Comparative Study of Landform Mapping Using Terrain Attributes and Topographic Position Index (TPI): a Case Study in Al-Alamien – Ras El-Hekma Region, Egypt

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ABSTRACT

The aim of this study is to compare the classification of the landscape of the area located between Al-Alamien and Ras El-Hekma to landform classes using two different classification methods; the terrain attributes method and the topographic position index (TPI) method. Terrain attributes classification method derived from a digital elevation model and were overlaid using cell statistics to generate a landform map with seven classes. The landform classes were: (1) Lower coastal plain (17.86%), (2) Upper coastal plain (43.61%), (3) Piedmont plain (2.33%), (4) Dissected escarpment (2.64%), (5) Plateau (26.79%), (6) Ridges and coastal bars (3.62%), and (7) Inland dunes (3.15%). The topographic position index (TPI) method which generate the landform classes uses only the digital elevation model. The generated landform classes were: (1) Valleys (2.1%), (2) Midslopes drainages and shallow valleys (1.1%), (3) Plains (92.77%), (4) Hills in plains (0.34%), (5) Mesas (2.44%), and (6) Ridges (1.25%). The comparison of the two methods showed that using the terrain attributes method was more detailed.

Keywords: Landform Classification, Soil Catena, Terrain Attributes, Topographic Position Index (TPI), Digital Elevation Model (DEM)

INTRODUCTION

Landforms can be understood as a geomorphological integral part of the landscape (Barker, 2009), they reflect the influence of geology and climate on a global or regional scale (Strahler, 2008). The integration of landform and climate is obviously affects the development of soils. The significance of landform studies in terms of understanding the potential and constraints within the landscape associated with them, is well documented (Wiens et al., 2007). From a geological perspective, landforms were created by geological processes, (Drescher and Frey, 2009). Landform study imparts itself to the fields of hydrology, pedology, and environmental studies. Landforms can be used to obtain a general impression of soil forming processes, due to its significant role in the current sedimentary processes, (Chabala et al., 2013). Soil catena conceives that soil is a function of topography, therefore, classifying the terrain into landform classes, is essential to understand the soil pattern (Young and. Hammer, 2000). The landform digital mapping can be performed using digital elevation models (DEMs) derived from remote sensing or conventionally from contour lines and spot heights. Although several methods of landform classification have been applied, the absence of standards (MacMillan, 2011), the applied classifications has to be modified according to the local environment.

This present study aims to integrate landform classification of Al-Alamien – Ras El-Hekam region, using two different classification methods (The terrain attributes and Topographic Position Index (TPI)), and derive landform classes to indicate or suggest marked differences in local topography and geomorphology.

MATERIALS AND METHODS

1-Study area:

The study area is located in Matrouh Governorate, along the north western part of Egypt on the Mediterranean coast (Figure 1). The study site covers an area of approximately 2230 km^2, and extends between longitudes 28° 54' 9.68" to 27° 29' 51.47" E and latitudes 30° 52' 44.48" to 31° 2' 7.08" N. The study area is stretched along 3 districts: Al-Alamien, Dabaa and Marsa Matrouh, with the Mediterranean Sea is the northern border while El-Gaish road is the southern border. The study area has a Mediterranean climate characterized by mild and rainy winter and warm summer extends from May to September, (UNEP, 1995). The area's elevation ranges from 0 m to 180 m above the sea level. The geology of the study area according to the geological map of Egypt, has 3 geological surfaces, *(1) Undivided Quaternary* is exposed in wadis, represented by limestone, *(2) Middle Miocene* forming the surface beds of the tableland represented by biogenic carbonates with marl and shale, and *(3) Pilocene* represented by Oolitic limestone, sandstone with chalky limestone and gypsum.
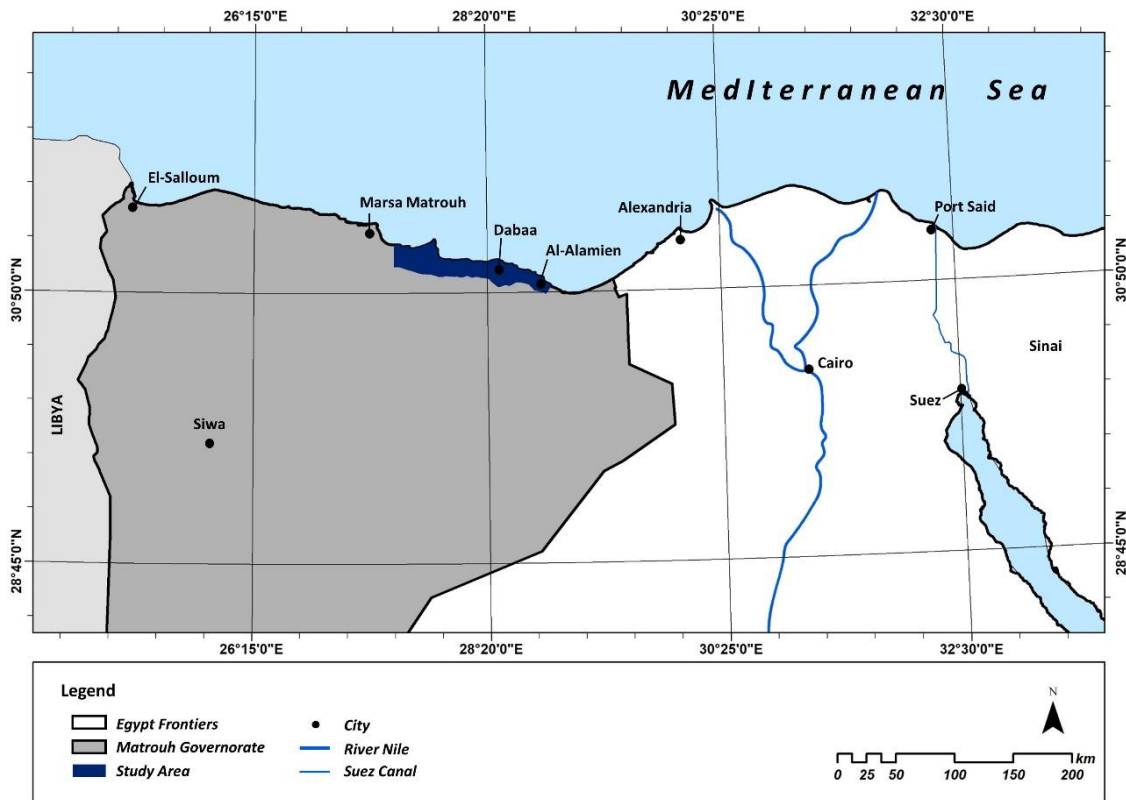
Figure 1. Study area location

2-Landform classification process using terrain attributes:

Landform classification reflects the terrain attributes of the landscape. Terrain attributes can be overlain in order to develop the landform classes. The landform classification was done using the method presented by Chabala et al., 2013. Figure 2, shows the process model for extraction of terrain attribute from digital elevation model (DEM) to produce landform map. The selected attributes were elevation, slope, relief intensity, and curvature. The extraction of terrain attributes and generation of the landform map was implemented in ArcGIS 10.3 software.
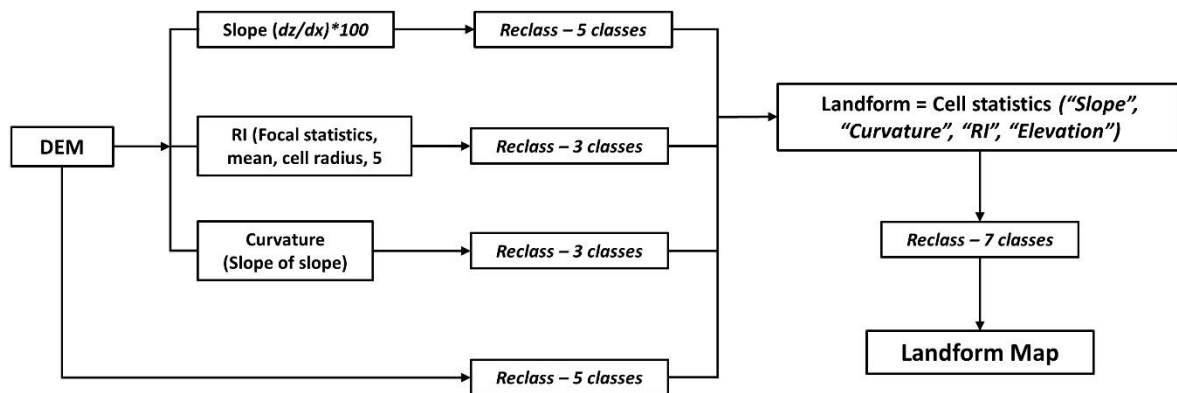

Figure 2. Process model for extraction of terrain attributes and landform classification

Digital Elevation Model (DEM):

Twenty-three topographic maps scaled 1:25000, (Figure 3) were scanned and acquired in digital format, georeferenced in ArcGIS 10.3 software using Universal Transverse Mercator (UTM) coordinate system, to create the mosaic of the study area. 983 Contour lines and 10943 spot heights were digitized from the final mosaicked 23 topographic maps of the study area, to develop a Digital Elevation Model (DEM), using the Topo to Raster tool, which is an interpolation method designed for developing correct digital elevation models (DEMs) utilizing contour lines and spot heights (Hutchinson et al., 2011). The elevations were reclassified to 5 classes, based on field observations as shown in (Table 1).

Table 1. Digital Elevation Model (DEM) classes (m)

Elevations (m)	
Class	Description
1	0 – 35
2	35 – 70
3	70 – 105
4	105 - 140
5	140 - 180

Slope:

Slope is an important aspect of the landscape and functions as an input in the landform classification process which has been applied in a number of studies (Chabala et al., 2011; Dobos et al., 2005; Huting et al., 2008; Iwahashi and Pike, 2006 and Saadat et al., 2008). It is a measure that denotes the change in steepness of the surface over the horizontal plane. Slope was developed using ArcGIS 10.3, based on the average maximum technique. The developed slope was then reclassified into 5 classes based on the FAO guidelines for soil description, 2006 (Table 2).
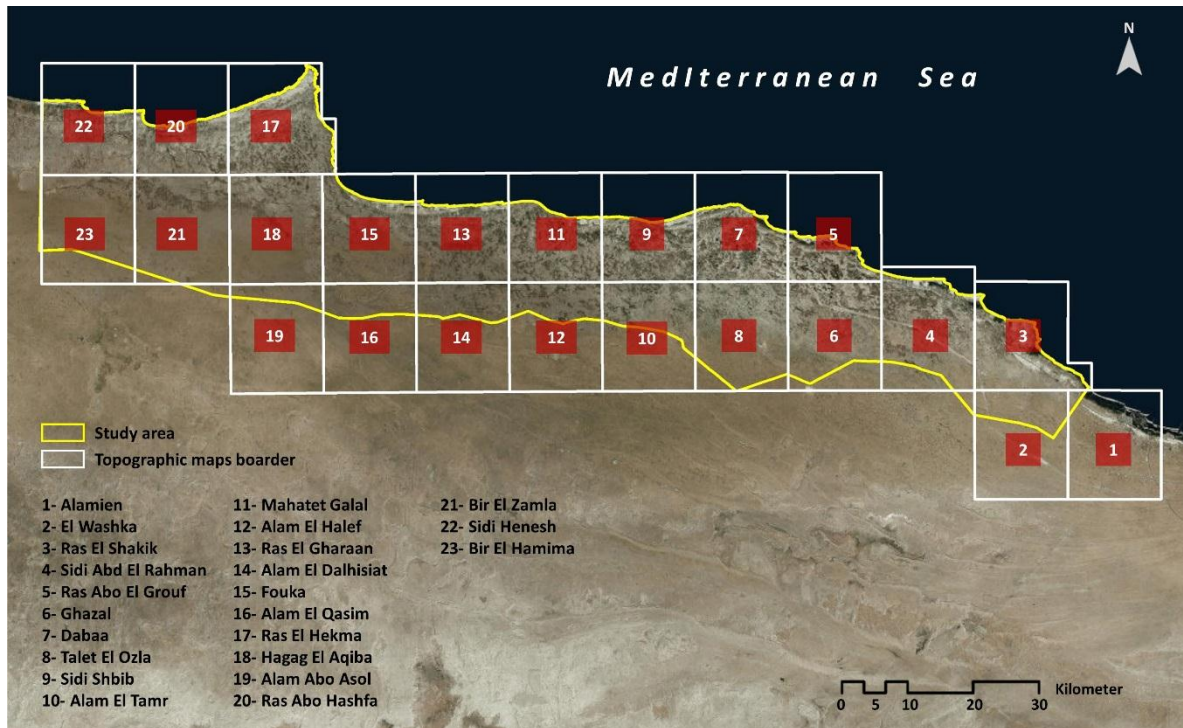

Figure 3. Topographic maps covering the study area

Table 2. Slope gradient (%) classes

	Slope Gradient (%)	
Class	Slope %	Description
1	0 - 0.2	Flat
2	0.2 - 5	Gently sloping
3	5 - 10	Sloping
4	10 - 15	Strongly sloping
5	15 - 45	Moderately steep

Relief intensity (RI):

Relief intensity (RI) refers to the changes in elevation between the lowest and highest points over a specific area of the landscape. The process of the extraction of the RI was based on the algorithm described by Dobos et al., 2005, using the focal statistics tool in ArcGIS 10.3. The focal statistics tool calculates the average value for each input cell location in a circular neighborhood with a radius of 5 cells (The pixel size (cell) was adjusted to 30 m). The generated RI was reclassified to 3 classes of relief intensity as showen in (Table 3).

Table 3. Relief intensity (m) classes – Altitude range in 5 cell diameter

	Relief Intensity (m)
Class	Description
1	<46
2	46 - 101
3	101 - 167

Curvature:

Curvature can be defined as curves of a surface and can be represented as profile, plan or general curvature (Thorne et al., 1987). General curvature is the curvature of the surface itself and is the second derivative of Z (elevation) with respect to S (aspect) or the slope of the slope. According to Wilson and Gallant, 2000, the general curvature (K) can be derived from the equation below:

$$Z = Z^2_{xx} + 2Z^2_{xy} + Z^2_{yy}$$

The curvature was calculated with the curvature tool in ArcGIS 10.3. The tool calculates the second derivative value of the elevation grid (DEM) on a cell by cell basis and fitted to a surface composed of a 3x3 window. The output curvature was then classified to 3 classes to represent peaks shapes, concave shapes and flat surfaces. The classified curvature values are shown in (Table 4).

Table 4. Curvature classes

	Curvature	
Class	Range	Description
1	-2.43 – 0.01	Concave
2	0.01 – 0.06	Flat surfaces
3	0.06 – 1.43	Peaks

Landform Generation:

The landform map was generated by overlaying the reclassified attributes representing relief intensity, curvature, elevation and slope (%). This was performed by using the cell statistics tool in ArcGIS 10.3, with the mean set as the overlay statistic. The expression for the operation is given as:

Landforms = CellStatistics (["Slope", "Curvature", "Elevation", "Relief Intensity"])

The output from the cell statistic tool was a continuous grid which was classified into 7 landform classes according to the field observation and the literature describing the north western coast. The continuous classified grid was smoothed to remove the tiny isolated pixels.

Landform classification process using topographic position index (TPI):

Topographic position index (TPI) measures the difference between elevation at the central point of a neighborhood and the average elevation around it within a predetermined radius (Wilson and Gallant, 2000; Weiss, 2001). The higher index values represent the areas with higher elevation than surroundings pixels and the lower values characterized as valleys which are lower than surroundings, zero values represents flat areas or areas with a constant slope. The degree to which the cell value is higher or lower, plus the slope of the cell, can be used to classify the cell into slope position. If it is significantly higher than the surrounding neighborhood, then it is likely to be at or near the top of a hill or ridge. Significantly low values suggest the cell is at or near the bottom of a valley. TPI values near zero could mean either a flat area or a mid-slope area, so cell slope can be used to distinguish the two, (Weiss 2001).

The TPI can be calculated according to the formula presented below using ArcGIS platform:

$$TPI_i = T_0 - \frac{(\sum_{n-1} T_n)}{n}$$

Where T_0 elevation of the model point under evaluation, T_n elevation of grid and n the total number of surrounding points employed in the evaluation. With combining TPI at small and large scales a variety of nested landforms could be distinguished automatically, (Weiss, 2001).

RERSULTS AND DISCUSSION

Landform classification using terrain attributes method:

The landform classification presented in this study was based on terrain attributes. The elevation, slope gradient (%), relief intensity and curvature maps where prepared based on the digital elevation model developed from contour lines and spot heights extracted from the topographic maps scaled 1:25000. Based on (Figure 4), the study area elevation is between 0 m to 180 m Above Sea Level (A.S.L), and where classified to 5 classes (Table 5). The dominant elevation class that occupies 30 % of the study area ranges from 35 to 70 m A.S.L.

The study area was classified into five slope gradient classes based on FAO guidelines for soil description, 2006, (Table 6 and Figure 5). It is obvious that the majority of the study area lies in the gently sloping class with an area 87 % of the total study area.
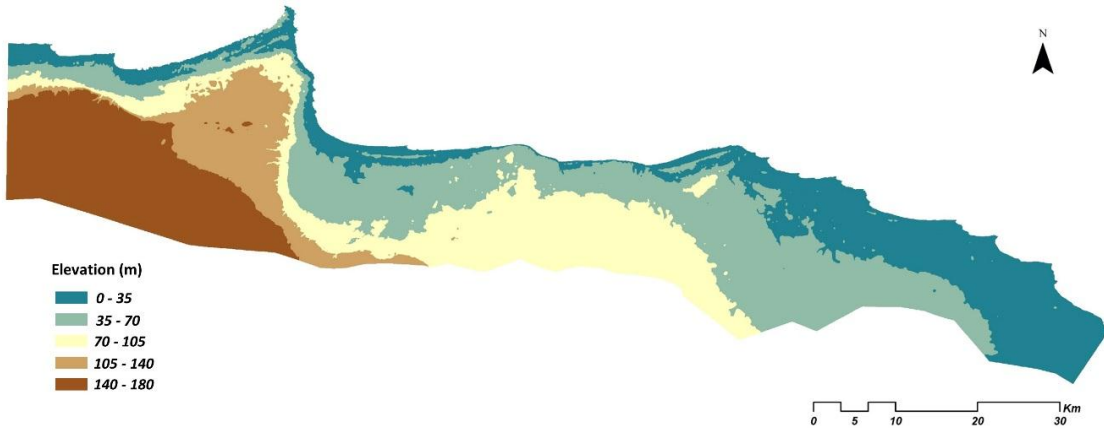

Figure 4.The classified digital elevation model (DEM)

Table 5.Digital Elevation Model (m) classes and their areas percentages of the study area

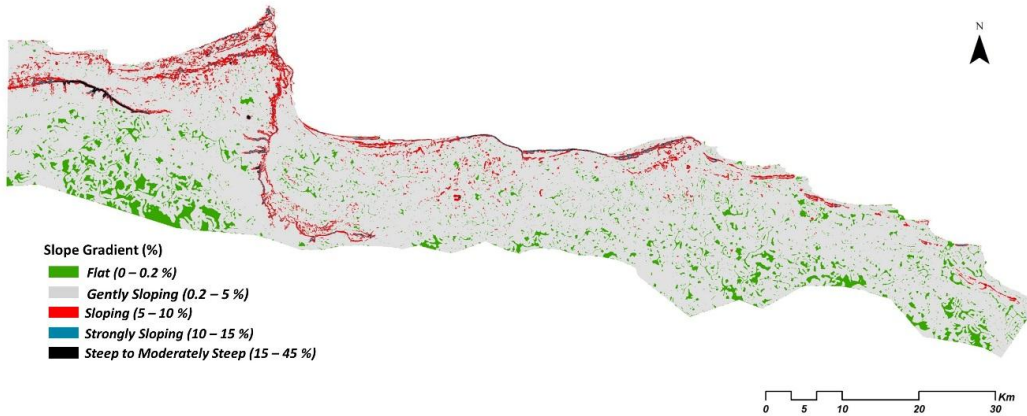| Elevations (m)			
Class	Elevation (m)	Area ha	%
1	0 - 35	50844	22.8
2	35 - 70	66900	30
3	70 - 105	45715	20.5
4	105 – 140	21185	9.5
5	140 - 180	38356	17.2

Figure 5. The classified slope gradient (%)

Table 6. Slope gradient (%) classes and their areas percentages of the study area

Slope Gradient (%)				
Class	Slope %	Description	Area ha	%
1	0 - 0.2	Flat	17862.3	8.01
2	0.2 - 5	Gently sloping	194010	87
3	5 - 10	Sloping	9499.8	4.26
4	10 - 15	Strongly sloping	1226.5	0.55
5	15 - 45	Moderately steep	401.4	0.18

Relief intensity after applying the focal statistics the relief value is between <45 m to 167 m. Table 7 and Figure 6, show the spatial distribution of the changes in elevation between the lowest and highest points RI over the study area.

The curvature values were between -2.43 to 1.34. The classification of the curvature (Table 8 and Figure 7) was according the K value. Flat surfaces from 0.01 to 0.06 which dominating the majority of the curvature class with 93% of the total study area.

The landform classification map was developed using the overlaying technique by the cell statistics tool in ArcGIS 10.3 software, by overlaying the terrain attributes (elevation, slope gradient, relief intensity and curvature). Figure 8, shows the landform map, which consists of 7 classes: (1) Lower coastal plain, (2) Upper coastal plain, (3) Piedmont plain, (4) Dissected escarpment, (5) Plateau, (6) Ridges and coastal bars, and (7) Inland dunes. In general, different types of landform occur with increasing slope and elevation. It can be noticed that the lower and upper coastal plains are dominating the whole northern part of the study area with increasing differences in the width to the south because of the increasing in the slopes, elevation and the curvature changes in the south of Ras El-Hekma region performing more landform classes. Therefore, using the layers of slope, elevation, relief and curvature are effective layers for preparing the landform classification map. An area (%) and terrain attributes comparisons were calculated for each landform classes and the results are shown in Table 9.
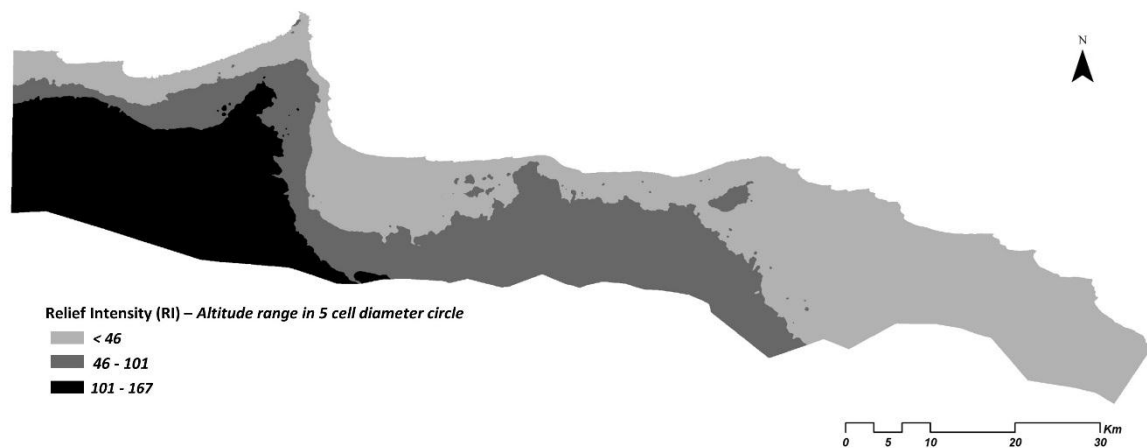

Figure 6. The classified relief intensity (RI)

Table 7. Relief intensity (m) classes and their areas percentages of the study area

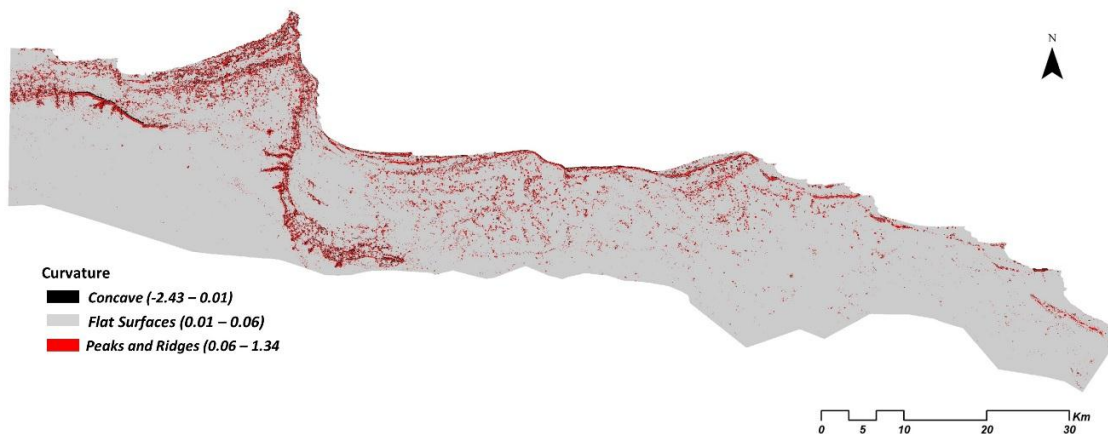| Relief Intensity RI (m)			
Class	RI (m)	Area ha	%
1	<46	107040	48
2	46 – 101	62440	28
3	101 - 167	53520	24

Figure 7. The classified curvature

Table 8. Curvature classes and their areas percentages of the study area

		Curvature		
Class	Range	Description	Area ha	%
1	-2.43 – 0.01	Concave	4460	2
2	0.01 – 0.06	Flat surfaces	207390	93
3	0.06 – 1.34	Peaks	11150	5

Table 9. Characteristics of landform classes of the study area

Landform class	Elevation (m)	Slope (%)	Curvature	Area (ha)	%
Lower coastal plain	0 - 35	Flat to gently sloping	Flat surface	39827.8	17.86
Upper coastal plain	35 - 70	Gently sloping	Flat surface	97250.3	43.61
Piedmont plain	70 - 105	Sloping to strongly sloping	Flat surface	5195.9	2.33
Dissected escarpment	105 - 130	Strongly sloping to steep slopes	Flat to peaky	5887.2	2.64
Plateau	130 - 180	Flat slopes	Flat surface	59741.7	26.79
Ridges and coastal bars	Max 25	Gently sloping	Peaky	8072.6	3.62
Inland dunes	Max 15	Gently sloping	Peaky	7024.5	3.15

Landform classification using topographic position index (TPI) method:

The landform classification map was developed using the topographic position index (TPI) method using the TPI extension in the ArcGIS 10.3 platform. Figure 9, shows the landform map, which consists of 6 classes generated automatically by the TPI extension: (1) Valleys, (2) Mesas, (3) Hills in Plains, (4) Plains, (5) Midslopes Drainages and Shallow Valleys, and (6) Ridges. The results of the TPI classification indicated that most of the area are classified as plains with flat surfaces and dominated by 92.77% of the total study area, and the least percentage is classed as hills in plains occupying 0.34% of the study area as shown in Table 10.

The landform classification methods presented in this study showed that using the terrain attributes (elevation, slope, relief intensity and curvature) more detailed than the automated method (Topographic position index) which uses only the digital elevation

Table 10. Landform classes and their areas percentages of the study area

Landform class	Area (ha)	%
Valleys	4683	2.1
Mesas	5441.2	2.44
Hills in Plains	758.2	0.34
Plains	206877.1	92.77
Midslopes Drainages and Shallow Valleys	2453	1.1
Ridges	2787.5	1.25

Landforms (Terrain Attributes)

- Lower Coastal Plain
- Upper Coastal Plain
- Piedmont Plain
- Dissected Escarpment
- Plateau
- Ridges and Coastal Bars
- Inland Dunes

Figure 8. Landform map of the study area using terrain attributes method

Landforms (TPI)

- Valleys
- Mesas
- Hills in Plains
- Plains
- Midslopes Drainages, Shallow Valleys
- Ridges

Figure 9. Landform map of the study area using TPI method

model by measuring the difference between elevation at the central point of a neighborhood and the average elevation neighbor it within a predetermined radius (Wilson and Gallant, 2000; Weiss, 2001).

CONCLUSION

This research aims to compare two landform classification methods. Both methods depend on digital elevation models (DEMs). The terrain attributes method was highly effective and more smoothed in preparing a landform classification map, because of taking in consideration the real shape of the landscape, while the topographic position index (TPI) showed coarse results with one only dominated landform class (Plains) without taking in consideration the differences in the elevation between the flat surfaces. According the results presented in this research the terrain attributes method is more accurate and flexible in generating landform mapping which we can call it Supervised Landform Classification, while the generated landform can be classified to many different classes, but also, the accuracy of the elevation model highly effects the landform generated classes, also the researcher knowledge and experience of the study area and his software skills will affect the final result.

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الملخص العربي

دراسة مقارنة لإنتاج خرائط شكل سطح الأرض

بإستخدام طريقتى صفات التضاريس الأرضية و مؤشر الموقع الطبوغرافي:

منطقة العلمين – رأس الحكمة، مصر

سامي زكي محمد، محمد بهنسي ، هشام جابر و خالد درويش

تهدف الدراسة الي مقارنة تقسيم اشكال سطح الأرض للمنطقة المحصورة بين العلمين ورأس الحكمة بإستخدام كلا من طريقة صفات التضاريس الأرضية وطريقة مؤشر الموقع الطبوغرافي. تم استخراج صفات التضاريس الأرضية من نموذج الإرتفاعات الرقمي ثم عمل تطابق للصفات بإستخدام وظيفة Cell Statistics فى برنامج ArcGIS 10.3 لإستخراج خريطة شكل سطح الأرض. وقد احتوت الخريطة النهائية علي سبعة رتب وكانت علي النحو التالي: (١) سهل ساحلي منخفض بنسبة ١٧,٨٦% من اجمالي مساحة منطقة الدراسة ، (٢) سهل ساحلي مرتفع بنسبة ٤٣,٦١%، (٣) سهل صخري بنسبة ٢,٣٣%، (٤) حافة صخرية متفتتة بنسبة ٢,٦٤%، (٥) هضبة بنسبة ٢٦,٧٩%، (٦) مرتفعات ساحلية بنسبة ٣,٦٢%، (٧) كثبان رملية داخلية بنسبة ٣,١٥%. اما طريقة مؤشر الموقع الطبوغرافي فقد اعتمدت فقط علي نموذج الإرتفاعات الرقمي لإنتاج الخريطة النهائية لشكل سطح الأرض، وكانت أقسام الخريطة المستخرجة كالتالي: (١) أودية بنسبة ٢,١% من إجمالي مساحة منطقة الدراسة، (٢) اودية ضحلة بنسبة ١,١%، (٣) سهول بنسبة ٩٢,٧٧%، (٤) تلال داخلية بنسبة ٠,٣٤%، (٥) هضاب صغيرة بنسبة ٢,٤٤%، (٦) مرتفعات ساحلية بنسبة ١,٢٥%. أظهرت الدراسة ان إستخدام طريقة خصائص التضاريس الأرضية أكثر دقة وتفصيلا لانتاج خريطة شكل سطح الأرض.