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The Slopes of El-Mokattam Plateau: A Study in Engineering Geomorphology

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ABSTRACT

Engineering geomorphology is concerned with the new challenges of climate change, and human intervention with the increase in land use. It is now seen as an indispensable partner in civil engineering as an applied science, through the study of the morphological characteristics of the surface slopes of the earth and their formation processes, with special interest in studying their engineering properties and behavior with the aim of developing solutions to the complex problems that may result from it. Furthermore, geomorphological knowledge of the dynamics of the landform, whether short-term or long-term, provides maps that illustrate the different geomorphological forms and their potential effects on engineering structures and human activities. Engineering geomorphology is a new applied field for the identification and evaluation of slope performance through their properties as a basis for engineering solutions. El-Mokattam plateau is currently facing the danger of environmental degradation of its slopes due to the dynamic development that occurred on its surface with the increase in land use to create sustainable urban communities.

Keywords: Engineering geomorphology, slope, El-Mokattam plateau, morphological characteristics, land use**.**

Introduction

El-Mokattam plateau in eastern Cairo is currently facing the danger of deterioration and collapse of its slopes due to the dynamic development that occurred on its surface with the increase in land use in the field of establishing sustainable urban complexes. The urbanization of the place, using modern technology and finding an aesthetic harmony between its slopes and construction with the good use of water, was a must; the misuse resulted in environmental problems and repeated rockslides from its cliffs that led to losses of lives and property.

The present study provides a scientific basis for mitigating the environmental problems that may result from it in the future, by using the spatial capabilities of GIS through combining slope assessment with its dynamic processes and engineering characterization of the deformation in combination with the hydrological properties of the materials.

Purpose of the Study

The research aims to study the changes that occurred on the surface of El-Mokattam limestone plateau, and converting its natural slopes to artificial slopes due to the increased use of its surface, which may need regular maintenance to ensure its stability**.** This is mainly done using modern techniques and prediction of future developments that may occur, because it represents an environmental problem on human activities in the scope of the plateau, by classifying them and evaluating their risks using the simulation system, predicting what will result from them in the future in terms of threats to the built environment, identifying threatened areas and developing solutions to them, and geomorphological mapping of the current slopes of the plateau as an observational and interpretive technique that attempts to combine the geology of the past with the geomorphology of the present and the expected future. With continuous geomorphological translation of environmental follow-up after project completion, assessment of slopes as past, recurring and potential future hazard components always requires continuous assessment as a critical pathway activity for human use in scope.

Study Method

Corona 1967 aerial photography, SPIIN 1997 satellite imagery, Ikons 2002, Sentinel-2 2020 (National Remote Sensing Authority), 1:5,000 scale topographic plates (Public Survey Authority), and 1/250.000 scale digital geological map (Geological Survey Authority), different GIS layers and ARCGIS and ERDAS Imagine software were used to identify the changes of the plateau over the past fifty years, whose topography has been changed by the increased use of its surface**.** In addition, the field study was used in order to monitor the technical findings that covered the most dangerous areas, and to draw various maps that combined the field study with the interpretation of aerial images, sensor images and digital elevation models.

Location, Boundaries and Area

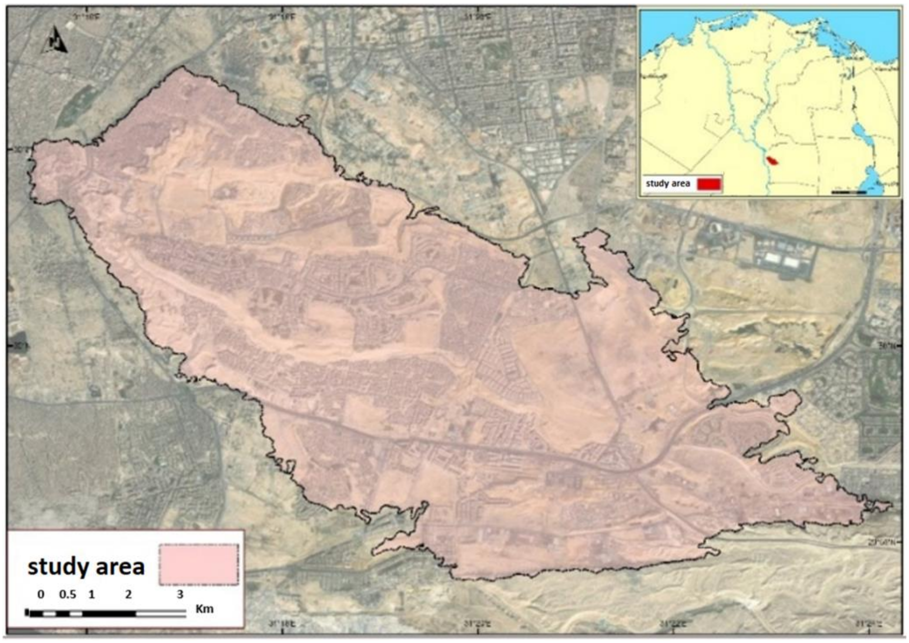
El-Mokattam plateau is located to the east of Greater Cairo, and it represents the northwestern edge of Al-Ma’azah limestone plateau. It is a well-defined block, bordered in the north by the Nasr City Depression, on the south by El-Maadi Depression, on the west by the plains of the Nile River, and on the east by an expansive sandy gravel plain. The plateau is astronomically confined between two latitudes 29° 57' 36″ - 30° 2' 50″ N, with a latitude difference of 00° 5' 14″ and a maximum extension of 6.3 km, and between longitudes 31° 15' 27″ - 31° 24' 14″ with a length difference of 00° 9' 4″ and a maximum extension of 15.3km**.** It has an area of 61.9km^2 (Fig. 1).

Previous Studies:

They included a set of geological and geographical studies as follows:

-**Geological studies:** the studies of Rushdi Said (1975), El-Shazly (1976), and Abd El Tawab (1986).

- **Geographical studies:** the report of the National Authority for Remote Sensing (1997), and the studies of Fathi Al-Sharqawi (1994), Azza Abdullah (1999), Amal Shawar (2002), Samir Sami (2003), Reham Waseem (2004), Essam Attia (2008), Amira Al-Banna (2010), and Safa Maher (2012).



Source: Based on the Sentinel- 2 satellite image.

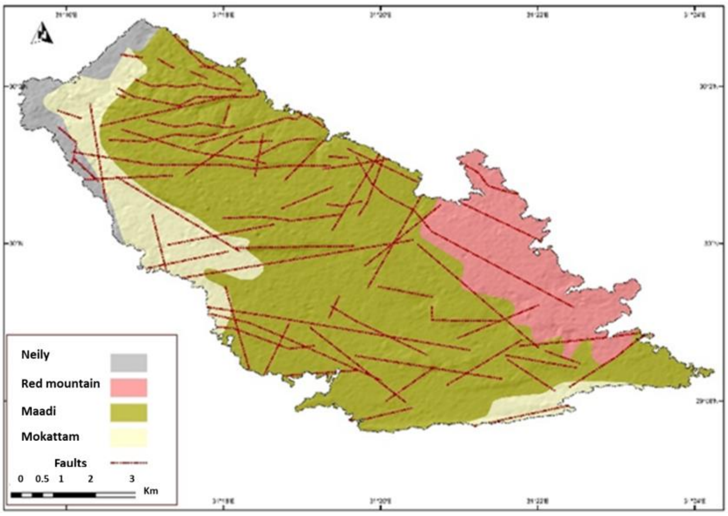
Fig. 1: The Location of the Study Area

First: The Geological Features

The oldest surface rock formations of El-Mokattam plateau date back to the middle Eocene of the Tertiary period, and by studying Figure (2) and the data of Table (1), the following can be shown**:**

El-Mokattam Formation

El-Mokattam Formation is the oldest visible formation on the surface and disappears under the newer formations. It belongs to the middle Eocene of the Tertiary period. It is divided into two parts: the first is lower (Geza Hensis) with thickness of 110m, and it was determined by drilling wells (Remote Sensing Authority, 1997); the second is upper, and it extends to its high cliffs in the southern part of the plateau with seventeen layers, most of which are white stony limestone mixed with marl, and their thickness vary between 25-0.5m, with a total thickness of 62.5m (El Shazly, et al., 1976)**.** Besides, its characteristics indicate that it is of medium hardness and contains little lime, local chert and nummulite, its deposition is due to the shallow marine environment, and it covers an area of 8.1 km^2 with a percentage of 13.1% of the total area of the plateau.



Source: Digital Geological Map at 1:250,000Scale, GIS.

Fig. 2: The Geology of El-Mokattam Plateau

El-Maadi Formation

El-Maadi Formation is harmoniously based on El-Mokattam Formation. It belongs to the Late Eocene. It has an area of 43.1km^2 with a percentage of 69.6%. It consists of fourteen successive layers of yellowish-brown sandy limestone of varying hardness overlapping with layers of gypsum oil shale, its thickness varies between 11.5-0.5m with a total of 47.5m, and its deposition is due to the shallow marine environment (El Shazly et al., 1976).

Table 1: The Rock Characteristics of El-Mokattam Plateau

Age	Formation	Thickness(m)	Area(km^2)	٪
Pleistocene	**Nile**	**30**	**2.2**	**3.6**
Oligocene	**Red Mountain**	**40**	**8.5**	**13.7**
Top Eocene	**El-Maadi**	**47.5**	**43.1**	**69.6**
Middle Eocene	**El-Mokattam**	**172.5**	**8.1**	**13.1**
Total			**61.9**	**100**

Source: Digital Geological Map at a scale of 1:250,000, Geological Survey.

Red Mountain Formation

The Red Mountain Formation, whose deposition belongs to the Oligocene in the northeastern plateau, is harmoniously based on El-Maadi formation, although the latter is higher at its western noon side, indicating that El-Maadi Formation responded to the process of torsion and folding before its deposition (Strougo, 1985). It consists of six layers with a total thickness of 40m; two layers of petrified sandy marley oil shale with a thickness of 7 m, and two layers of petrified sandy limestone with a thickness of 2m (El Shazly et al., 1976). The surface layer consists of sand and colored gravel (reddish brown, yellow and white), quartz veins and petrified wood around the faults, especially at its northeastern tip. Its area reached 8.5 km^2, with a percentage of 13.7%.

Alluvial Nile Formation

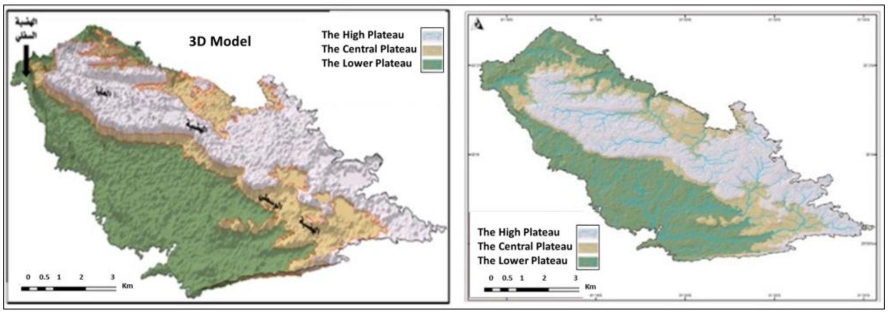
The Nile formations appear on the northwestern edge of the plateau, and their deposition at this high level (60 m) is due to the Nile terraces belonging to the Pleistocene of the Quaternary**.** They consist of silt of dark brown color mixed with gravel and sand (Shazly et al., 1976).

El-Mokattam plateau arose as part of a weak monoclinic fold following the structure of the Cairo-Suez region to echo the movement of the Syrian arcs, and left a group of major refractions (24 refractions) with different characteristics and directions (Abdel Tawab, 1986). This led to the presence of jumping fault blocks varying in their vertical displacement, and gave the morphological shape the plateau takes in three graded levels, up from its edges to its interior, the longest of which is 9.6 km**.** In addition, there was a group of breaks (47 breaks) with lengths ranging between 0.1-2.8 km, and the total lengths of faults and breaks are 128.3 km, with a density of 2.1 km/km2**.** The remarkable volcanic activity appears along some fault zones and inactive hot springs (El Shazly et al., 1976).

Second: The Terrain Features

A - General Features

The heights on the surface of the plateau ranged from 56meters in its northwest (Nasser institution) to 250m for the highest hilltop in the upper plateau (Fig. 3). The outer edge of the plateau rises from the surrounding surface by an average of 30meters from the north, south and west where there are edges. Its surface appears in three levels determined by a group of refractions, the most important of which is the main refraction that separates the upper and lower plateaus from the south, so the slope of the upper levels prevails towards the north and the lower level is towards the south**.** Its surface is decorated with a group of knolls of varying height, and through modal and morphometric study (Table 2), the following can be displayed:



Source: Based on the digital elevation model.

Fig.3: Topographical Units of the Study Area

The Upper Plateau

The upper plateau is represented at an altitude ranging between 190-250 m, with a terrain interval of 60m. Most of the valleys that descend to the north originated from it. The main fracture edge separating the upper plateau from the lower plateau from the southwest side is the water dividing line for most of the drainage basins that sloped towards the north and south.

The Central Plateau

The central plateau is represented more in the northern section in a striped form, and is located at an altitude of 190-160m with a terrain interval of 30m. Its maximum length is 6.8km, and its maximum width is 1.3km. Its categories are the most extensive in area (6.1 km^2), and are characterized by their ruggedness in the northeastern and southeastern sections because they contain the main sewers of the drainage networks.

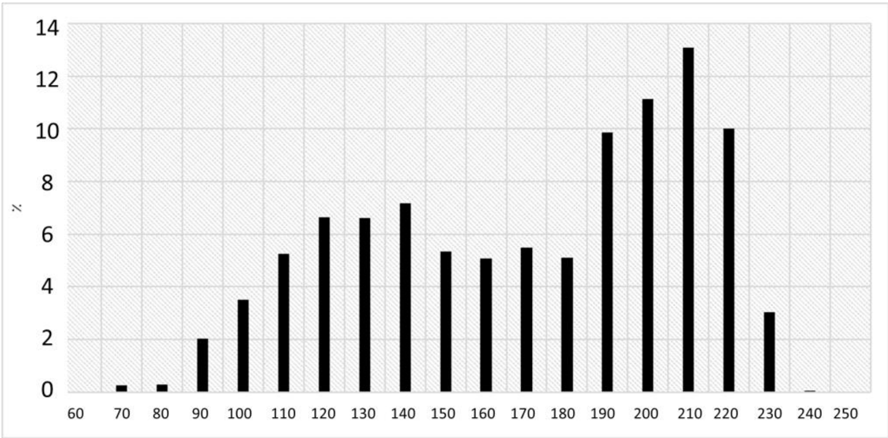
Table 2: Characteristics of Elevations at the Surface of the Plateau

Categories	Area (km^2)	٪	Directory	Area (km^2)	٪
less than**70**	**0.1**	**0.2**	Lower plateau	**26.1**	**42.2**
70-80	**0.2**	**0.3**			
80-90	**1.2**	**1.9**			
90-100	**2.2**	**3.6**			
100-110	**3.2**	**5.2**			
110-120	**4.1**	**6.6**			
120-130	**4.1**	**6.6**			
130-140	**4.4**	**7.1**			
140-150	**3.3**	**5.3**			
150-160	**3.1**	**5.0**			
160-170	**3.4**	**5.5**	Central plateau	**12.7**	**20.5**
170-180	**3.5**	**5.7**			
180-190	**6.1**	**9.9**			
190-200	**6.7**	**10.7**	Upper plateau	**23.1**	**37.3**
200-210	**8.1**	**13.1**			
210-220	**6.2**	**10.0**			
220-230	**1.9**	**3.1**			
230 and more	**0.1**	**0.2**			
Total	**61.9**	**100**	El-Mokattam	**61.9**	**100**

Source: Based on the digital elevation model

-The Lower Plateau

The lower plateau is more represented in the southern and western sections. It is located at an altitude ranging between 160-56m, with a terrain interval of 104m. Its maximum length is 5.3km. The width varies between several meters (2.5 km). It occupies an area of 26.1km^2 with a percentage of 42.2%. The category 120-140 m is the most extensive category (Fig. 4) in area (4.4km^2). A shallow drainage network was established on it heading towards the south.



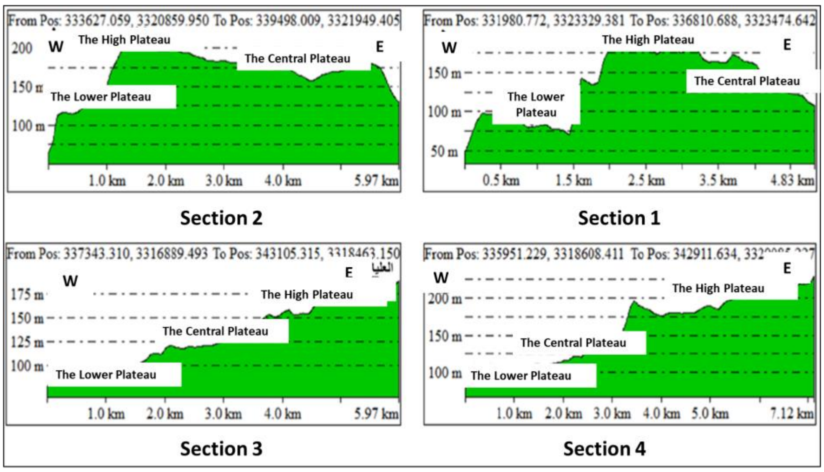
Source: Based on Table (2) using Excel.

Fig. 4: Areas of the Contour Categories

B- Topographic Sectors

Four topographical sectors were made to illustrate the levels of the main plateau, and all of them extend in a transverse direction that cuts the plateau from east to west (Fig. 5**)**. Their characteristics are presented as follows:

- **The first sector:** its length is 4.8km, its height ranges between 182-56m, its slope rate is 26.2m/km, and its maximum slope is 89.1°.
- **The second sector:** its length is 5.9km, its height ranges between 62- 206m, its slope rate is 24.4m/km, and its maximum slope is °79.6. It shows the widening of the central plateau and the contraction of the upper and lower ones.
- **The third sector:** its length is 7.1km, its elevation ranges between 80.4- 226.2 meters, its slope rate is 20.5m/km, and the maximum slope is 85.6°**.** It shows the gradient of the plateau levels from east to west.



Source: Based on Global Mapper 13.

Fig. 5: Topographic Sectors of the Plateau

- **Fourth sector:** Its length is 5.9km, its elevation ranges between 200-60.8m, its slope rate is 23.6m/km, and the maximum slope is 52.1°.

Third: Geomorphological Changes

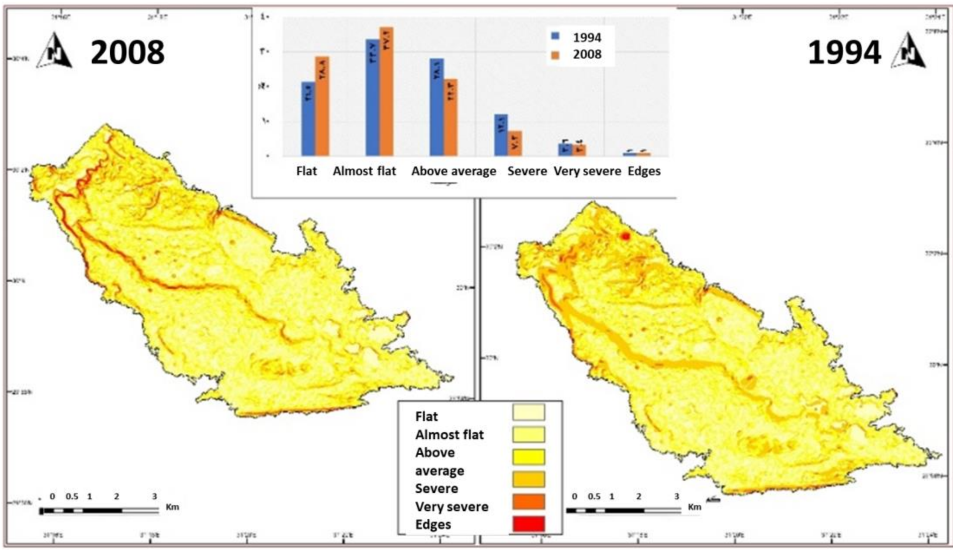
The geomorphological features greatly controlled the horizontal expansion of land uses in El-Mokattam plateau, which led to the dispersal of urbanization since its inception in its early stages and its growth in different directions. Also, it lost its urban homogeneity, and the neighborhoods took irregular geometric shapes. For this reason, some mechanical methods have been applied to make a comparison in order to identify the geomorphological changes of the plateau by humans as a geomorphological factor, and they can be presented as follows:

1-Geomorphological change

This method aims to make an automatic comparison between two digital models for two different periods to calculate the extent of the geomorphological change due to the land use of the surface of the plateau**.** This is mainly done in order to calculate the areas affected by the process of carving and removal to settle the land or the process of filling in the depressions to raise the level, as well as calculating the change of the areas of the surface sections of the plateau. Accordingly, the detailed maps of the plateau on a scale of 5000/1 in 1994 were converted into a digital elevation model with an accuracy of 5 meters, using ArcGIS software technology Topo to Raster in order to make an automatic comparison between it and another digital elevation model with an accuracy of 12.5 meters for the year 2008 (the latest data available for the plateau). In order to perform the Quality Assurance of Digital Input Data QC, the technical correspondence of both models was confirmed so that the outputs would be accurate and realistic. In addition, a technical comparison was applied using ArcGIS software between the two models to automatically determine the geomorphological changes that affected the surface of the plateau over a period of 14 years (Fig. 6) in order to monitor the role of man as a geomorphological factor in the engineering of slopes for its developmental uses regardless of the safety and security standard for subsurface geological features**.** The outputs can be presented as follows:

A- Sections of the Plateau Surface:

The study of the characteristics of the surface forms of the plateau is an important aspect for development purposes for a number of reasons. First, it has an impact in determining the geomorphological processes that pose a threat to the various uses of the land. Second, it is always in constant change due to its structural origin with sharp refractions. So it constitutes a sensitive environment associated more with the processes of encroachment of materials and avalanches. Young's method was used to classify the slope sections of the plateau surface. The automatic comparison of the two aforementioned models was applied, and the outputs can be presented as follows (Table 4):



Source: Based on digital elevation models 1994 and 2008.

Fig. 6: Changes in the Surface Sections of El-Mokattam Plateau

Table 3: Characteristics of Changes in the Surface Sections of the Plateau

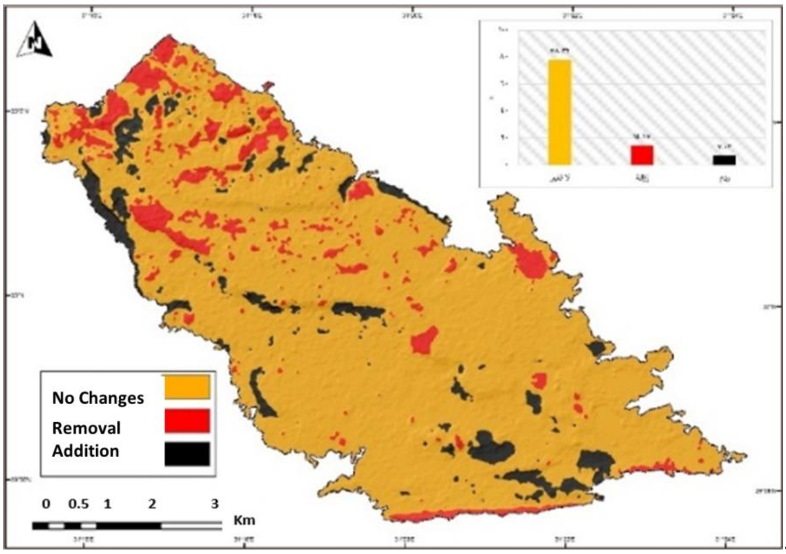
Class	Classification	Accuracy 5m in 1994		Accuracy 12.5m in 2008		Change
		Area (km^2)	٪	Area (km^2)	٪	km^2
less than 2	Flat	**13.3**	**21.5**	**17.9**	**28.8**	**4.6**
2-5	Almost flat	**20.9**	**33.7**	**23.0**	**37.2**	**2.1**
5-10	Above average	**17.4**	**28.1**	**13.8**	**22.3**	**3.6-**
10-18	Severe	**7.5**	**12.1**	**4.5**	**7.3**	**3.0-**
18-30	Very severe	**2.2**	**3.6**	**2.1**	**3.4**	**0.1-**
More than 30	Edges	**0.6**	**1.0**	**0.6**	**1.0**	**0**
Total		**61.9**	**100**	**61.9**	**100**	**0**

Source: Based on a comparison of the 1994 and 2008 digital models.

It was noticed from the comparative study that there is a change in the surface sections that were automatically monitored. The flat areas of land increased to 4.6km^2 and semi-flat lands to 2.1km^2 than they were before during the period from 1994 to 2008 due to the leveling processes for use. There is no doubt that this increase will be at the expense of other surface areas with a higher slope. It was noted that the added value (6.7km^2) for the flat and semi-flat land is equal to the value deducted from the other surface sections, and this indicates the accuracy of the mechanical comparison.

B- Removal and Addition

The results of the comparison appeared in three categories (Fig. 7)**.** The first category represents the unchanged areas, which are the common ones (Table 4), with an area of 48.5km^2 and a percentage of 78.4%. The second category refers to the operations of removing hills and leveling them for use, and spread**s** over the surface of the upper and middle levels and light areas in the lower level**.** Its total area was 9.1km^2 and a percentage of 14.6%. The third category refers to the processes of backfilling in addition to raising the level of the surface for use. This element was linked to the lower level and a few areas in the middle level, especially the locations of valleys' streams, with an area of 4.3km^2 and a percentage of 7%.



Source: Based on GIS.

Fig.7: The Areas of Backfilling and Removal of the Levels of the Study Area

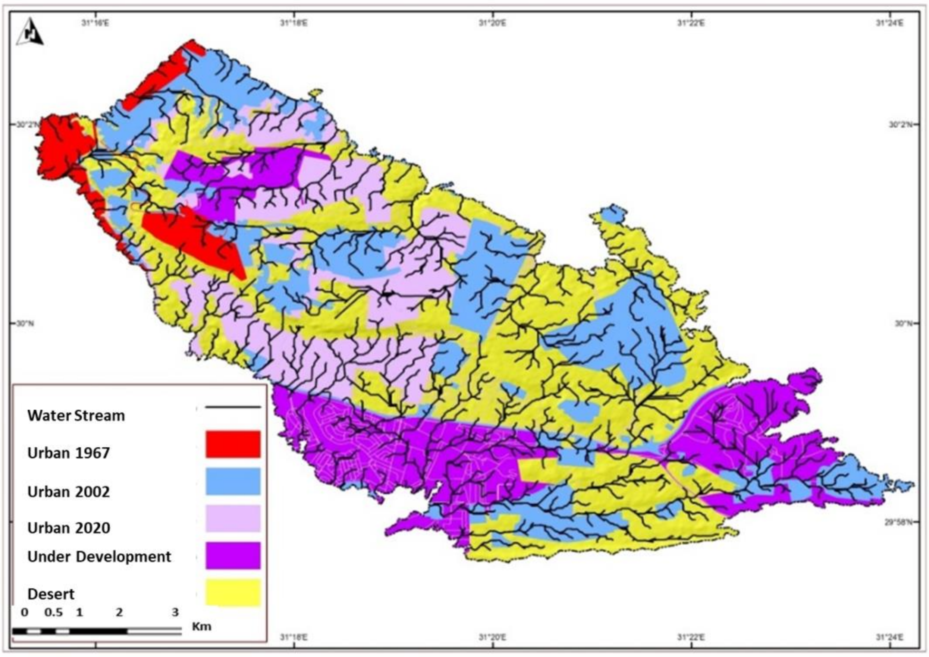
Table 4: Characteristics of backfilling and Removal in Areas on the Surface of the Plateau

Element	Area km^2	٪
Do not change	48.5	78.4
Removal	9.1	14.6
Addition	4.3	7
Total	61.9	100

Source: Based on the outputs of Figure .7

Development of Use

The development of the land use of the surface of the plateau has been applied for three comparative periods (1967, 2002, 2020), using the mechanical comparison as in the treatment of the previous point (Fig. 8). This is in order to link the growth of land use with the topographic units of the surface, and to identify the extent of the influence of geomorphology on growth trends. The outputs are presented as follows (Table 5):



Source: Based on a comparison of 1967, 2002, 2020 photography.

Fig. 8: Land Uses on the Surface of the Plateau

Table 5: The Development of Land Use on the Surface of the Plateau

Land Use	Area (km^2)		Area (km^2)		Area (km^2)	
	1967	٪	2002	٪	2020	٪
Urban	2.3	3.7	19.1	30.9	32.9	53.1
Methods	0.3	0.5	0.7	1.1	6.4	10.4
Under construction	0	0	8.2	13.2	12.5	20.2
Space	0	0	0.8	1.3	1.5	2.4
Desert	59.3	95.8	33.1	53.5	8.6	13.9
Total	61.9	100	61.9	100	61.9	100

Source: Based on GIS outputs for comparison**.**

- **The First Stage (1967)**

Aerial photography (Corona) of the surface of the plateau in 1967showed the city of El-Mokattam built on an area of 0.8km^2, representing 1.3% of the total surface of the plateau. This is in order to avoid any danger from flood flow. It was linked to the city of Cairo by an asphalt road from the northern direction, following one of the valleys' streams, and it occupied an area of 0.3km^2 with a percentage of 0.5%, adding to it the area of Salah al-Din Castle (0.07km^2), which was erected in the corner of the northwestern part of the plateau on the hill of Sowwah in 1176. Omran Al-Duwaiqa, Nasser institution, Al-Abagiya and tombs were built on the lower edge of the plateau from the northwest side in the vicinity of the castle, with an area of 1.5km^2**.** The total land use for that period was 2.3km^2 with a percentage of 4.2%, and the desert land remained an area of 59.6km^2 with a percentage of 95.8% of the area of the plateau.

- **The Second Stage (2002)**

The use of the land for the surface of the plateau spread scatteredly, and the use of the upper plateau increased towards the south with divergent neighborhoods, most of which were associated with the hilly areas from which the streams of the upper tributaries from which the valleys originate, and down to the middle and lower plateaus. For the characteristics of the local surface for each urban locality, the urbanization area for the current and previous period was 19.1km^2 with a percentage of %30.9, and a large area of the surface under construction was prepared, amounting to 8.3km^2, with a rate of 13.4%, most of which was associated with the lower plateau and a few of them with the upper plateau. It was associated with more rutted areas of the central areas of the wadi basins with an area of 8.2km^2 and a percentage of 13.2%, and away from the main streams of the valleys because they need backfilling, modification and settlement as well as being costly operations before starting use. The vacant land represented an area of 0.8km^2, which is the spatial axes within the urban shops, and the vacant area decreased to 33.1km^2 with a percentage of 53.5%.

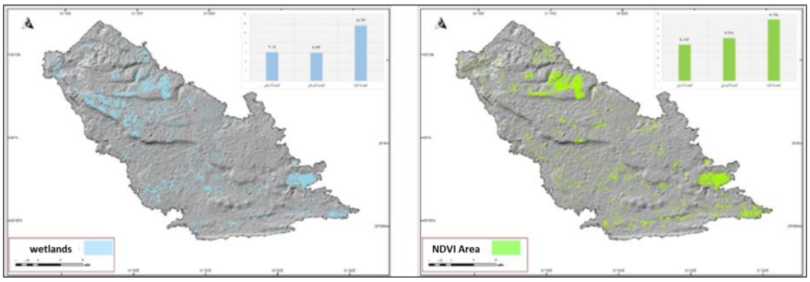
- **The Third stage (2020)**

The use of land increased and the areas that were more eroded on the surface of the upper plateau were exploited, which separated the construction of 2002. The total area of all urban neighborhoods reached 32.9km^2 with a percentage of 53.1%, and the total area of built roads was 6.4km ^{2}with a percentage of 10.4% due to the increase in linking the urbanization of the plateau to a group of roads from different directions**.** The areas under construction increased to 12.5km^2 with a percentage of 20.2%, and about half of them were built, and extended towards the areas of the headwaters of the valleys' streams and their bottoms in the northeast of the plateau, which was the most precipitous area in the east of the old city of El-Mokattam. Besides, the area of the rocky plateau surface decreased to 8.6km^2 with a percentage of 13.9%, and it is concerned with the backward hills of the central plateau, southeast of the plateau and some parts of the lower plateau.

2- Vegetation and Moisture Index

Green planning in urbanization achieves an important goal, which is to live in continuity, peace, safety, comfort, and spiritual and material well-being. It was noted during the field study that green spaces spread on the surface of the plateau (Fig. 9) as an aesthetic form in the form of public gardens within residential neighborhoods, golf courses and trees adjacent to urban structures, in addition to the natural vegetation scattered in the low areas due to the increased wetness of the soil and the drainage of Ain Mossa. For this reason, the vegetation and moisture index was applied from the European Sentinel- 2satellite image for the year 2020, and it was presented as follows (Table 6):

The green areas amounted to 3.9 km^2 with a percentage of 6.3% of the total area of the plateau. The upper plateau was the largest area and was linked to the modern neighborhoods of Wadi El-Lababa (Uptown Cairo) east of the old city of El-Mokattam with the spread of golf courses on the terraces of the southern side of the stream, and the gardens of the Stone Park complex in the far east of the plateau**.** It was followed by the lower plateau with an area of 1.3km^2 and a percentage of 33.3%, which are scattered areas and most of them are concentrated in its east (Baron City Gardens and the Higher Institute of Languages). The water of Ain Mossa descends to the north (Picture 1).



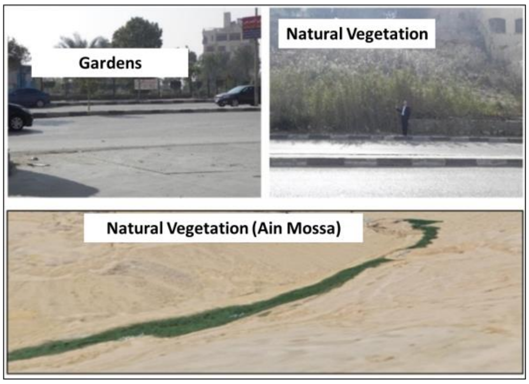
Source: Based on European satellite images Sentinel 2-.2020.

Fig. 9: Indicator of Vegetation and Moisture on the Surface of the Plateau

Table 6: Characteristics of Natural Vegetation and Moisture Index

Plateau levels	Natural vegetation		Wetlands	
	Area (km^2)	٪	Area (km^2)	٪
high plateau	1.9	48.8	2.7	52.9
central plateau	0.7	17.9	0.8	15.7
lower plateau	1.3	33.3	1.6	31.4
Total	3.9	100	5.1	100

Source: Based on GIS outputs.

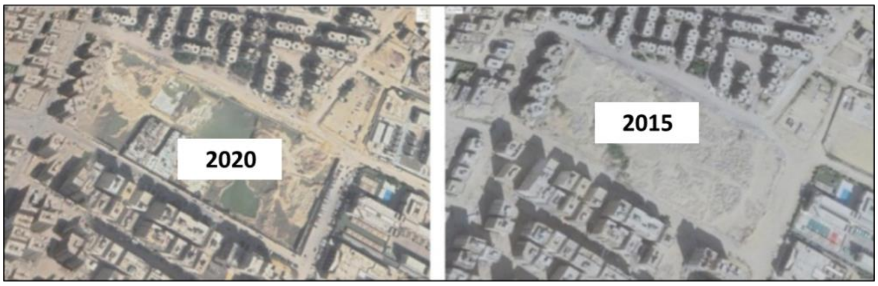


Source: Based on field study and Google Earth Pro.

Picture 1: Vegetation on the Surface of the Plateau

The wetness indicator indicated that the calculated areas of the wetland are larger than the area of vegetation, due to the increase in the leakage of irrigation water that exceeds the needs of vegetation and the water and sewage networks in urban neighborhoods. Their area reached 5.1km^2 and a percentage of 8.2% of the total area of the plateau, and the upper plateau was allocated the largest area of 2.7km^2 and a percentage of 52.9%.

It showed that the urban area of the old city of El-Mokattam is represented by the largest percentage of wetland in addition to the area of vegetation. This is mainly due to the deterioration of the sewage network followed by the lower plateau with an area of 1.6km^2 and a percentage of %31.4, and the emergence of water gatherings in the southern part of the plateau next to the power station (Picture 2) after 2015 to increase the use**.** The area of wetland (0.8 km^2) approached the area of vegetation (0.7km^2) in the central plateau.



Source: Based on Google Earth Pro.

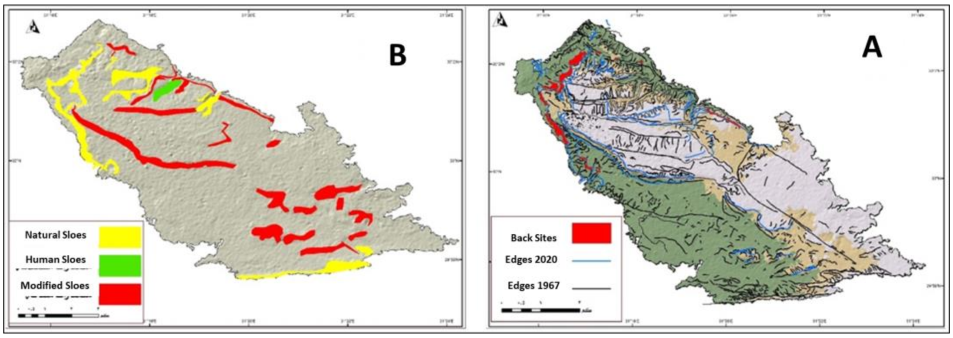
Picture 2: The Wetlands of the Lower Plateau

Fourth: The Slopes

Natural slopes were formed by natural activity (sculpting and depositing)**.** Using photography in 1967 (Picture 3), it turned out that they were a total of 850.5km with a density of 13.7km/km^2, and they decreased to 62.3 km in 2020 by 1km/km^2 (1010-a). They were classified into three categories (Fig. 10-b). The first is the natural slopes that are affected by natural factors, which are represented in the edge of the northwestern and southern plateau, the slopes of Wadi Mossa and the slopes of the northern side of Wadi El-Labbaba, representing an area of 2.9km^2 with a percentage of 37.5% of the slopes of the remaining plateau. The second is the modified slopes in which man intervenes by grading, covering or dumping the surface levelling products on its free surface. Most of them are internal slopes that needed to be modified to avoid their dangers, representing an area of 4.6km^2 with a percentage of 59%. The third is the used slopes located on the southern side of Wadi El-Labbaba, and they were graded and used as parks and golf courses, representing an area of 0.3km^2 and a percentage of 3.5%. In essence, slopes are geometric elements that make an angle with the horizontal surface of the earth, and their degree varies according to the sloping difference and their characteristics can be presented as follows:

Source**:** Wikipedia

Picture 3: The Density of the Slopes on the Surface of the Plateau



Source: Based on the results of analysis of aerial and satellite images in 1967 and 2020.

Figure 10: The Geomorphological Features of the Plateau

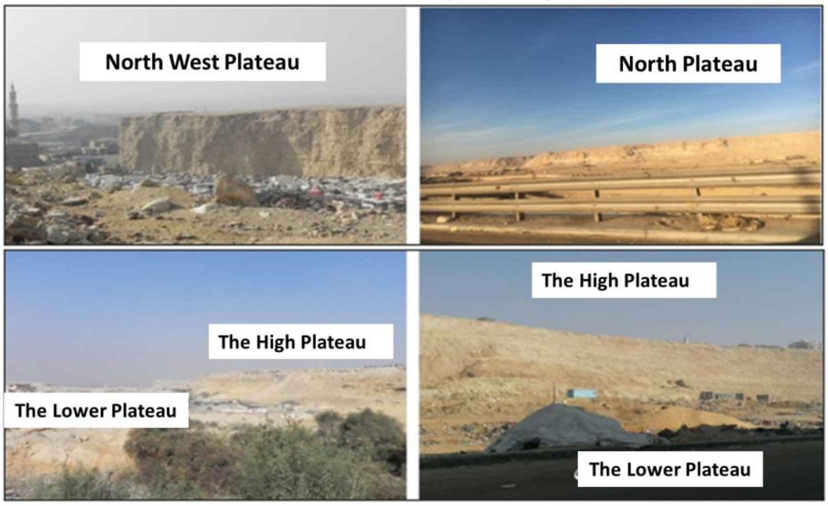
A - Slopes of Torsion and Fractures

The slopes of fractures were formed by the internal forces that led to the folding of the rocky layers of El-Mokattam plateau, which are two monoclinic folds. One of them is at its southeastern tip and the other is at its northwestern tip. It occurred in the upper Eocene rocks with layers of plastic clay, and the folding process was contemporaneous with the formation of the fractured mountain masses (Horst), which were identified by the group of major fractures. They were seven, and they took the direction of the axis of the plateau to 71 degrees (Remote Sensing Authority, 1997).

The remnants of the tectonic slopes that remain today are represented in parts of the edges of the plateau and inside it, in irregular lines, varying in their slope between the slight and the vertical. Most of them have been modified by being trimmed with slight slopes.

External slopes: The slopes are represented by three areas at the edges of the plateau. The first is at the northwestern edge of the lower plateau, and it starts from the east of Al-Duwayqa in the north to the end of the cemeteries in the southwest, with a length of 10.6 km. It overlooks the residential neighborhoods (Al-Duwaiqa, Nasser Institution and Al-Abagiya) and the graves with steep slopes (80-60degrees), and with local altitudes that ranged between 30-20m. The level of its peaks ranges between 140-104m (Picture 4). The second is located in the far southeast of the plateau, south of the industrial area and El-Katameya Golf Resort, with a length of 7.1km. It is represented by the tip of the lower plateau at a level of 158m and descends towards the desert in the south. The third slope appears in the north of the plateau, and it starts from the east of El-Asmarat Golden Heights and ends in the west of the mouth of Wadi El-Lelaba (Uptown Cairo Resort) with a length of 4.7km. It overlooks north from a height of 30m locally on the ring road at a level of 169 m, and is represented by the tip of the central plateau with an average slope of 33 degrees.

Internal slopes: They mean the slopes of the fractures shown by the tectonic map, determining the levels of the plateau and its surface by the cracks. Their lengths reached 128.3km; their paths followed most of the tributaries of the drainage lines, and others descended from its interface as the main edge separating the borders of the upper plateau and the lower plateau from the southwest, which is the main apparent witness to the fractures in the plateau overlooking the lower plateau in the south from a height ranging from 70-80m with a level of more than 200m (Picture 4).



Source: Based on the field study.

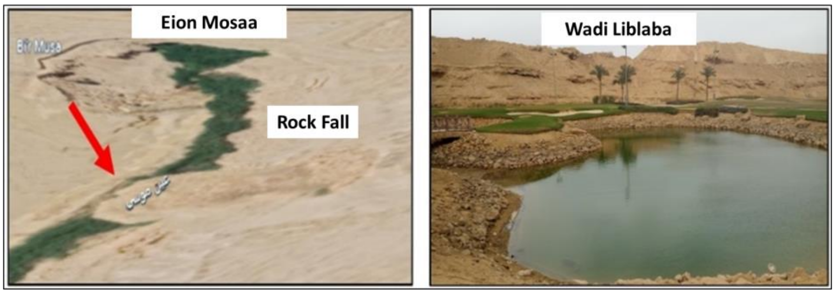
Picture 4: The Slopes of the Outer Plateau

A - Slopes of Sculpture and Deposition

They include the slopes that were formed by external forces such as the movement of rain water on the surface of the plateau, most of which have disappeared, leaving only the slopes of the main valley streams in its north-east. This is mainly because of the increased use of the plateau surface. They can be presented as follows:

Slopes of Wadi El-Labbaba: Only the steep slopes remain in the lower section of the stream, which is located in the northeastern plateau. Its cross-section extends more than 500 m at a contour of 140 m, and its bottom is occupied by a double road that ascends to the upper plateau and continues its extension through its northern tributary to the old block of the city of El-Mokattam. As for its southern tributary, its slopes were prepared in a gradual manner and were planted as a park and golf courses, and the lands between the valleys were used as residential resorts with artificial lakes (Picture 5). Its remaining slopes do not pose a danger to use unless a concentrated amount of rain falls, which increases the saturation of soil materials on the slopes and increases its weight and lubrication due to the lack of cohesive bonds between the particles, which leads to a greater force of Earth's gravity. The danger of flooding is on the openings below the road crossing its bottom and some of the slums on the slopes of its northern side, or the occurrence of water leakage from the urban shops above, which leads to avalanches on its sides due to the layers of the clay intertwined with the layers of limestone.

The slopes of Ain Mossa stream: The slope is located about 2.1km south of El-Lalababa stream, and its length is 700m from the edge of the plateau in the east to the spring from which water emerges in the west at a level of 155m at the intersection of the first north-west-southeast, and the other east-west. It is not groundwater, but rather wastewater designed by the Italian company in the interior of the plateau when establishing the city of El-Mokattam to save costs (Izzat Abdullah 1999, p. 60) because the groundwater is located at a depth of 180m from the surface of the upper plateau (Remote Sensing Authority 1997), and it led to the presence of a large pit with cliffs vertical with its perimeter and occupied the natural vegetation hall along the length of its course**.** Its slopes remained in its old terraces (2m-7m) unchanged until now. Its course appears in the form of a large convex towards the north, the width of its cross section near the eye is 200m at a contour of 163 m, its average depth is 18 m, and the thickness of the shale layer in the stream sector is 5m (El Shazly, et. al., 1976) below the limestone layer (12m). By examining the historical photographs of this stream, it was found that a large landslide occurred on its northern side (Picture 5) in 2018.



Source: Based on the field study and Google Earth Pro.

Picture 5: Uses of the Land in El-Lababa Stream and the Natural Vegetation in Ain Mossa Stream

Second: Artificial Slopes

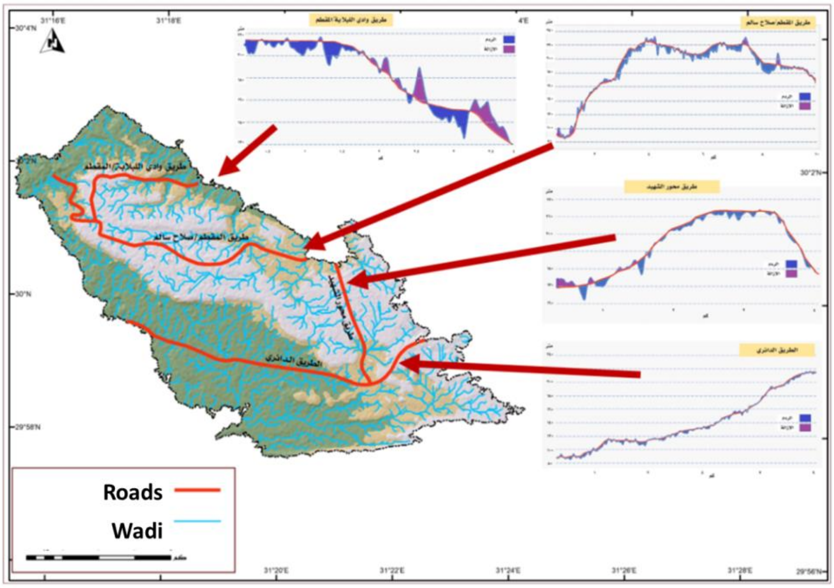
Civil engineering had a geomorphological role in changing the steep slopes of the plateau, whether it was in covering them, modifying them, grading them, or throwing surface leveling products on their free surface in the urban scale. The artificial slopes have acquired new characteristics than they were before, and have multiple geomorphological hazards such as concentrated rainfall, which leads to the erosion of settlement products in the form of severe aggregated movement that harms human activities at the lower level; earthquakes that lead to the collapse of these sediments down the slopes; water seeps through its layers, which leads to the wear of the cladding, and slippage; or subsidence of the rocky layers.

As for the process of severe engineering intervention in the slopes of the plateau, it is represented in the process of cutting the edges, penetrating the hills, and filling in the depressions of the tributaries of the valleys in order to establish several ways to link the urbanization of the plateau to each other and to the neighborhoods of Cairo from various sides. It was drawn from Visual 2020, its digital data was obtained, and its terrain sectors were made with an accuracy of 12.5m and were installed on each other in the GIS program**.** Besides, several intersections appeared showing the areas of removal and backfill during the construction of the road (Figure 11), and they can be displayed as follows:

Source: Based on the field study

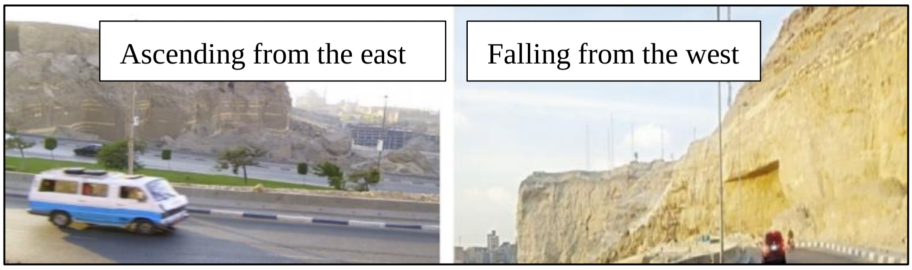
Picture 6: Forms of Artificial Slopes in the Plateau

El-Mokattam Road: It is the oldest road built on the plateau to connect the old city of El-Mokattam with Salah Salem Road in the west. It was extended to the east, passing through Street 9 in the new city of El-Mokattam and El-Asmarat Golden Heights neighborhood to meet El-Shaheed Axis Road outside the study boundaries in the north, and ending at the borders of the study area at a level of approximately 160m. Its length was 9.6km, and the road intercepted the top of a hill whose level rises to 182m at the beginning of El-Asmarat neighborhood from the west and at a distance of 1.4km from its beginning to the east on the surface of the central plateau. It goes 0.7km to reach a level of 220m after cutting a hill on the edge of the plateau and lowering it by 11m, which was at a level of 231m, and its vertical height represents a danger on the road (Izzat Abdullah, 1999, p. 65). Then the road extends at an average level of 200m for a distance of 3.6km, then begins to gradually descend from a level of 205m to a level of 156m of the lower plateau in a slope of 0.7km in length, at a rate of about one meter for every 14m**.** It gradually descends for a distance of 1.1km until it reaches a level of 122m, then is intercepted by a hill at a level of 133m**.** It was reduced by 11m at the point 8.7km from its beginning in the east, then it decreases to a level of 83m for a distance of 460m, with a slope of only one meter per 9m, which is the steepest slope ever on the plateau roads (Fig. 7)**.** It remains at this level in the remaining distance until it meets Salah Salem road, and the areas of filling were more than the areas of removal.



Source: Based on the digital model and GIS.

Figure 11: Topographic Sectors of the Roads



Source: Based on the field study

Picture 7: Roads Cutting Parts of the Slopes of the Upper Plateau

The Ring Road: It enters the borders of the upper plateau in the lands between the valleys in the upper plateau at a level of 218m from the east, and several hills rising above its level of 2m have been removed. It passes from the southern third of the plateau and is approximately parallel to El-Mokattam Road, and ends with the Autostrad road in the west, with a length of 9.1km, which is less moored than El-Mokattam Road, which extends on the upper plateau for a distance of 0.9km to a level of 190m. It extends 1.0km on the central plateau to a level of 160m, with a slope of one meter per 33m, descends gradually for a distance of 5.2 km to a level of 118m, then increases the slope to a level of 85m for a distance of 1.9km until it meets the highway. There are many backfilling areas because of its intersection with the tributaries of the drainage lines in the lower plateau.

El-Shaheed Axis Road: It connects the axis of El-Moshir Tantawi in the north and intersects with the Ring Road in the south, with a length of 4.1km. It starts at a level of 177m on the lands between the valleys on the surface of the central plateau. The slope of the upper plateau rises to a level of 215m, for a distance of 628m, at a slope of one meter per 16.5m; extends 1.7km on the upper plateau; then descends to the level of the middle plateau again by several slopes with the same slope as the degree of ascent to the upper plateau for a distance of 1.8

km until it meets the ring road at a level of 170m. The filling areas prevail over the removal areas.

Wadi El-Lebala Road: It connects Emaar Road in the north with El-Mokattam Road on the plateau with a length of 4.2km. It crosses the valley stream after raising its level to avoid any flash floods, and then pierces several rocky ledges on the northern side of the stream in its ascent to the surface of the plateau**.** The most of which reached a height of 20m from its level for a distance of 2.1km to a level of 205m. It then continues its extension on the upper plateau for a distance of 1.7km until it meets El-Mokattam Road at a level of 217m**.** The areas of filling are more than the areas of removal .

Development of Slopes (Dynamics)

The slopes of the plateau are subject to many changes, namely:

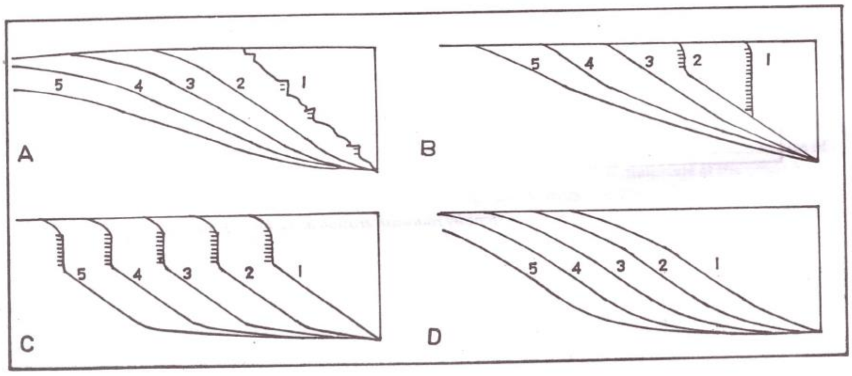
A - Retreat of slopes

The slope consists of the top (small convex), the free face (makes an angle with the horizontal), and the concave that contains the rocky debris (the eroded rubble of the top and the front). The slopes retreat due to a group of external processes that vary according to the prevailing climate. They are presented as follows:

Davies explained the phenomenon of slope retreat by the process of reduction, which is more severe at the beginning of its inception, and then erodes the top of the convex slope at a faster rate than its other parts (Fig. 12a). As for Bank, he explained it by the process of substitution, and the slope angle decreases due to the decline of steep or vertical slopes parallel to themselves and their advancement by the process of accumulating crumbs towards its concave (Fig. 12b).

King (1948, 1957) presented an alternative model for the Davis diagram of slope development, according to which the parallel regression of all slopes faces due to the weathering process, and the lengths and angles of the slope segments remain constant (Fig. 12c).

King’s model applies to the slopes of El-Mokattam plateau, which has a dry environment in its decline, which our ancestors of the Pharaohs moved away from, and to which the hand of modern man extended, starting from the date of the construction of the castle**.** This is evidenced by the parallel retreat of the slopes of the plateau under normal climatic conditions, and the preservation of the angle of its slope since its structural inception until now. Many failures of the northwest slopes have been repeatedly recorded during the past thirty years, due to the rapid development of human activities owing to road construction and engineering structures that have changed the topography of the plateau's surface, making its stability an exciting and continuing topic in the field of engineering geomorphology. These collapses are attributed to the appearance of cracks in their edges due to the disturbance in the geological structure during the development process, the increased loading of urban structures on top of the slopes, and the occurrence of water leakage in the rocky layers below the surface.



After: Clark et al.,1982.

Fig. 12: Models of the Theories of How Slopes Retreat

The collapse of rocky edges is one of the common natural hazards that affect the lives of people and property in El-Mokattam area, which has become the most affected area by this danger**.** It is a serious problem that requires attention to mitigate its damage; to assess the status of the current slopes, which have been reinforced by the field study; to identify areas sensitive to landslides, which can be useful to decision makers and warn of its dangers. The increased human intervention in recent times has contributed to the instability of the slopes in addition to the activity of natural factors**.** Moreover, the increase in the frequency of landslides since 1993 has been observed**,** and many homes have been demolished. There has been the collapse of another part of the aforementioned edge in 1995 and 2015 without causing any losses, the collapse of El-Duwaiqa edge (2008), the destruction of houses, the death of 63 people, the disappearance of the old Mokattam city corniche overlooking the edge of the main fracture, the appearance of cracks in the nearby buildings, the collapse of a rocky block on the road leading to the city of El-Mokattam between Radio and Blair Hotel (2014), the collapse of the northern side of the Ain Mossa stream (2018), and another fall in Nasser institution (2019) above Fawzi Eleiwa valley in the Nasser institution neighborhood. All of these are signs predicting future disasters on the urban environment, and the question that arises is: Were the mentioned disasters caused by natural factors or a result of the human intervention in the plateau**?**

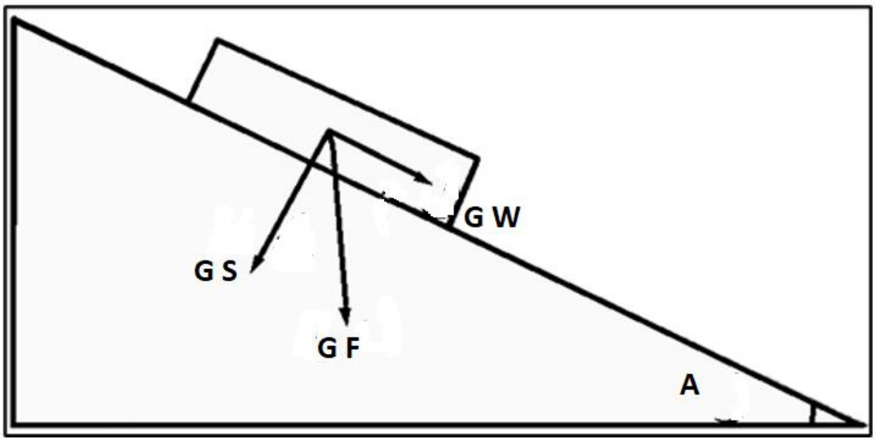
The increase in disasters is due to human intervention in the construction of thousands of buildings and poor sanitary connections to drinking water and sewage networks. Another source of water is that some residents of villas planted spaces around their villas, and the large number of residential communities “compounds with artificial lakes” and each residence has its own garden, so that the residents of the buildings planted around them, flooding the streets with water for car washes, public and private parks, golf clubs and more! This has led to the saturation of the sub-surface soil with these fluids, and they seeped and flowed into cracks and sub-surface joints, and reached the layers of the shale, and accordingly changed their properties and the rock blocks separated from the front of the slope.

The retreat of the edges of the plateau was calculated by comparing the edge from the 2020 photography to the 1967film, and the results showed that the edge retreated in three areas (refer to Figure 10). The first is the northern edge, east of the mouth of the Ain Mossa stream, along the northern front of El-Asmarat neighborhood and about 2km long, and the average retreat was slightly less than a meter, one per year. The second is the northwestern edge overlooking the neighborhoods of Nasser institution, Al-Duwaiqa and Al-Abagiya, with a length of 2.1km, ~~with~~ and an average retreat of 3.2m / year. The third is the southwestern edge overlooking the cemeteries, with a length of 2.3km, and an average retreat of 2.5m / year, and the amount of its retreat was estimated by both Abdel Tawab (1989, p87) with an average of 6.1m/year, and Fathi Al-Sharqawi (1994, p. 27) with an average of 2m/year.

The Forces That Cause Avalanches on the Slopes

Several forces act on the movement of materials on the slopes of the plateau or its collapse, which we summarize as follows:

Gravitational force: It is the force responsible for moving rock debris down the slope and sediments to valley streams and rock avalanches. The movement of materials depends on the weight of the rock mass and the angle of the slope. The Earth's gravitational force, symbolized by the symbol (G F), is divided into two forces (Fig. 13). The first is force parallel to the surface of the slope that moves the materials towards the bottom of the slope and is symbolized by the symbol (G W). The second is the natural force that stabilizes the materials on the slope and is symbolized by the symbol (G S). These two forces are directly proportional to the angle of the slope symbolized by the symbol (A) (Clark, et al., 1982). This process depends on a set of time scales that work on the decline of slopes and their instability under natural conditions (Fig. 8), which is the shear force that prevailed the force of cohesion and maintained the parallel decline of the slopes of the plateau since its inception, and the types of movement involved between slow and sudden according to the degree of gradient. Furthermore, with the increase in the use of the surface of the plateau, the forms of movement increased on the rocky slopes and avalanches from its current edges whose slope is more than 35degrees, which is the minimum degree from which the rapid movement of rockfall begins.



After: Clark, and Small, 1982.

Fig.13: The Force of Gravity Controls the Movement of Materials on Slopes

Source: Remote Sensing Authority Report, 1997.

Picture 8: Rockfall due to Natural Processes

Leakage of water and drainage Water, sewage and irrigation in excess of the plants' need lead to two process. The first is the swelling of the pressured layer of the shale layer within the formations of the plateau, a witness that is divided into sandy silt and limestone, and the pressure increases inside the rock when it is saturated with water leading to the separation and collapse of the interface of the cliffs and their collapse**.** Several factors control the rate of the shale's swelling, namely: its composition, its density, and the extent of its saturation with water**.** The swelling strength of samples from the sandy shale in Al-Duwayqa of the upper and lower plateaus was measured in the laboratory after washing, drying, separating them from the sandy content and mixing them with tap water in the presence of sodium chloride (1997). The first represents a greater danger to the foundations of urbanization, and it is the force responsible for the frequent collapse of the edge in its northwest, where water was observed behind the collapsed edge of unknown source (Remote Sensing Authority, 1997).

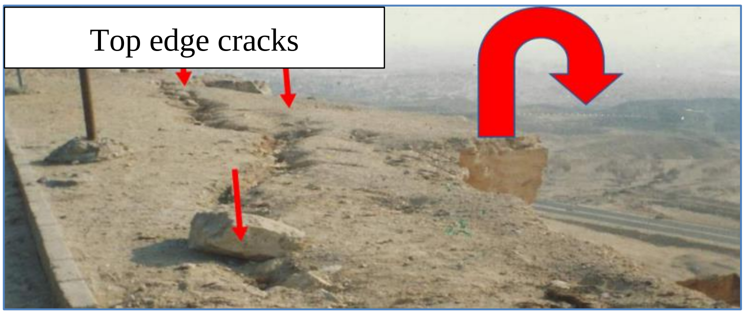
The second process is the flow of water through the pores of limestone rocks, the pores of which range between 7.5– 22.3% in cubic centimeters**.** The percentage of water absorption ranges between 3.06- 9.15 % (Remote Sensing Authority**,** 1997) until it reaches the layer detector at the slope, and its exit in the form of seepage (Picture 9). This leads to the separation of the rock particles that make up the slope in the form of loose grains from its surface**.** With the continuation of this process, it causes the removal of a certain weight from the layer over time, which undermines and decays the layers of the slope, and affects its stability, or the form of avalanche as happened next to the Ain Mossa stream.

Picture 9: Water Leakage from the Vertical Cliffs in Al-Duwaiqa Area on the Western Slope of the Plateau

Sudden drop of water adjacent to the slope: Rapid water withdrawal near steep slopes leads to the subsidence of the subsurface layers and thus their collapse due to the low water level, which causes an increase in shear stress, and increases the additional leakage of groundwater to the withdrawal area, thus increasing the chance of slope collapse**.** This is what was seen in the field study in the south of Al-Imam Al-Shafi'i neighborhood, near the edge of the tombs: Groundwater drawing machines in preparation for the establishment of new urban areas.

Slope angle: The angle of the slope affects the extent to which the slope materials retain rainwater and their infiltration, and therefore is a major reason for the stability or collapse of the slope.

Vibrations: Vibrations cause the collapse of the slopes of the hill or the collapse of blocks of the hilly compound if the mass of the slopes is subject to vibration, whether these vibrations originate from seismic waves, construction equipment, or heavy trucks passing on their roads, especially the ring road**.** This is due to the fact that they work to decrease the pressure between the grains, increase the neutral pressure and lead to the collapse of the entire ramp block. The field study revealed the presence of cracks parallel to the northwestern edge of the plateau, which prepares the ground for its collapse (Fig. 10).



Source: Based on the field study.

Picture 10: Blocks Ready to Collapse

C- Predictability of Collapses

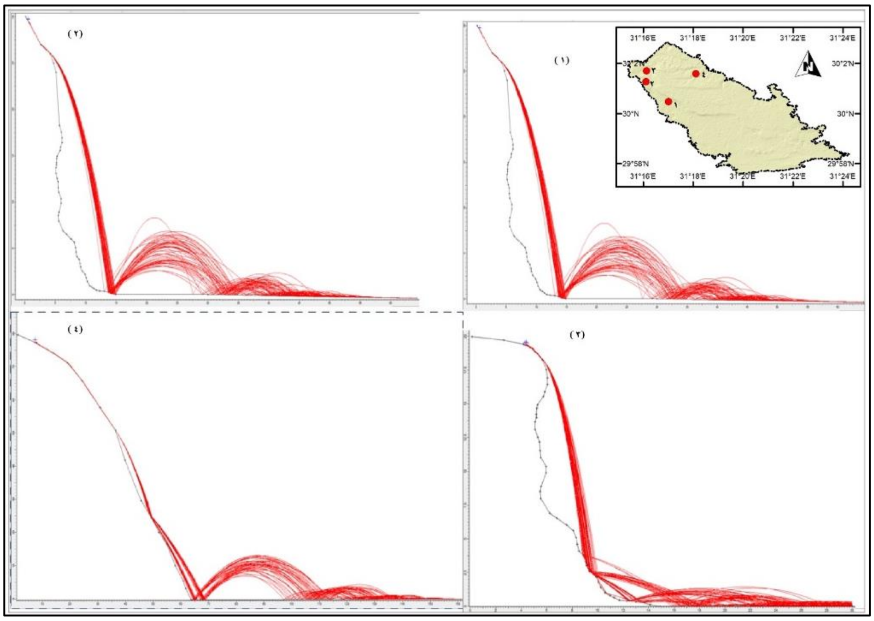
Forecasts of collapsible slopes are focused on the spatial probability of a landslide occurring in a specific area. The forecast can be divided into two parts: physical and technical, and they can be presented as follows:

-Physical prediction: There is some physical and geotechnical information related to the rock layers that can be relied upon to derive the engineering deformation that may affect them in the future. It was shown that the layers of limestone were exchanged with the shale in the upper plateau (below the city of El-Mokattam) in particular. The layer of the sandy shale with a sharp bulge is found at a depth of 10m from the surface with a thickness of 8.6m (Remote Sensing Authority 1997, p. 155)**.** In the event that it reaches the leaking water, it will turn into a paste due to its high liquidity and lead to the slipping of the upper layer with its construction, and there will be an eclipse in the city and cracks and collapses of its buildings. The limestone rock masses above it on its steep southern slope, which rises to 70m above the lower plateau, may separate and fall down the slope with its structures.

The radar waves revealed the presence of cavities and cracks at a depth of 10m from the surface of the central plateau in the limestone formations, whose pressure is reduced by half when saturated with water (Remote Sensing Authority, 1997, p. 161). The large number of old sub-surface faults when they reach the seeping water become underground sewers that expand due to the processes of dissolution of limestone components by acid water, which creates the opportunity for the collapse of its roofs due to the high pressure from the constructions on its surface. The northern, northwestern and southern slopes, and the internal edges are characterized by their steep slopes and heterogeneous geological formations. When they reach the seeping waters and emanate from the exposure of their layers, they become subject to collapse.

-**Technical forecast:** The technical forecast is based on field data for spatial sectors of selected sites for models of slopes on the rocky edges, and includes the elements of the slope with its degrees of slope and height and the distance to roads or urbanization. These factors were used to analyze the spatial relationship between them and the occurrence of the landslide, by re-drawing their dimensions on the Rockfall software to model the possible paths for the movement of rock materials, and the size of the rock masses of one ton was fixed as an input to the program (Fig. 14).

This method aims to perform a simulation about the predictive capabilities of four models of rock fall-off in the plateau slopes, and it is a method to assess the extent of their impact on the occupancy adjacent to the edge. In the first model, the rock falls from a height of 30m and hits the ground, then bounces up about six meters, fragmenting and making an acute angle with the axis of its fall and in an arc shape. In the second, it falls from a height of 80m, bounces up after the impact about 13m, falls back at a distance ranging between 35-25m, and then rolls back for a distance of more than 90m..



Source: Based on Rockfall.

Fig. 14: Simulation of Rockfall in Places from the Slopes of the Plateau

Conclusion and Results

1- El-Mokattam Plateau suffers from environmental problems due to faulty engineering techniques and insufficient consideration of the impact of geology and geomorphology on it, which did not take into account preventive measures to maintain the stability of its slopes**.** This, in turn, increased the frequency of landslides during the past three decades, and resulted in loss of life and property.

2-The city of El-Mokattam was built before 1967on the surface of the plateau and its sewage was disposed of at the bottom of the plateau, which led to the emission of water in Ain Mossa stream. The environmental leakage of irrigation water from excess plants below the surface, as well as the sewage water of the dilapidated networks in the old city of El-Mokattam, led to an increase in the surface wetlands, which exceed 5km^2, most of them in the upper plateau. The road ascending to the upper plateau from the east and descending to the west towards Salah Salem Road is threatened at any time by the process of rockfall.

3-It was found that the surface of the upper plateau has eroded due to the presence of a layer of sandy shale at a depth of 10m from its surface. When it reaches the leaking water, it will expand and increase in size and turn into a paste and increase its fluidity, in addition to the large number of faults and sub-surface cavities that may collapse their roofs due to the increase in pressure on them, and the pressure of stone formations decreases**.** The limestone is halved when it becomes saturated with water. The danger lies in the precipitation process in the areas adjacent to the northwestern edge (Nasser institution, Al-Duwayqa and Al-Abagiya), the edge of the graves to the south, and the southern interior edge separating the upper and lower plateaus.

Recommendations

- Removal of urbanization near the edges of the plateau.
- Lining artificial lakes and irrigating gardens by sprinkling, not by immersion.
- Monitoring changes in the level of water seeping under the surface.
- Installing tilt sensors on the front of slopes and forecasting what will happen in order to provide technical support and implement safety solutions for them before the disaster strikes.
- Making artificial holes in the surface of steep slopes, and the ground radar measures the movement with high accuracy of the potential deep slip surface of the avalanche.
- Monitoring the detected cracks and measuring the displacement and deformation accurately using (GPS) through a reference point, and readings are to be taken once in a while.

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منحدرات هضبة المقطم

(دراسة في الجيومورفولوجيا الهندسية)

مستخلص

تهتم الجيومورفولوجيا الهندسية بالتحديات الجديدة لتغير المناخ، والتدخل البشري بزيادة الاستخدام الأرضي، ويُنظر لها الآن كشريك لا غنى عنه في الهندسة المدنية كعلم من العلوم التطبيقية، وذلك من خلال دراسة الخصائص المورفولوجية لمنحدرات سطح الأرض وعمليات تشكيلها، مع اهتمام خاص بدراسة خصائصها الهندسية وسلوكها بهدف وضع حلول للمشاكل المعقدة التي قد تنتج عنها، وتوفر المعرفة الجيومورفولوجية لدينامية الشكل الأرضي سواء قصيرة الأجل أو الطويلة خرائطاً توضح الاشكال الجيومورفولوجية المختلفة وآثارها المحتملة على الهياكل الهندسية والأنشطة البشرية، وتعد الجيومورفولوجيا الهندسية مجالًا تطبيقيًا جديدًا لتحديد وتقييم أداء المنحدرات من خلال خصائصها كأساس للحلول الهندسية. وتواجه هضبة المقطم حاليًا خطورة التدهور البيئي لمنحدراتها بسبب التطور الديناميكي الذي حدث لسطحها

بزيادة استعمالات الأراضي لإنشاء مجتمعات عمرانية مستدامة، ونتج عن سوء الاستخدام تسرب المياه إلى الطبقات تحت السطحية مما تسبب في حدوث عدداً من الانهيالات من حوافها أدت لخسائر في الأرواح والممتلكات، وغدت تمثل خطرًا على ساكنيها.

الكلمات المفتاحية: الجيومورفولوجيا الهندسية، المنحدر، هضبة المقطم، الخصائص المورفولوجية، استخدامات الأرض.