861. Validation results revealed that the average prediction rate is 0.719. Based on the closeness coefficient statistics, Benghazi, Al Jabal al Akhdar, Al Marj, Darnah, Al Hizam Al Akhdar, and Al Qubbah cities are ranked in that order of suitability. The outputs of this study provide solution to subjective decision making in prioritizing cities for development.

1. INTRODUCTION

Across the world, urbanization has been happening in a drastic way. According to a report, about 65 percent of the world's population will live in urban areas by the year 2025 (Schell and Ulijaszek, 1999). The rate of population growth in many countries has led to significant developments in urban transportation and many other infrastructures. Proper planning and management of development projects require advance geospatial solutions that can improve the benefits and sustainability of such projects. In developing countries such as Libya, budget for organized urban developments is insufficient. Selection of cities or areas to be developed is decided by single organization or individuals which is highly subjective and challenging to address sustainable development. Automating the process of selection of cities for development is therefore an important task. Areas that need development to modern urban society can be selected and prioritized by considering all the factors that affect future state of the development vis-à-vis the current development in the area.

Several multi-criteria decision-making systems such as Analytic Hierarchy Process (AHP) (Youssef et al., 2011), Fuzzy AHP (Kamas et al., 2017) and Fuzzy Overlay (FO) have been developed to evaluate alternatives and selecting ideal spatial solutions for various applications including urban projects. These tools are widely reported in literature for prioritizing a set of given factors and a specific goal. For example, priorities are established in AHP using pairwise comparisons and judgment (Saaty, 1990). Of recent, researchers have adopted ranking methods such as TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) (Coutinho-Rodrigues et al., 2011; Pourjavad et al., 2013), Fuzzy TOPSIS (Berger 2006; Ekmekçioglu et al., 2010; Awasthi et al., 2011a, b; Uysal and Tosun 2012; Baysal et al., 2015), and Grey programming (Lin and Li 2008) to rank a set of given alternatives.

Although FO and TOPSIS have been widely used for selecting and prioritizing various types of alternatives in many disciplines, very few studies have been done on selecting and prioritizing cities according to their need for developments. Applying such methods in countries such as Libya creates additional challenges because the process of projects initiation and implementation is neither well organized nor well-funded. Thus, developing automatic methods for selecting and prioritizing cities according to their importance for development will help reduce the subjectivity and improves sustainable urban developments for the well-being of the citizens. This study proposes a GIS-based decision-making support system using FO and TOPSIS to prioritize and select cities for development in Libya according to some criteria.

2. STUDY AREA AND DATA USED

This study focuses on Libya, a country in the Maghreb region of North Africa (Figure 1). Libya is bordered by the Mediterranean Sea to the north and Egypt to the east. Along the southeast is Sudan, Chad and Niger to the south, while Algeria and Tunisia constitute the western border. Libya is the17th largest nation in the world with a landmass of over 1,759,540 km^2. The study area in the north part of Libya covers six districts Darnah, Al Jabal al Akhdar, Benghazi, Al Marj, Al Qubbah, and Al Hizam Al Akhdar (Figure 1). Geographically bounded between 20^o 00’ 00’’ E and 23^o 30’ 00’’ E and 31^o 00’ 00’’ N and 33^o 00’ 00’’ N.

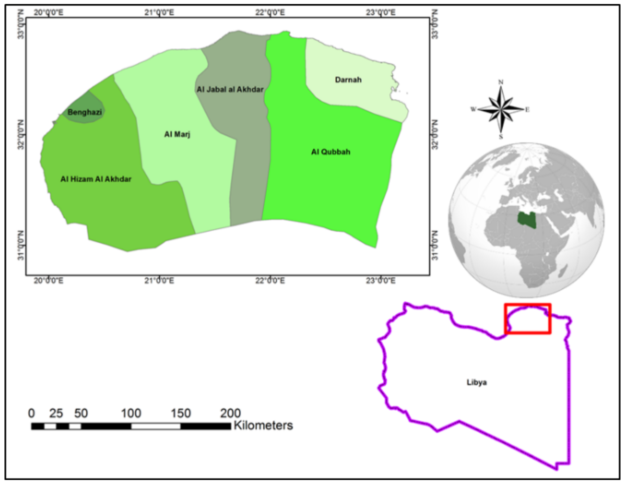

Figure 1. Study Area.

In this study, fifteen GIS factors were prepared from various space borne remote sensing data sources - Landsat, MODIS, and ASTER. The factors and their importance for developing cities for sustainable future were selected based on the literature review. These factors are categorized into six groups: topography, land use and infrastructure, vegetation, demography, climate, and air quality. The topography group includes terrain altitude (Figure 2a) and slope (Figure 2b). Population density (Figure 2c) was selected as a demography indicator and land use factors include land use pattern (Figure 2d), road networks (Figure 2e-h), percentage of built-up areas (Figure 2i), and distance to Benghazi city (Figure 2h). Land surface temperature (Figure 2j) and rainfall (Figure 2k) were selected as the climatic factors. In addition, net primary productivity (Figure 2l) and NDVI (Figure 2m) were selected as vegetation factors and two air quality factors, CO (Figure 2n) and NO_2 (Figure 2o) were included. The spatial resolution of these factors varied according to the source of the datasets. However, during the GIS analysis, they were resampled to 30 m to match the spatial resolution of the DEM and Landsat image. The criteria, data source and reasons for selection of each factors are summarised in Table 1.

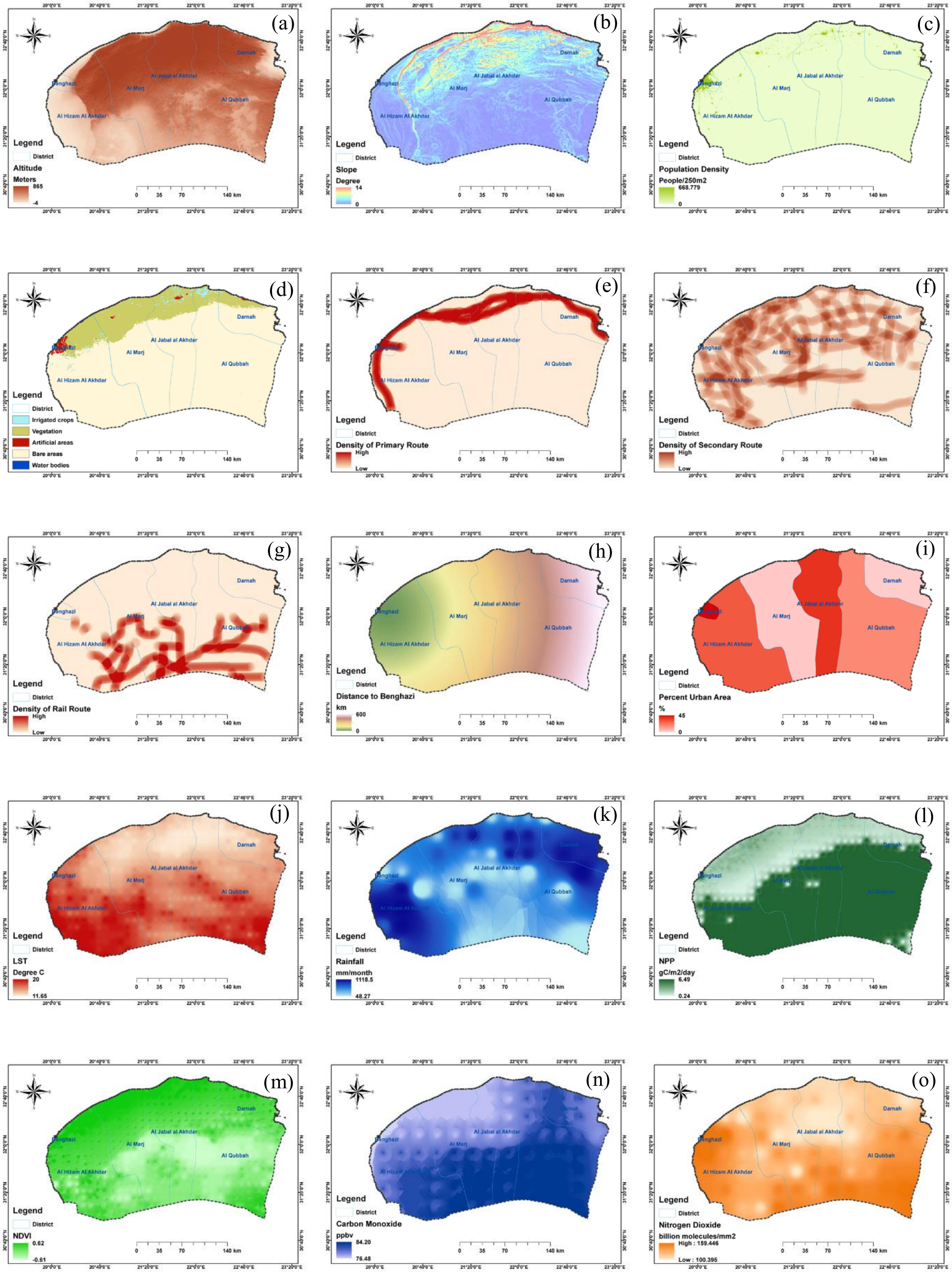

Figure 2. Criteria Maps: a) Altitude, b) Slope, c) Population Density, d) Land use, e) Density of Primary Routs, f) Density of Secondary Route, g) Density of Rail Route, h) Distance to Benghazi, i) Percent Urban Area, j) LST, k) Rainfall, l) NPP, m) NDVI, n) Carbon Monoxide, o) Nitrogen Dioxide.

Table 1. The evaluation criteria used in this study and their descriptions.

Criteria	Sub-Criteria	Data Sources	Reasons for Selection	Original Resolution/ Feature Type
Topography	Altitude	DEM	The air in high altitude cities is thinner, with lower oxygen content, and dryer than it is at lower elevations	30 m (raster)
	Slope	DEM	Slope affects the ease of construction and maintenance	30 m (raster)
Demography	Population Density	GHSL	Rapid population growth will have a dramatic effect on the increased demand for jobs, housing, energy, clean water, transportation infrastructure, and social services.	250m (raster)
Land use	Land use	Derived from Landsat 8 OLI Images	Land use is a criterion representing the environmental impacts of the economic and human development	15 m (raster)
	Road Density	Diva GIS	Allowing for better access for construction and maintenance	polyline
	Percent Built-up Areas	Landsat 8 OLI	Open spaces are easy to develop compared to compact cities	15 m (raster)
	Distance to Large City	Google Maps	Viable commuting distances of capital cities offer attractive	point feature
Climate	Maximum Surface Temperature	Landsat 8 OLI	Temperature influences weather and climate patterns controls the life of food crops	80 m (raster)
	Average Annual Rainfall	MODIS	Rainfall is essential for life on Earth. Rain is the main source of fresh water for plants and animals	0.25 degrees (raster)
Vegetation	Net Primary Productivity (NPP)	MODIS	Because carbon dioxide gas helps warm our world	0.1 degrees (raster)
	Vegetation Index (NDVI)	Landsat 8 OLI	Our lives depend upon plants and trees	15 m (raster)
Air Quality	Carbon Monoxide (CO)	MODIS	Causing global warming and is one of the air pollutants that leads to smog	0.25 degrees (raster)
	Nitrogen Dioxide (NO_2)	MODIS	Plays an important role in the formation of ozone in the air we breathe.	0.25 degrees (raster)

3. METHODOLOGY

This study proposes a GIS-based decision-making support system using Fuzzy Overlay (FO) and TOPSIS to select and prioritize cities in Libya (Figure 3). First, fifteen criteria factors namely; land use, percent build up, NDVI, altitude, slope, road density, distance to the large city, population density, rainfall, surface temperature, net primary productivity, carbon monoxide, nitrogen dioxide were extracted from different datasets. Then, an AHP analysis using fuzzy Overlay (FO) was carried out to determine the degree of importance of each parameter for sustainable city development. Finally, the cities are sorted by their importance using the results of AHP and by applying the TOPSIS model as a ranking method.

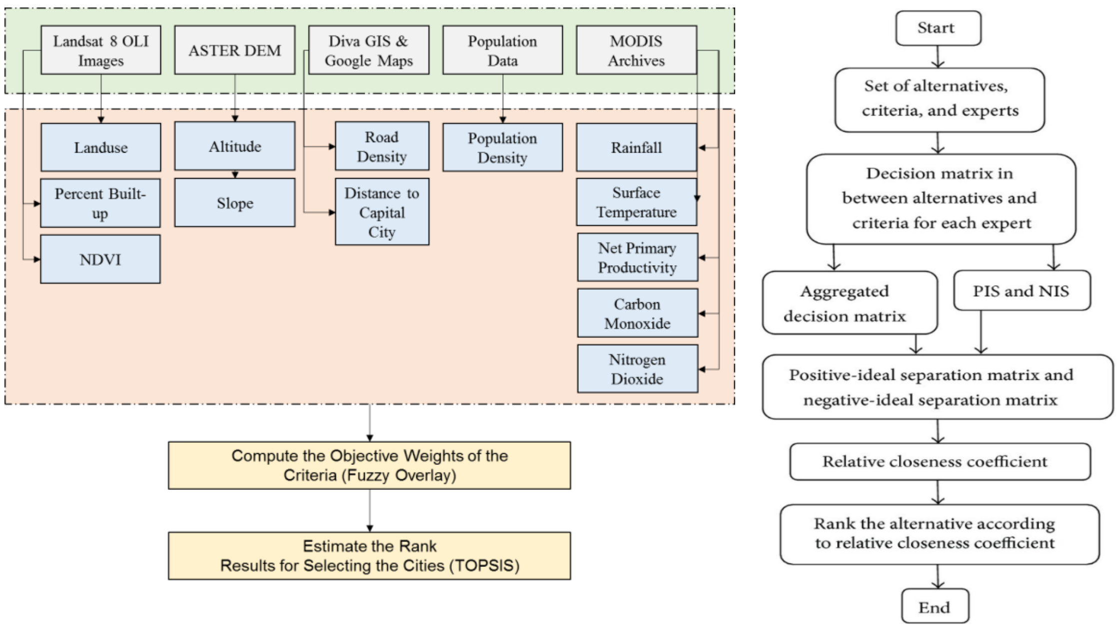

Figure 3. a) Overall proposed methodology in this study; and b) Flowchart of TOPSIS procedure.

3.1 Fuzzy Overlay versus TOPSIS Method

Fuzzy Overlay (FO) analysis is based on set theory which relies on membership relationship of events to define specific sets or class (Baidya et al., 2014). Operationally, FO is similar to overlay analysis but differs in the reclassified values and results from the combined multiple criteria. It involves problem definition, partitioning into sub-models and determining significant layers. FO transforms the data values to a common scale and defines the likelihood of it belonging to a specified class; for example, slope values being transformed into the probability of fitting into the favourable suitability set based on a scale of 0 to 1 expressed in terms of membership (Baidya et al., 2014). Input raster are not weighted in FO method since the transformed values indicate the possibility of membership rather than using ratio scale as applicable in weighted overlay and weighted sum.

Developed in 1981 (Hwang and Yoon 1981) and subsequently refined for effectiveness (Yoon, 1987; Hwang et al in 1993), TOPSIS is a multi-criteria decision tool (Figure 3b) which relies on the idea that a selected alternative has the shortest possible geometric distance from the positive ideal solution (PIS); that is, the alternative has the longest geometric distance from the negative ideal solution (NIS) (Kore et al., 2017). The analysis compares a set of alternatives by assigning weightage to each criterion to compute the geometric distance between possible alternatives to determine the ideal alternative based on the assumption that the criteria uniformly increases or decreases. TOPSIS allows trade-offs between criteria; a poor result in one criterion can be compensated for by a good result in another criterion. TOPSIS provides a more realistic model than non-compensatory methods by including or excluding alternative solutions using hard cut-offs.

4. RESULTS AND DISCUSSION

A suitability map was produced using FO method (Figure 4a). In this map, the study area was divided into a continuous scale ranging from 0 (less suitable) to 1 (highly suitable). It can be seen that most areas indicated to be suitable are situated in the northern part of the study area, specifically areas surrounding Benghazi city and northern parts of Al-Marj and Al-Jabal Al-Akhdar cities. To refine the suitability map in the previous step, several samples were selected from unsuitable and highly suitable areas to generate training and testing data for machine learning algorithms. Then, support vector machine method (SVM) as a machine learning approach was applied to develop a linear regression that links the suitability of a city for development and the selected factors. This method is very critical because first, it can refine the suitability map and make it more effective to understand. In addition, it quantifies the importance of the selected factors. Based on the estimated coefficients (Table 2), suitability map was reproduced (Figure 4b). It can be seen that the map reflects the same thing as in the previous suitability map; however, it has become much more effective and clear for decision makers to take actions. The map was further used to rank the cities according to their importance for the selection process using the TOPSIS method.

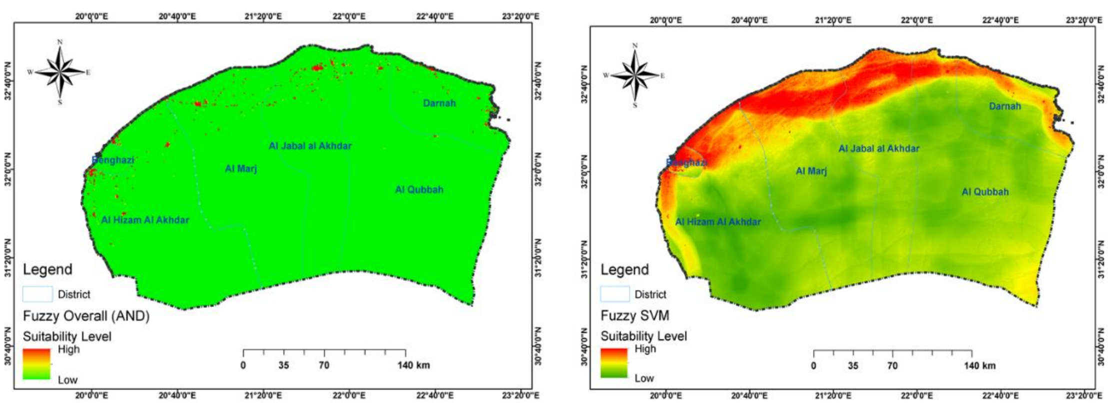

Figure 4. a) Results of FO, b) FO after Refinement with SVM.

Table 2. Estimated coefficients of the factors by the SVM method.

Evaluation Criteria	SVM Weight	Evaluation Criteria	SVM Weight
Land use	-0.36	Distance to Capital City	-0.62
Percent built-up area	0.97	Population Density	4.88
NDVI	2.15	Rainfall	-1.17
Altitude	0.60	LST	0.23
Slope	0.96	NPP	-0.10
Distance to Primary Route	-2.35	Carbon Monoxide	1.23
Distance to Secondary Route	0.74	Nitrogen Dioxide	-1.18
Distance to Trail Lines	0.27		

The refined suitability map is the main input for TOPSIS analysis. We validated the SVM model with the same randomly picked samples from the study area (the results are summarized in Table 3). It can be seen that the SVM model accurately classified the 1178 samples which equals to 78.5% total samples tested with Kappa statistic of 0.67. In addition, both the unsuitable and highly suitable classes are important for the final mapping and ranking of the cities and the result was validated using area under the curve (ROC), which shows global accuracy statistics for each model. If the AUC which varies from 0.5 to 1 increases, the prediction performance of the method increases (Erener and Düzgün 2010). Also, the average success rate yields 0.861 while the average prediction rate is 0.719.

Table 3. Accuracy assessment of SVM modelling.

Accuracy Metric	**Value**
Correctly Classified Instances	1178 (78.5%)
Incorrectly Classified Instances	322 (21.4%)
Kappa statistic	0.67
ROC Area	0.861
PRC Area	0.719

Table 4 shows the positive ideal, negative ideal, closeness coefficient, and the TOPSIS rank for each of the Libyan cities analyzed in this study. According to the closeness coefficients, the ranking order for the cities: Benghazi, Al-Jabal al-Akhdar, Al-Marj, Darnah, Al-Hizam Al-Akhdar, and Al-Qubbah. The city selected as the best is Benghazi, followed by Al-Jabal al-Akhdar. Results of the ranking was used to generate a map which is also useful for decision making. The map in Figure 5a shows the ranking order of the cities. The cities with green and light green colors are suggested to be selected first for development. Based on the results, the importance of the group of factors was evaluated for selecting a city for development (Figure 5b). The bar chart shows the importance of the standardized factor weights in each group. The results suggest that demography and vegetation are the two factors that mostly influenced the selection of a city for development in Libya (Table 4). It also shows that topography is more important than the other remaining factors while air quality is the least important factor.

Table 4. The closeness coefficients estimated by TOPSIS.

City	**A+**	**A-**	**Closeness Coefficient**	**TOPSIS Rank**
Darnah	2.58	1.41	0.35	4
Al Jabal al Akhdar	2.05	1.74	0.46	2
Benghazi	0.98	3.40	0.77	1
Al Marj	2.23	1.57	0.41	3
Al Qubbah	3.13	1.08	0.25	6
Al Hizam Al Akhdar	2.69	1.29	0.32	5

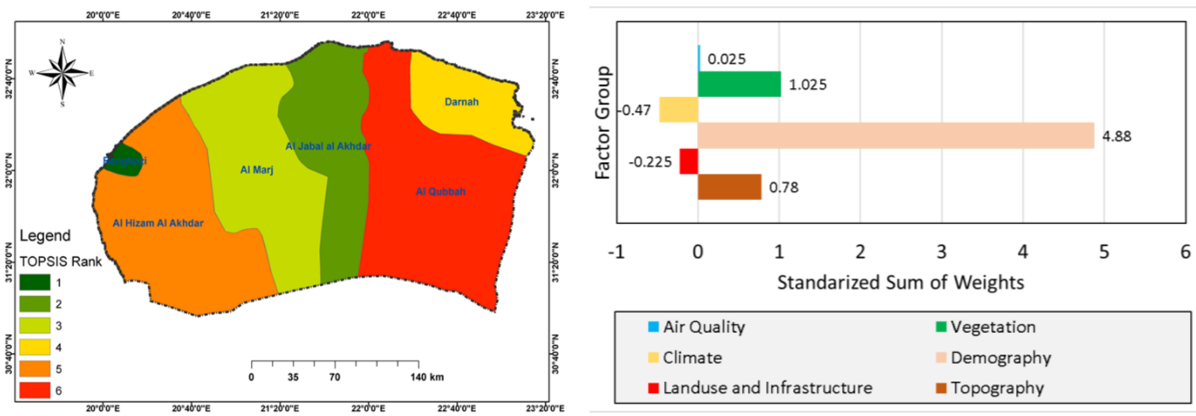

Figure 5. a) The cities ranks determined by TOPSIS method, b) Importance degree of factor groups.

5. CONCLUSION

This study developed an automated geospatial solution for selecting and ranking cities in Libya for development. The main motivation of the study was that the current practice is highly subjective, many cities are not considered for development even though they might have more benefits than other cities so selected. The developed solution can be useful as a decision tool to reduce subjectivity through automated computer program. Other advantages of the proposed solution include the assessment of effects of many factors on the selecting and ranking of cities. Although the results of the current study indicate that the proposed method is effective and can be a promising decision-making tool. It is recommended that the method should be extended for specific applications such as transportation and healthcare projects.

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