Engineering Geomorphology and Geotechnical Assessment of Wadi Abu Daraj, El-Galala Plateau Using Geomatics Applications

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Abstract

Wadi Abu Daraj is located on the eastern edge of El-Galala Plateau on the western coast of the Gulf of Suez. Recently, it has witnessed manifestations of large-scale human change, which appeared in the form of building roads as well as urban and tourist facilities. Work still continues to modify the topography of the wadi in preparation for establishing many engineering facilities. The research aims to assess the relationship between physical determinants and hazards, and human uses through geomatics applications, particularly the assessment of methods of protection from the hazards of slopes and flash floods so as to identify the extent of their effectiveness in regard to engineering facilities and sustainable development projects, and they turned out to be convenient to a large extent for the places and degrees of danger. However, they need to be periodically purified and maintained, particularly the methods of protection from the hazards of flash floods.

***Keywords*:** Engineering Geomorphology, Geotechnical, Abu Daraj, Geomatics, Sustainable development.

الجيومورفولوجيا الهندسية والتقييم الجيوتقني لوادي أبودرج بهضبة الجلالة البحرية باستخدام تطبيقات الجيوماتيكس

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مستخلص

يقع وادي أبودرج بالحافة الشرقية لهضبة الجلالة البحرية على الساحل الغربي لخليج السويس، وقد شهد في الفترة الأخيرة مظاهر من التغيير من قبل الإنسان واسع النطاق، والذي ظهر في صورة إقامة طرق ومنشآت عمرانية وسياحية، ومازال العمل مستمر في تعديل طبوغرافية الوادي تمهيداً لإنشاء العديد من المنشآت الهندسية. ويهدف البحث إلى تقييم العلاقة بين المحددات والأخطار الطبيعية والاستخدامات البشرية وذلك عن طريق تطبيقات الجيوماتيكس، وخاصة تقييم وسائل الحماية من أخطار المنحدرات والسيول للتعرف على مدى فعاليتها بالنسبة للمنشآت الهندسية ومشروعات التنمية المستدامة، والتي تبين أنها تتناسب إلى حدٍ كبير مع مواضع ودرجات الخطورة، ولكنها تحتاج إلى تطهير وصيانة بصفة دورية وخاصة وسائل الحماية من أخطار السيول.

الكلمات المفتاحية: الجيومورفولوجيا الهندسية، الجيوتقنية، أبودرج، الجيوماتكس، التنمية المستدامة.

Introduction:

Engineering geomorphology is one of the significant topics that give geography an applied scientific aspect, and make it a science that is related to human problems and interested in finding solutions to them.

It provides practical support for engineering decision making (project planning, design and construction). Engineering geomorphologists need to work as part of an integrated team and provide information at many levels, ranging from crude qualitative approximations to quantitative analyses. The level of precision and understanding required needs to be sufficient for a particular problem or context, to enable an adequately informed decision to be made (Fookes, et al., 2007).

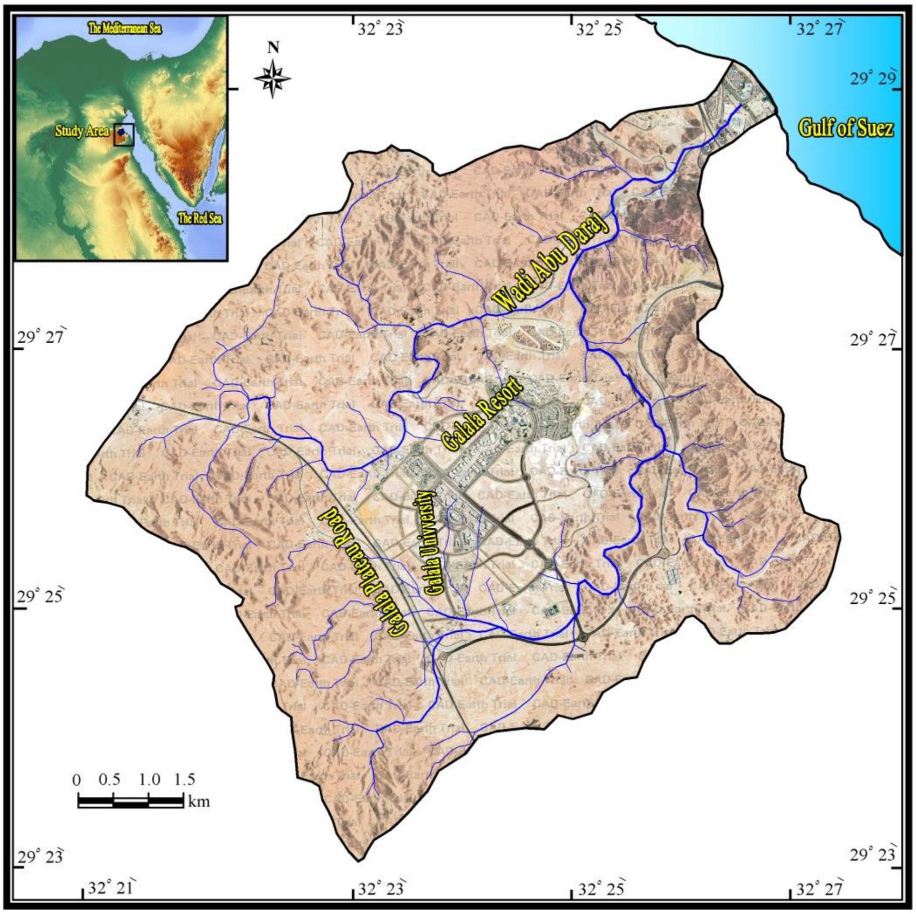
The study aims to assess the interaction between two basic dimensions: the environment, represented in the characteristics of the site and location, and human activity, as well as the interrelationship between them, and then come up with suggestions and recommendations to solve current or potential problems and hazards in the future in order to achieve sustainable development.

To achieve the objective of the study, Wadi Abu Daraj is chosen at the eastern edge of El-Galala Plateau on the western coast of the Gulf of Suez, where it is located between latitudes 29° 23' 02" and 29° 29' 15" north, and longitudes 32° 20' 41" and 32° 27' 21" east, with an area of 66.39 km^2. The area of Wadi Abu Daraj is chosen as the subject for the study, where the value of the role played by physical conditions and the status of the human factor are manifested. This factor, which could not stand idly by in front of the physical determinants of sustainable development, led to changing the topographic features and overcoming the obstacles encountered so as to show a new picture of life in this area.

Accordingly, the research is classified into the following topics:

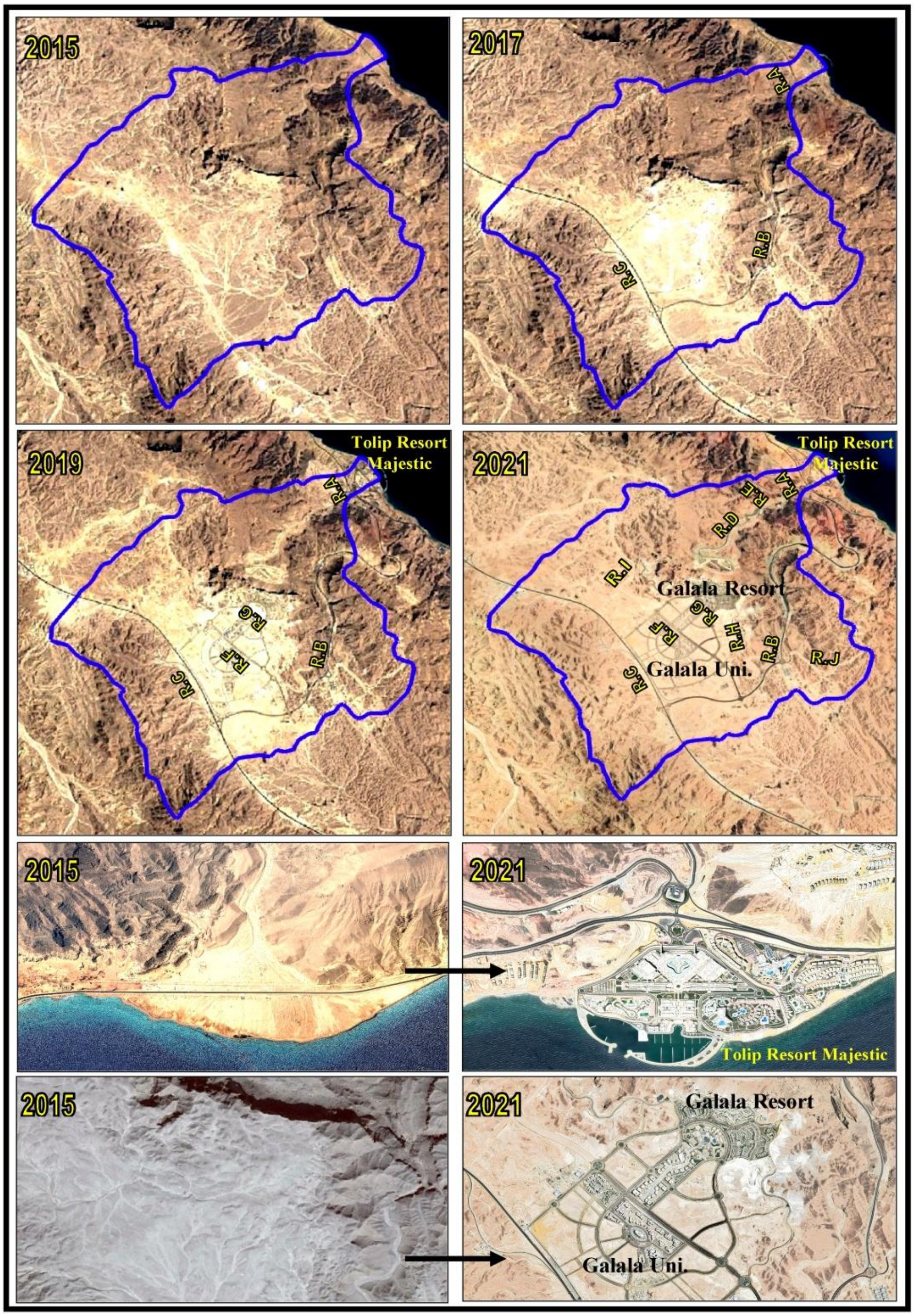
First: Human Use of Wadi Abu Daraj.

The area of Wadi Abu Daraj has recently witnessed manifestations of large-scale human change. Its high surface, distinctive appearance, and location on the Gulf of Suez were elements that made it a theater for human intervention, which appeared in the form of building roads, urban facilities and tourist villages, and the forms of change can be traced as follows (Fig. 1, 2, 3 and 4):



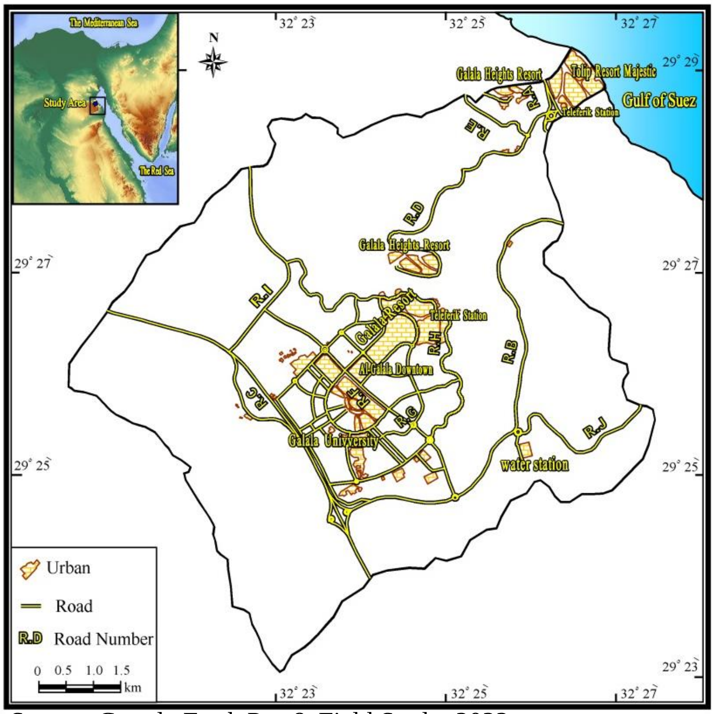
Source: Google Earth Pro & Topographic Maps, Scale 1:50000, 2006

Fig.1: Wadi Abu Daraj



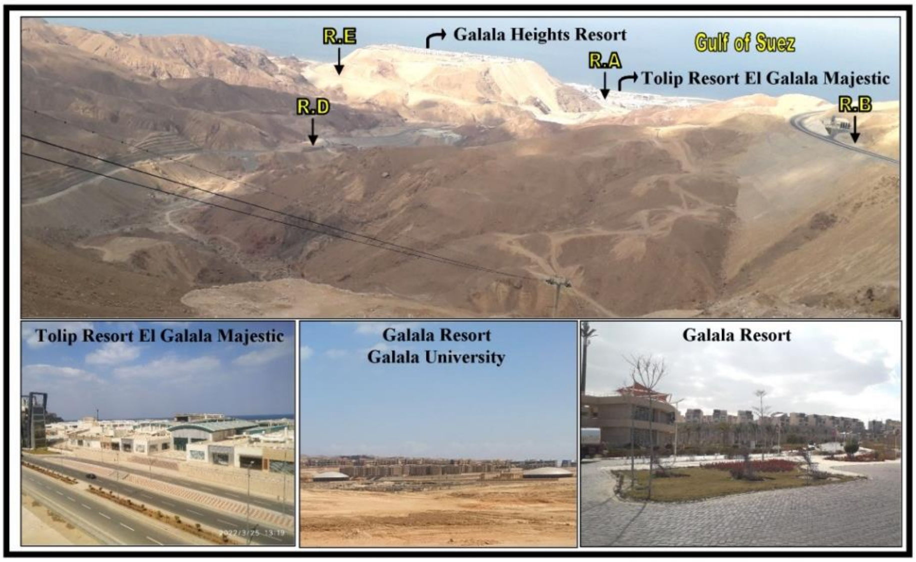
Source: Google Earth Pro.

Fig. 2: Evolution of human use of Wadi Abu Darj



Source: Google Earth Pro & Field Study, 2022

Fig. 3: Human Use of Wadi Abu Daraj, 2022



Source: Field Study, 2022

Fig. 4: Human Use of Wadi Abu Daraj

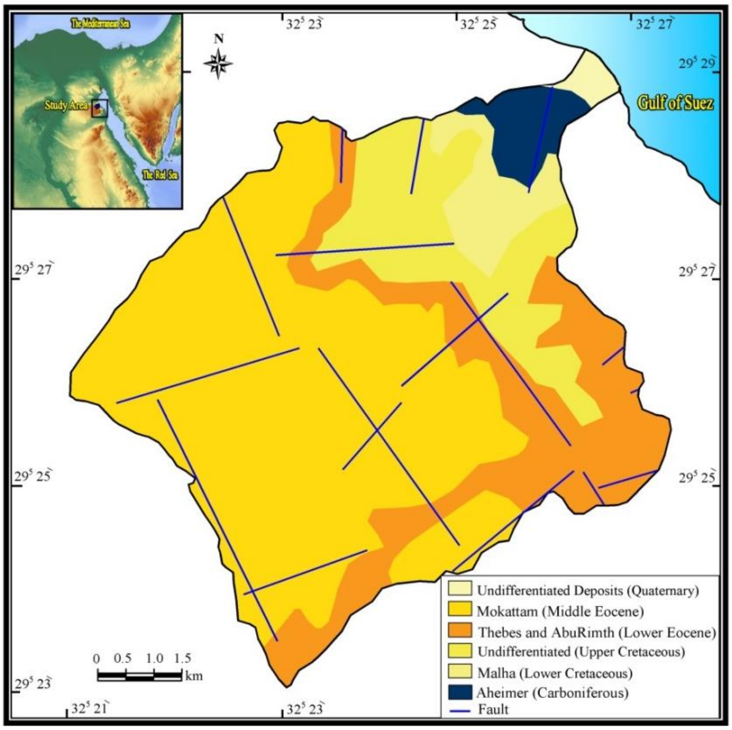
Wadi Abu Daraj did not witness any human intervention during the twentieth century and the beginning of the twenty-first one, except for the construction of the old coastal road (Suez-Hurghada) within the narrow coastal plain. This has changed since 2017, with the construction of a new coastal road R.A instead of the old road inland at the expense of high areas with a length of 0.7 km inside the study area, to provide space for the establishment and expansion of the urban space for the village of Tolip Resort El-Galala Majestic. It was followed by large-scale modifications, as the year 2017 is considered the year that most witnessed a boom in the construction of resorts, tourist villages and roads, and the following were established: Bobos Water Sports Aqua Center, Tolip Resort El-Galala Majestic, El-Galala Food Court, El-Galala Resort Ain El-Sokhna, El-Galala Cable Car G1 on the eastern side, particularly the alluvial fan, El-Galala Road (Ain El-Sokhna–Zafarana) R.C with a length of 7.3 km, and El-Galala Watanya Gas Station on the western side, particularly the level surface of the plateau. In addition, there were the construction of transverse roads linking the coastal road to El-Galala road, such as the R.B road with a length of 8.6 km, and the preparation for the construction of the internal roads of El-Galala city, as well as the two roads of R.E with a length of 1.5 km and R.D with a length of 6.7 km, and they were completed at the beginning of 2018. During this year, the R.G road was constructed with a length of 8.5 km, the R.H road with a length of 9.2 km, and the R.F road with a length of 5 km, El-Galala Cable Car was completed into the city, El-Galala Mountain Mosque was built, and some urban facilities were established within the city such as the Panorama Restaurant, El-Galala Resort, Monte Galala Facility and Asnaf Restaurant. In the same year, the inauguration of El-Galala University began.

The year 2019 witnessed the establishment of many service facilities such as Galala Plateau Corniche and Al-Marg–El-Galala Station. In the middle of 2020, a fundamental change occurred in the topography of Wadi Abu Daraj with the construction of El-Galala Heights Resort, the completion of R.F and R.G roads and most of the R.H road, the preparation for the construction of the R.I road with a length of 4.0 km and the R.J road with a length of 3.8 km, and the increase in the urban space of El-Galala University with its faculties and El-Galala hospital. In the middle of 2021, the pavement of the R.H road, the university facilities, and the completion of the unpaved R.I road were completed. Work still continues intensively until the present time in modifying and leveling large areas of Wadi Abu Daraj in preparation for establishing many engineering facilities.

Second: The Physical Determinants of Human Use in Wadi Abu Daraj.

1- Geological Characteristics:

Studying the stratigraphic sequence of rocks and knowing their lithological characteristics are of great importance to assess the situation in Wadi Abu Daraj area, which is witnessing a large-scale urban expansion due to the implementation of many engineering projects, and the avoiding of the expected geomorphological hazards. The following deals with the geological formations (Fig.5) and (Table 1):



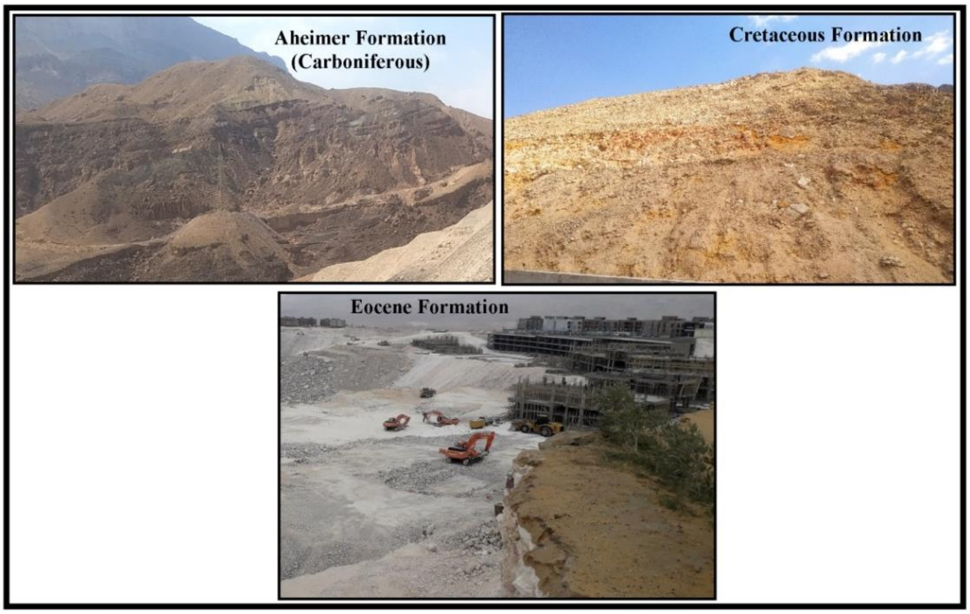
Source: Geological Maps (CONCO) 1: 500.000, 1987.

Fig. 5: The Geological Characteristics of Wadi Abu Daraj

Table 1: Formations and Geological Deposits of Wadi Abu Daraj

Ears and Ages	Formation and Deposits	Area (km^2)	Area (%)
Quaternary	Undifferentiated Deposits	0.62	0.93
Eocene (Tertiary)	Mokattam Formation	37.02	55.76
	Thebes and AbuRimth Formation	14.04	21.15
Cretaceous (Secondary)	Undifferentiated Upper Formation	9.33	14.06
	Malha Formation	3.16	4.76
Carboniferous (Primary)	Aheimer Formation	2.22	3.34
Total		66.39	100

Source: Based on Figure (5) using Auto CAD Civil 3D.



Source: Field Study, 2022

Fig. 6: Geological Formations of Wadi Abu Daraj

A- Aheimer Formation (Primary):

Carboniferous formations consist of sandstones interchanged with layers of shale and dolomite (Abdelazeem, et al., 2019), and cover an area of 2.22 km^2 and a percentage of 3.34%. They are represented in the Aheimer Formation, which is 175 m thick (Kora, 1998) and occupies areas of low and medium altitude in the lower sector of Wadi Abu Daraj, and through which pass three roads: the R.A coastal road, and the two roads of R.D and R.E. It appears sporadically in some areas as a result of being affected by a fault extending from the northeast to the southwest. The Aheimar Formation is also affected by erosion factors, particularly water erosion, which resulted in spreading the phenomenon of undercutting and the retreat of edges.

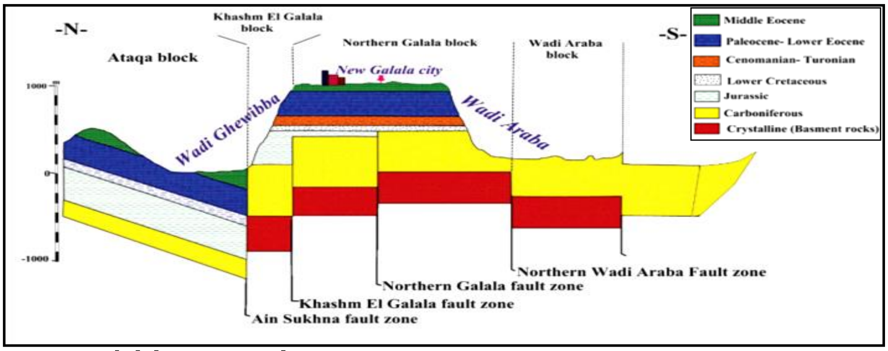
B- Cretaceous Formation (Secondary):

Cretaceous formations appear in the fault edge range along the cliff fronts, which lie northeast of Wadi Abu Daraj Basin near the Gulf of Suez, with an area of 12.49 km^2 and a percentage of 18.82%. Two roads pass through these formations, one of which (R.B) extends from El-Galala road until it meets the coastal road, and the other (R.D) consists of two formations, namely: Malha Formation, the oldest Cretaceous rock, which consists of coarse-grained to fine-grained white sandstone layers and kaolin shale (Abdel-Gawad, et al., 2006) and is characterized by its clastic nature, as more than 90% of its rocks are sandstone, alluvial stones and claystones (Abd-Elshafy and Abd El-Azeam, 2010). The second Undifferentiated Upper Formation is characterized by the diversity of its composition of sandstones, limestones and chalkstones.

The porosity of the Cretaceous formations ranged between 1.0% and 6.74%, and its decrease is due to the processes of Recrystallization, Cemenation and Micritization, which increase the strength of the rock that ranges between 53.0 and 58.5 Mpa. This means that it falls in the category of hard rocks according to the Egyptian code (Al Shakr, 2021). However, the Cretaceous formations are characterized by the plenitude of joints and cracks, and the heterogeneity of their composition, which led to the retreat of edges and their manifestation in the form of cliffs.

C- Eocene Formation (Tertiary):

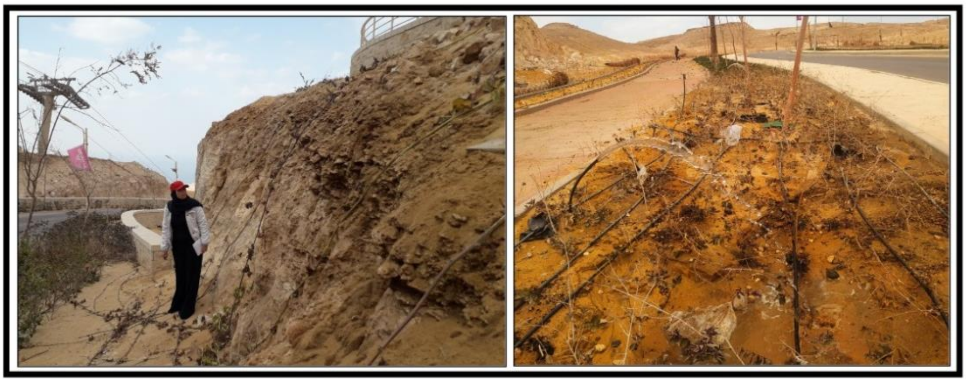
Eocene formations cover the vast majority of Wadi Abu Daraj, with an area of 51.06 km^2 and a percentage of 76.91%. They appear in the form of a longitudinal zigzag line that extends from the north of the study area to its south, cutting through areas whose levels range between 700 and 900 m, and which are being cut through by R.C, R.B and R.J roads. It occupies the upper part of El-Galala Plateau, which is the bedrock of El-Galala city (Fig. 7), and is being cut through by a network of internal roads. It consists of Thebes and AbuRimth Formation, which consists of chalky limestone and chert nodules (Abdelazeem, et al., 2019); and Mokattam Formation, which consists of limestone, dolomitic limestone and dolomite. It is considered the most widespread formation, and is characterized by the prevalence of processes of Recrystallization, Cemenation and Micritization, particularly along the main fault range (Abdelazeem, et al., 2019).



Source: Abdelazeem, et al., 2019

Fig. 7: The Structural and the Stratigraphic Setting of the Lithological Succession beneath the New Galala City

The porosity of the Eocene formations in Wadi Abu Daraj ranges between 0.25% and 15% (Al Shakr, 2021). They are also characterized by the plenitude of joints and cracks. Due to the abundance of water resulting from human intervention in the recent period (Fig. 8), Karst phenomena spread on a large scale, causing many holes and sinkholes (Fig. 9) because of the solubility of limestone, which in turn caused many engineering problems in the study area such as the process of rockfall and subsidence.



Source: Field Study, 2022

Fig. 8: Water Resources Resulting from Human Activity in Wadi Abu Daraj

Source: Field Study, 2022

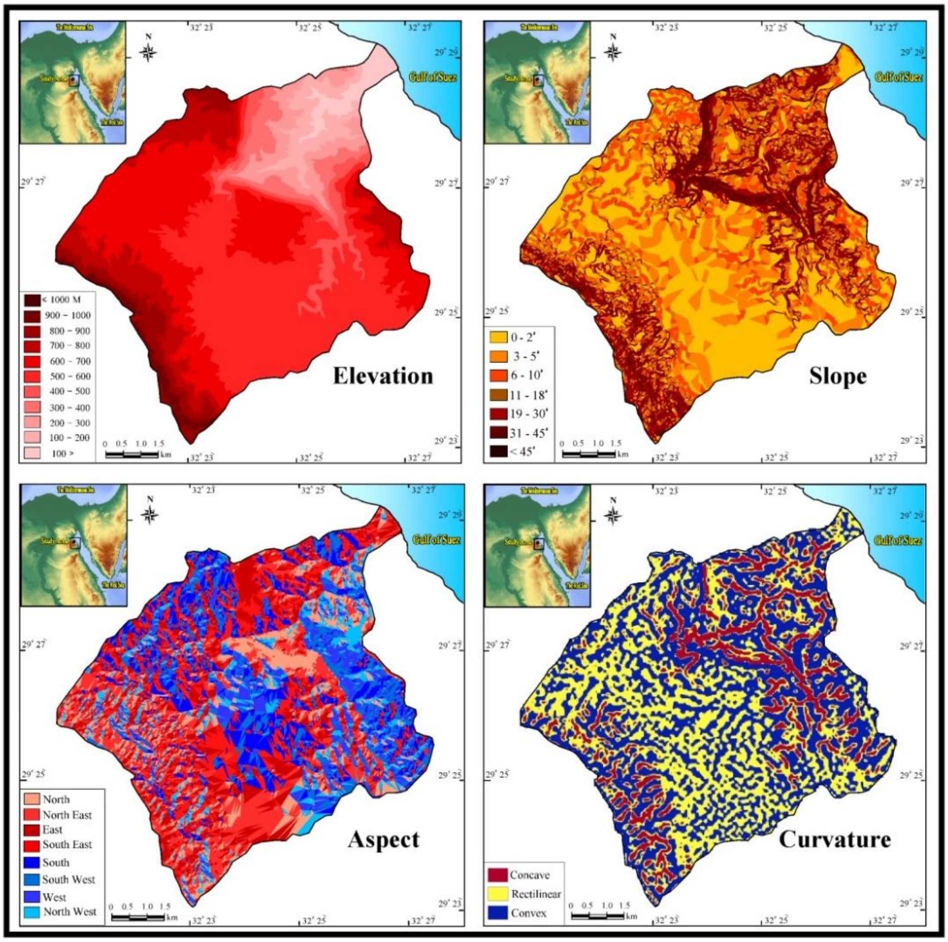
Fig. 9: The Effect of the Karst Process on the Eocene Formations of Wadi Abu Daraj

D-Undifferentiated Deposits (Quaternary):

The undifferentiated deposits occupy a limited area of Wadi Abu Daraj, reaching 0.62 km^2 and a percentage of 0.93%, and are represented by the alluvial fan sediments that consist of shale, marl and gravel. Their features have vanished and turned into the village of Tolip Resort El-Galala Majestic.

2- Topographical Characteristics:

Topographical characteristics are the main physical indicators and determinants of human activities, as they identify areas suitable for sustainable development in its various forms, as well as predicting the hazards that engineering facilities may be exposed to, and identifying and evaluating appropriate methods of protection (Fig. 10) and (Table 2).



Source: Topographic Maps, Scale 1:50000, 2006 using Auto CAD Civil 3D & ArcMap10.5

Fig. 10: The Topographical Characteristics of Wadi Abu Daraj

Table 2: The Topographical Characteristics of Wadi Abu Daraj

Elevation			Aspect		
Categories (M)	Area (km^2)	Area (%)	Categories	Area (km^2)	Area (%)
100 >	1.84	2.8	North	8.51	12.8
100-200	3.04	4.6	North East	11.44	17.2
200-300	3.61	5.4	East	10.45	15.7
300-400	2.92	4.4	South East	8.84	13.3
400-500	3.23	4.9	South	8.73	13.1
500-600	21.78	32.8	South West	6.57	9.9
600-700	17.82	26.8	West	6.14	9.2
700-800	7.47	11.3	North West	5.71	8.6
800-900	2.99	4.5	Total	66.39	100
900-1000	1.40	2.1			
< 1000	0.29	0.4			
Total	66.39	100			

Slope			
Categories (degrees)	Slope Type	Area (km^2)	Area (%)
0-2	Level	21.34	32.1
3-5	Gentle	8.97	13.5
6-10	Moderate	7.72	11.6
11-18	Moderately Steep	10.09	15.2
19-30	Steep	11.69	17.6
31-45	Very Steep	5.55	8.4
< 45	Cliffs	1.03	1.6
Total		66.39	100

Curvature		
Type	Area (km^2)	Area (%)
Concave	9.75	14.69
Rectilinear	25.88	38.98
Convex	30.76	46.33
Total	66.39	100

Source: Based on Fig. (10) using Auto CAD Civil 3D.

A – Elevation:

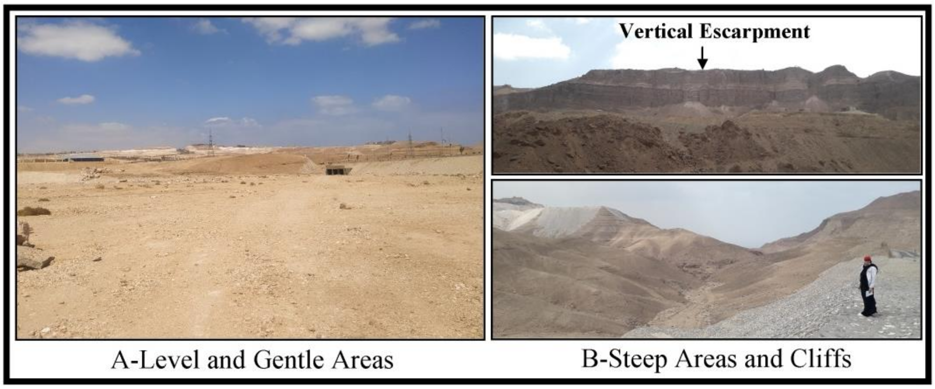
Elevations are increasing in the direction from east to west in Wadi Abu Daraj, starting from zero level represented by the coast line in the east to the level of 1160 m in the western slopes (Fig.10) and (Table 2). The areas below the level of 400 m occupy an area of 11.4 km^2 and percentage of 17.2%, and cover the alluvial fan and the lower sector of Wadi Abu Daraj, while the areas whose level ranges between 400 and 800 m occupy an area of 50.3 km^2 and a percentage of 75.8%, represent the bottom of the main fault edge slopes and most of the surface of the plateau, and are occupied by a large part of the facilities of El-Galala city to benefit from the elevation factor in decreasing temperature. As for the areas whose level exceeds 800 m, they occupy an area of 4.68 km^2 and percentage of 7.0%, covering the western edges of Wadi Abu Daraj.

B – Aspect:

The study and analysis of aspects aim to determine the direction of movement of masses, rock debris, and flash floods over engineering facilities. It is evident from Figure (11) and Table (2) that the surface of the study area descends in general to the northeast and east with percentages of 17.2% and 15.7% respectively. This aspect is consistent with the natural direction of the flash flood, as Wadi Abu Daraj descends from the southwest to the northeast to flow into the Gulf of Suez. As for the other aspects, they range between 8.6% and 13.3%, and they mostly descend into the wadis scattered in the study area.

C – Slope:

Wadi Abu Daraj descends in general from the southwest to the northeast (Fig. 11) and (Table 2). Level and gentle areas occupy the first place with an area of 30.3 km^2 and a percentage of 45.6%, and they are focused in the alluvial fan, the surface of the plateau, and the lower sector of Wadi Abu Daraj, as well as on its beds, estuary and tributaries. Steep areas and cliffs, on the other hand, occupy the second place with an area of 18.3 km^2 and a percentage of 27.6%, and they appear on the upper and middle slopes on the mountain edges that represent the upstreams of the tributaries of Wadi Abu Daraj, on the upper slopes of the fault edge, and on the mountain peaks in their upper sectors. Vertical cliffs occupy the vertical fault edges and mountain peaks that appear in most of its sectors in the form of vertical walls.



Source: Field Study, 2022

Fig. 11: Variation of Slopes in Wadi Abu Daraj

D – Curvature:

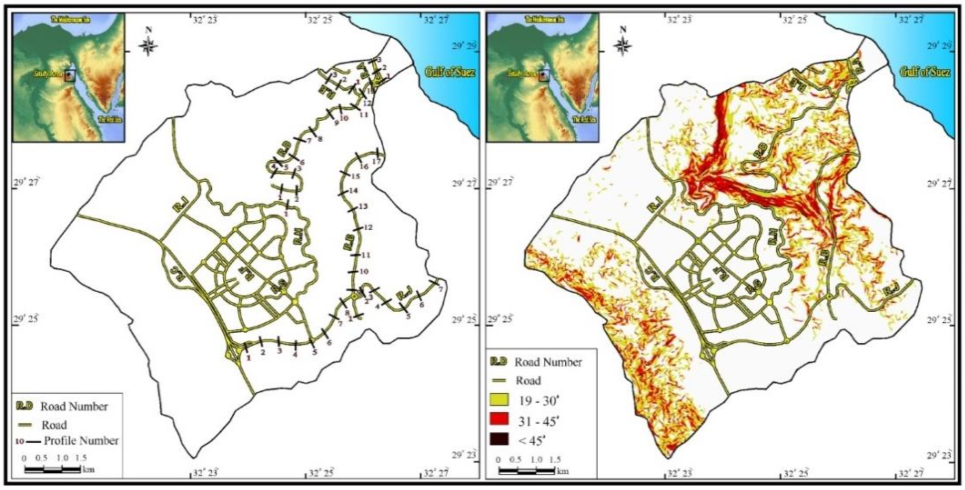
The shape and degree of the curvature help with the continuity of the disintegration and fragmentation processes, and the degree of stability of the masses and debris above it. The analysis of Fig. (11) shows that the concave elements cover an area that does not exceed 15% of the total study area, while the vast majority of the area of Wadi Abu Daraj lies within the convex elements, covering nearly half of the area with a percentage of 46.33%, followed by the rectilinear ones with a percentage of 38.98% that spread on the surface of the plateau in particular. Hence, the basic components of development are available, particularly the rectilinear sections closest to the horizontal shape.

E- Relief Profiles:

The study focuses on the morphological characteristics of the slopes on both roadsides in danger of material movement, which are six roads: R.A, R.B, R.D, R.E, R.J, R.H, and which are located in areas ranging between steep slopes and cliffs, and characterized by many bends posing a danger to road users (Fig.12). Relief profiles are made on the slopes adjacent to the roads at equal distances of 500 m, except for the two roads of R.A and R.E, as their profiles were chosen to represent the beginning, middle and end of the road, and a ground distance of 150 m was determined on both sides of the roads, right and left[1] (Fig. 13), and due to the modification of the shape of the slopes because of human intervention on the roadsides (Fig. 14), field profiles were only allowed in some locations by the use of Total Station (Fig. 15). Geomatics programs, such as AutoCAD Map 3D, Google Earth, Global Mapper and GeoRock 2D (Fig. 15), were used in the other areas. Accordingly, 44 relief profiles are drawn (Fig.16) and (Appendix.1 and 2).

Source: Field Study, 2022

Fig. 12: The Spread of Accidents on the Roads of Wadi Abu Daraj



Source: Google Earth Pro, Topographic Maps, Scale 1:50000, 2006 and Field Study, 2022

Fig. 13: Steep Areas and Cliffs, and Locations of Relief Profiles in Wadi Abu Daraj

[1] The profile number is placed on the right, and the other side represents the left of the road (Fig. 13).

Source: Field Study, 2022

Fig.14: The Effect of Human Intervention in Modifying the Slopes on Both Sides of the Roads in Wadi Abu Daraj

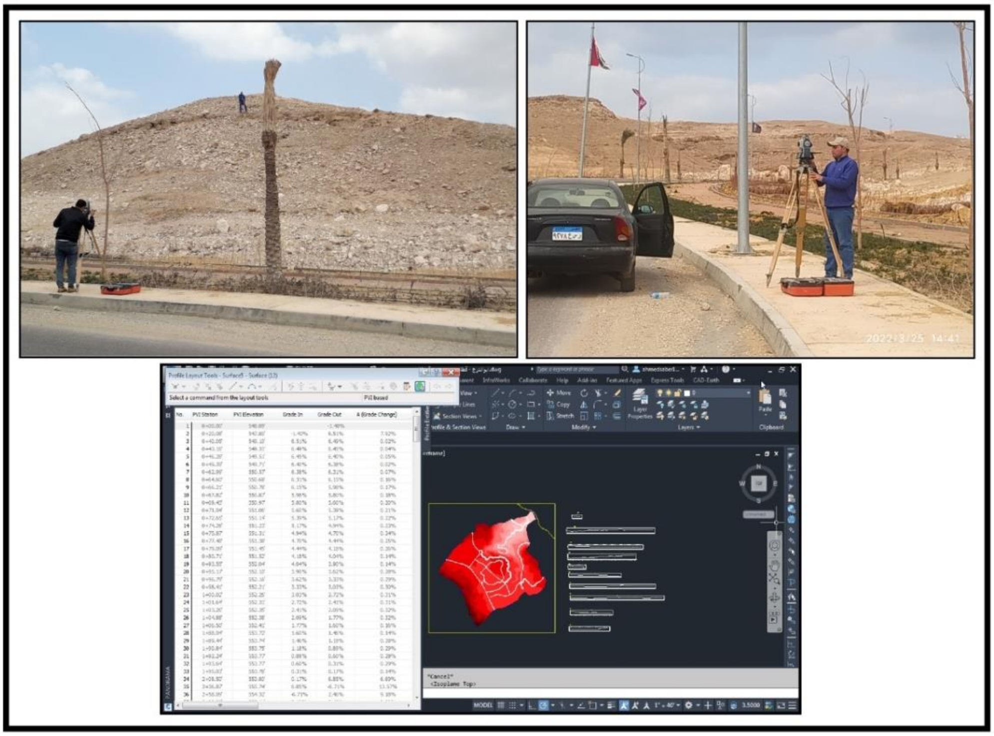
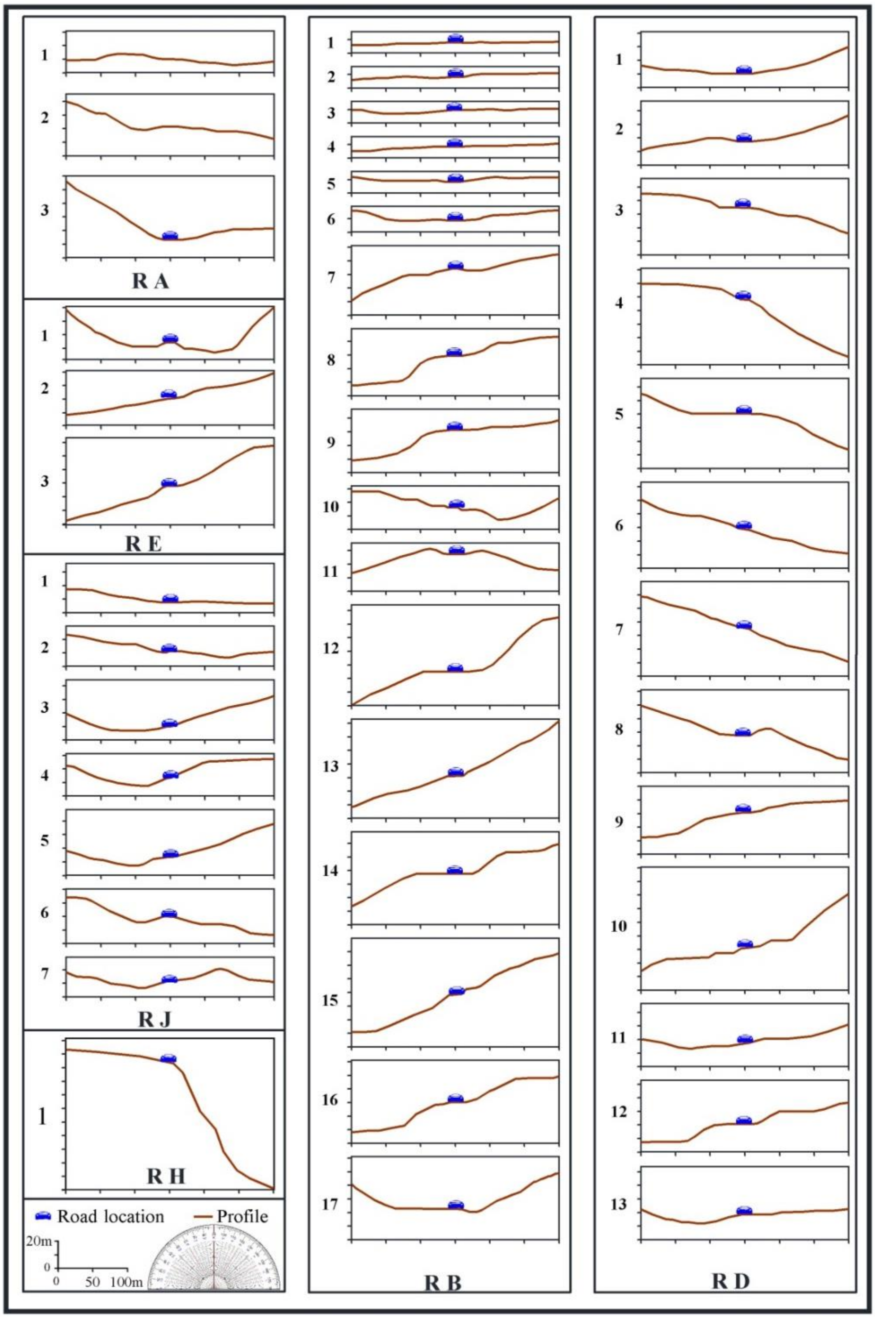


Fig. 15: The Use of Surveying Devices (Total Station) and Geomatics Programs in Drawing Relief Profiles



Source: Google Earth Pro, Topographic Maps, Scale 1:50000, 2006 and Field Study, 2022 (Total Station)

Fig. 16: Relief Profiles of the Slopes of Wadi Abu Daraj

Table (3): Characteristics of Slope Degrees of Relief Profiles in Wadi Abu Daraj

Road Name	Degree Range	Slope Type	Left		Right		Total	
			Total Length		Total Length		Total Length	
			M	%	M	%	M	%
R.A	0-2	Level	108.5	22.3	182.2	39.9	290.7	30.9
	3.0-5.0	Gentle	37.8	7.8	35.0	7.7	72.8	7.7
	6.0-10.0	Moderate	23.9	4.9	135.4	29.7	159.3	16.9
	11.0-18.0	Moderately Steep	73.8	15.2	103.6	22.7	177.4	18.8
	19-30	Steep	119.2	24.5	0.0	0.0	119.2	12.6
	31-45	Very Steep	123.5	25.3	0.0	0.0	123.5	13.1
	46-90	Cliffs	0.0	0.0	0.0	0.0	0.0	0.0
	Total		486.7	100	456.2	100	942.9	100
R.B	0-2	Level	730.3	27.0	850.3	31.4	1580.6	29.2
	3.0-5.0	Gentle	361	13.3	345.1	12.7	706.1	13.0
	6.0-10.0	Moderate	461.8	17.1	330.1	12.2	791.9	14.6
	11.0-18.0	Moderately Steep	305.7	11.3	348.4	12.9	654.1	12.1
	19-30	Steep	623.7	23.1	521.4	19.2	1145.1	21.2
	31-45	Very Steep	152.3	5.6	217.7	8.0	370	6.8
	46-90	Cliffs	70.8	2.6	97.2	3.6	168	3.1
	Total		2705.6	100	2710.2	100	5415.8	100
R.D	0-2	Level	426.6	21.1	319.3	15.5	745.9	18.3
	3.0-5.0	Gentle	274.9	13.6	125.9	6.1	400.8	9.8
	6.0-10.0	Moderate	322.7	16.0	355.3	17.2	678.0	16.6
	11.0-18.0	Moderately Steep	413.7	20.5	349.7	16.9	763.4	18.7
	19-30	Steep	390.0	19.3	618.3	29.9	1008.3	24.7
	31-45	Very Steep	191.5	9.5	217.5	10.5	409.0	10.0
	46-90	Cliffs	0.0	0.0	79.8	3.9	79.8	2.0
	Total		2019.4	100	2065.8	100	4085.2	100.0
R.E	0-2	Level	46.1	9.6	15.1	3.0	61.2	6.3
	3.0-5.0	Gentle	4.5	0.9	71.5	14.3	76.0	7.8
	6.0-10.0	Moderate	98.3	20.6	72.5	14.5	170.8	17.5
	11.0-18.0	Moderately Steep	169.0	35.4	79.5	15.9	248.5	25.3
	19-30	Steep	80.6	16.8	136.8	27.4	217.4	22.2
	31-45	Very Steep	67.6	14.1	75.9	15.2	143.6	14.7
	46-90	Cliffs	12.3	2.6	48.5	9.7	60.8	6.2
	Total		478.4	100	499.8	100	978.3	100
R.H	0-2	Level	0.0	0.0	9.0	5.8	9.0	2.3
	3.0-5.0	Gentle	0.0	0.0	43.0	27.9	43.0	10.9
	6.0-10.0	Moderate	0.0	0.0	53.0	34.4	53.0	13.5
	11.0-18.0	Moderately Steep	0.0	0.0	49	31.8	48.0	12.4
	19-30	Steep	38.0	15.8	0.0	0.0	38.0	9.6
	31-45	Very Steep	75.0	31.3	0.0	0.0	75.0	19.0
	46-90	Cliffs	127.0	52.9	0.0	0.0	127.0	32.2
	Total		240	100	154	100	394	100
R.J	0-2	Level	156.5	14.4	207.4	19.1	363.9	16.8
	3.0-5.0	Gentle	89.7	8.3	163.7	15.1	253.4	11.7
	6.0-10.0	Moderate	275.1	25.3	141.7	13.1	416.8	19.2
	11.0-18.0	Moderately Steep	253	23.3	313.5	28.9	566.5	26.1
	19-30	Steep	266.5	24.5	241.9	22.3	508.4	23.4
	31-45	Very Steep	45.5	4.2	15.8	1.5	61.3	2.8
	46-90	Cliffs	0	0.0	0	0.0	0	0.0
	Total		1086.3	100	1084	100	2170.3	100

Source: Based on Figure (10) using Auto CAD Civil 3D and appendix (1 and 2)

The analysis of the relief profiles of the slopes of the study area, Fig. (13, 14, 15 and 16), Appendices (1and 2), and the field study in 2022 shows the following:

- **Slope profiles of R.A roadsides:** Three profiles are measured on the slopes of both sides of the R.A road, with a total length of 942.9 m, representing 6.6% of the total lengths of roadside profiles, and with an overall average slope angles of 11.65°, thus the road falls in the category of moderately steep slopes. Profile (3) has the highest average degree of slope on its left side (27.3°), which has made it in the steep slope category because it represents the slopes of the fault edge that overlook the Gulf of Suez. However, its right side is located within the alluvial sediments of Wadi Abu Daraj fan, which represent the tourist village facilities, and this has made most of them fall into a category ranging between level and gentle, noting the absence of the category of vertical cliffs from all profiles.
- **Slope profiles of R.B roadsides:** Seventeen profiles are measured on the slopes of both sides of the R.B road, with a total length of 5415.8 m, percentage of 38.7%, and an overall average slope angles of 12.0°, thus making it fall in the category of moderately steep slopes. In addition, the average degree of slope ranged between 11.9° on the side left and 12.1° on the right side. The category of level and gentle slopes constituted more than one third of the total lengths of the road profiles, and profiles (1, 2, 3, 4 and 5) occupied the largest proportion of 51.9% of the total lengths of the category along the road. This is mainly due to the fact that these profiles are located on the more level surface of the plateau on which El-Galala city was built. On the other hand, the vertical cliffs category appeared in profiles 8, 9, and 16 on the left side of the road, and in profiles 12, 13, 14 and 15 on the right side, due to the cutting of these profiles through the main fault edge east of the study area. The level of many places where the road cuts through the wadi beds has also been raised to reduce the vertical distance and lower the degree of slope. However, the reason for this is to create very steep slopes down both sides of the road.

- **Slope profiles of R.D roadsides:** Thirteen profiles are measured on the slopes of both sides of the R.D road, with a total length of 4085.2 m, percentage of 29.2%, and an overall average slope angles of 13.2°, thus making it fall in the category of moderately steep slopes. In addition, the average ranged between 14.3° right of the road and 12.1° left of the road. The category of steep, very steep and vertical slopes ranked first among the lengths of the road profiles with a total of 1497.1 m and percentage of 36.7%, and the right side of the road occupies the largest proportion. Due to the fact that the road cuts through the slopes of the main fault edge, which directly overlooks the right side of the road, represented by profiles 10 and 12. It is found that the level of the R.D road in most of its parts is higher than the level of the beds of the neighboring wadis, particularly profile (4), which caused the increase of steep, very steep and vertical slopes and in the right side in particular.
- **Slope profiles of R.E roadsides:** Three profiles are measured on the slopes of both sides of the R.E Road, with a total length of 978.3 m, percentage of 7.0%, and an overall average of 18.9° slope angles, making it fall in the category of moderately steep slopes. The average slope angles along the road ranged between 20.3° right of the road and 17.4° left of the road. The proportion of the category of steep, very steep and vertical slopes is 43.1% of the total slope angles of the road profiles, while the level and gentle slopes together constitute the lowest percentage of 14.1%, and they are related to the parts on which weathering processes are active, particularly with the formations characterized by rock heterogeneity with Aheimer formation (sandstone and limestone interspersed with shale).
- **Slope profiles of R.J roadsides**: Seven profiles are measured on the slopes of both sides of the R.J Road (unpaved) with a total length of 2170.3 m, percentage of 15.5%, and an overall average of 11.4° slope angles, thus making it fall in the moderately steep slope category. The average degree of slope is 10.6° on the right side of the road, and 12.1° on the left side. The category of moderately steep slopes ranked first

with a percentage of 26.1%, and profiles (2, 3, 5 and 6) occupied the largest proportion of 83.7% of the total lengths of the category along the road, and this category was associated with the middle slopes of the mountain mass cut through by the road. As for the category of very steep slopes, they ranked last with a percentage of 2.8% and appeared only in profiles 5 and 6, while the cliffs category was completely absent in the slope profiles of both sides of the road. The impact of human intervention was also evident in the category of level and gentle slopes at 28.5% of the total angles of the road profiles, and profile (1) occupied 34.3%, particularly its right side because of the establishment of construction projects on it, which led to the leveling of the slopes and reduced the degree of their slope.

- **Slope profiles of R.H roadsides**: The R.H road is located within the roads that are safe from the danger of slopes, except for approximately 800 m, overlooking the fault edge directly. One profile was measured, with a total length of 394 m, and representing 3.0% of the total lengths of slope profiles on the roads of the study area. The vertical cliffs category ranked first with 19.0% of the total angles of the road profiles, particularly the left side of the road with 52.9%, while the right of the road recorded the highest percentage of average and moderately steep slopes, with a total of 66.2%, on which the road and the city of El-Galala are located.

The following is evident from the study of the topographical features of Wadi Abu Daraj:

Most of the urban facilities are related to the elevation factor, as about 90% of these facilities are located on levels ranging between 400 and 700 m, and are mainly concentrated in three areas. The first area includes the tourist village built on the alluvial fan, and the coastal road represents its western border. The second area is represented by the tourist village that is located at the end of R.D Road, and the fault edge, which appears in the form of vertical cliffs, is its western border. The third area is represented in most of the roads and facilities of the city of El-Galala, which are built on the most level and elevated areas, but some convex hills of varying height are spread over it. The surface of these areas is currently being levelled and constructed (Fig. 17). The mountain edge is considered an obstacle to the extension of the city to the east, and the western highlands to the west. The degrees of slope vary on both sides of the roads as there are roads located in areas whose degrees of slope range between level and moderate slopes, which are safe from the danger of slopes, particularly the internal roads in the city of El-Galala; and roads located in areas whose degrees of slope range between steep slopes and cliffs, and these roads are the ones that are vulnerable to the danger of material movement, particularly R.A, R.B, R.D, R.E, R.J and R.H roads.

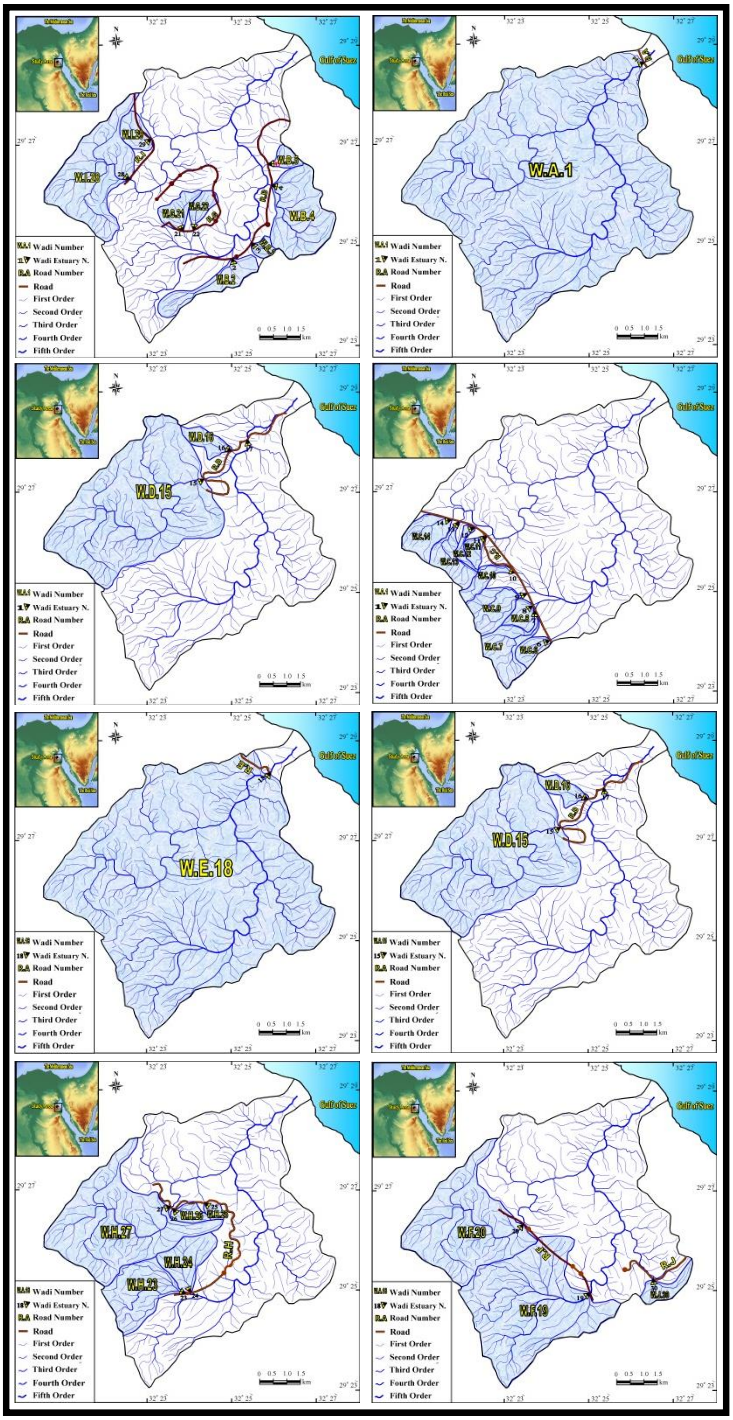
Source: Field Study, 2022

Fig. 17: The Effect of Human Intervention in the Leveling of the Convex Areas in Wadi Abu Daraj

3- Hydrological Characteristics:

The hydrological characteristics of the drainage basins are one of the most important determinants responsible for the occurrence of flash flood, and they are also a reflection of both climatic factors and the characteristics of the drainage basins, as it is through them that the amount of losses and thus the net flow can be determined.

Human activity in its various forms covers most parts of Wadi Abu Daraj basin, and therefore it is affected variably by the flow depending on its location in the basin. Accordingly, the main basin was divided into sub-basins, whose estuaries end at their intersection with human activity into 31 basins, 30 of which intersect with roads, and one basin (the main) flows into the village of Tolip Resort El-Galala Majestic (Fig.18). This is done with the aim of reaching the net flow expected to actually reach these facilities, and then determining the degree of real danger posed to each part of it.



Source: Topographic Maps, Scale 1:50000, 2006 using Auto CAD Civil 3D.

Fig.18: Drainage Basins Affecting Human Use in Wadi Abu Daraj

Wadi Abu Daraj (the main) is considered one of the extremely dangerous basins, with a total area of about 66.39 km^2[(1)], while the area of the sub-basins ranges between 0.40 and 65.56 km^2.The smallest ones have an area of less than 1.0 km^2, and they are 10 wadis, crossing the R.C, R.B, R.H and R.G roads. Their drainage density ranges between 4.40 and 5.82 km/km^2, and their slope between 2.55 and 22.55. The ones with the largest area has an area that exceeds 20 km^2, and they are 5 wadis. Their drainage density ranges between 4.20 and 5.84 km/km^2, and their slope between 5.44 and 8.82, and they intersect with R.A, R.D, and R.E roads.

The amount of rain falling on the study area increases in the north direction, reaching 35.7 mm on Suez Station, and 33.2 mm on Zafarana Station (Atallah, 2021). The study area is characterized by little rain, but there are periods in which large and concentrated amounts of rain fall, which causes flash floods. Wadi Abu Daraj was exposed to a flash flood in the winter of 2004, which resulted in the closure of the Suez-Hurghada road for a long time (Agya, 2011). However, the evaporation rate in the study area is high, reaching 11.48 mm, and evaporation values reach their peak in June up to 15.40 mm, then they begin to decline, reaching 7.40 mm in January due to the decrease in temperature in general during the winter season and the occurrence of some precipitation (Atallah, 2021).

The following deals with the hydrological characteristics of the drainage basins:

A- Hydrological Factors:

- **Lag time:** Lag time is defined as the time required from peak rainfall to peak runoff (USGS, 2012). It is clear from the analysis (Appendix.3) that the general average lag time in the drainage basins was 0.3 hours, and ranged between 0.06 hours in the W.B.5 and W.D.16 basins, and 0.93 hours in the W.D.17 basin. The decrease in the lag time was associated with small basins. Despite this fact, a very small-sized basins were found to have a high lag time such as W.B.3 basin, which has an area of 0.48 km^2 and lag time of 0.29 hours due to the increase in its slope degree (3.87).

(1) The rainstorm covers basins whose areas are less than 200 km^2 (Youssef, 1999).

- **Concentration time:** It reflects the time required for the water to travel from the most distant point on the basin perimeter to the basin estuary. Appendix (3) indicates that 80.6% of the total number of basins has a concentration time of less than an hour by 25 basins, due to the small basin areas, and consequently the decrease in losses by evaporation and leakage. However, it was found that there are small drainage basins with a concentration time higher than an hour such as W.H.24 and W.H.27 basins, due to the decrease in their slope degree.
- **Discharge time:** It is the period required for the basin to be able to discharge all of its water from the place of its fall to its exit at the basin estuary. It is evident from Appendix (3) that the general average of the discharge time is 0.07 hours, which is an average indicating the small area of the drainage basins and their main streams in general, while the rate of discharge time increases in four basins, namely W.A.1, W.D.17, W.E.18 and W.V.1, to 0.20 hours, which is reflected in the decrease in their velocity of flow.

B- Hydrological Budget of Drainage Basins:

The study of the hydrological budget aims to determine the net flow, and then to determine the degrees of danger of the drainage basins to the engineering facilities in the study area.

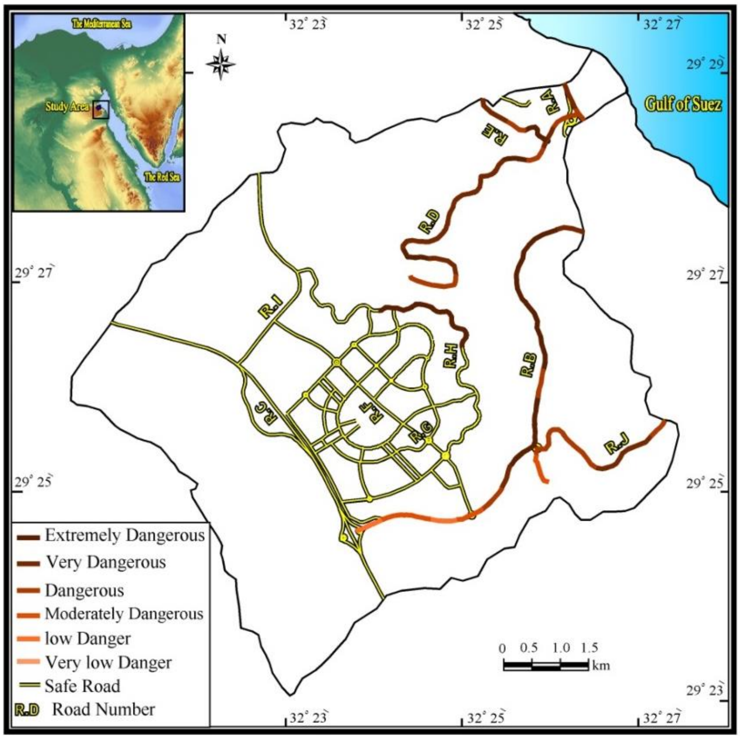
- **The amount of rainfall:** It is found from Appendix (3) that the amount of water expected to fall ranges between 4.4 million m^3 in Wadi W.A.1 and 27 thousand m^3 in Wadi W.H.25. The number of basins where the total amount of rainfall decreases 100 thousand m^3 are 14 basins, with a percentage of 45.2% of the total number of basins, and they are characterized as having small basin areas. On the other hand, the number of basins where the total amount of rainfall increases 200 thousand m^3 are 11 basins, with a percentage of of 35.4%, and they are occupied by medium and large basins.
- **Total losses (evaporation-leakage):** The amount of losses, both evaporation and leakage, affects the surface runoff process, as it affects the start of the runoff process and the possibility of whether or not it continues. It was found from

Appendix (3) that in 24 basins, representing 77.4% of the total number of basins, the total losses decrease 100 thousand m^3, ranging from 668 m^3 in the W.B.5 basin, and 91115 m^3 in the W.F.20 basin. On the other hand, the number of basins where the total losses increase 200 thousand m^3 or more, being the largest basins in area, are 4 basins represented in W.A.1, W.D.17, W.E.18 and W.V.1, with a percentage of 12.9%.

Third: Geomorphological Hazards in Wadi Abu Daraj.

1 - Degrees of Hazards of Slopes on the Roads.

The methodology for estimating the hazards of slopes on the roads of the study area depends on the highest degree of slope category in each sector separately, regardless of the ground distance it represents (Appendix 1 and 2) and (Fig. 19).

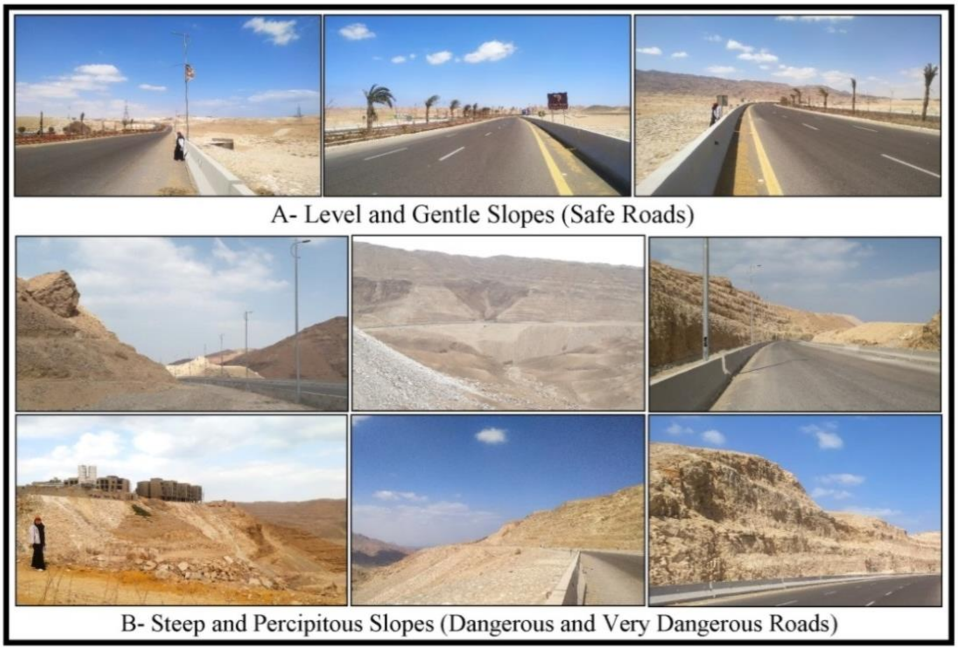


Source: Based on appendix (1) using Auto CAD Civil 3D .

Fig. 19: Dangerous Slopes on the Roads of Wadi Abu Daraj

The following is a classification of the degree of danger of the roads of the study area on this basis (Fig. 19):

- **Safe areas:** These are the roads located in the level and gentle areas with a length of 30.32 km, representing 58.8% of the total lengths of the roads in the study area. They are concentrated in the R.B road at the end of its western part; and they spread on the internal roads of El-Galala city (R.F-R.G), and represent the largest part of the R.H road, except for the part that directly overlooks the fault edge at 9.5% of the length of the road. They also spread on El-Galala Road (R.C).
- **Moderately dangerous areas:** Their length is 2 km with a percentage of 3.9%, and they are concentrated in the R.B and R.J roads at the end of each of them from the western side. The human intervention in R.J road played the main role in the emergence of these areas in its far western sector (a link between it and the R.B road). .
- **Dangerous areas:** Their length is 5.75 km with a percentage of 11.2%, and they spread on R.A, R.B, R.D, R.E, and R.J roads, ranging between 2.4 km at the beginning of R.A from the south, and 2.0 km on R.D and R.J roads. It is found that they spread along the R.J road, while they concentrate on the beginning and end of the R.D road.
- **Very dangerous areas:** Their length is 7.86 km with a percentage of 15.3%, and they spread on R.A, R.B, R.D, R.E, and R.J roads, ranging from 0.5 km in the middle and end of the R.A road, and 3.5 km on in separate parts of the R.D road, particularly in its middle.
- **Extremely dangerous areas:** Their length is 5.2 km, representing 10.8% of the total lengths of roads in the study area. They are concentrated in four roads: R.B, R.D, R.H and R.E, ranging between 0.5 km as a minimum length at the beginning of the R.E road, and 3.5 km extending along the R.B road in its eastern part to the end of the eastern border of Wadi Abu Daraj.



Source: Field Study, 2022

Fig. 20: Variation of the Degree of Slopes on the Roads of Wadi Abu Daraj

2- Flash Floods:

The importance of studying flash floods in Wadi Abu Daraj lies in the large-scale development that the wadi is witnessing. Flash floods is one of the most important hydrogeomorphological dangers to which it is exposed, particularly due to the location of some engineering facilities and roads in particular at the exits of its tributaries, and the tourist village at its estuary.

The degree of danger was estimated based on the methodology of (Saber and Al-Banna, 2013), as the danger can be represented in the form of a triangle whose three sides consist of the following: the first side, the human and what is related to him (tourist villages and roads), the second side is net flow, and the third side is the velocity of flow. What follows is a study of the dangers of flash floods in the study area. Table (4) and Fig. (21).

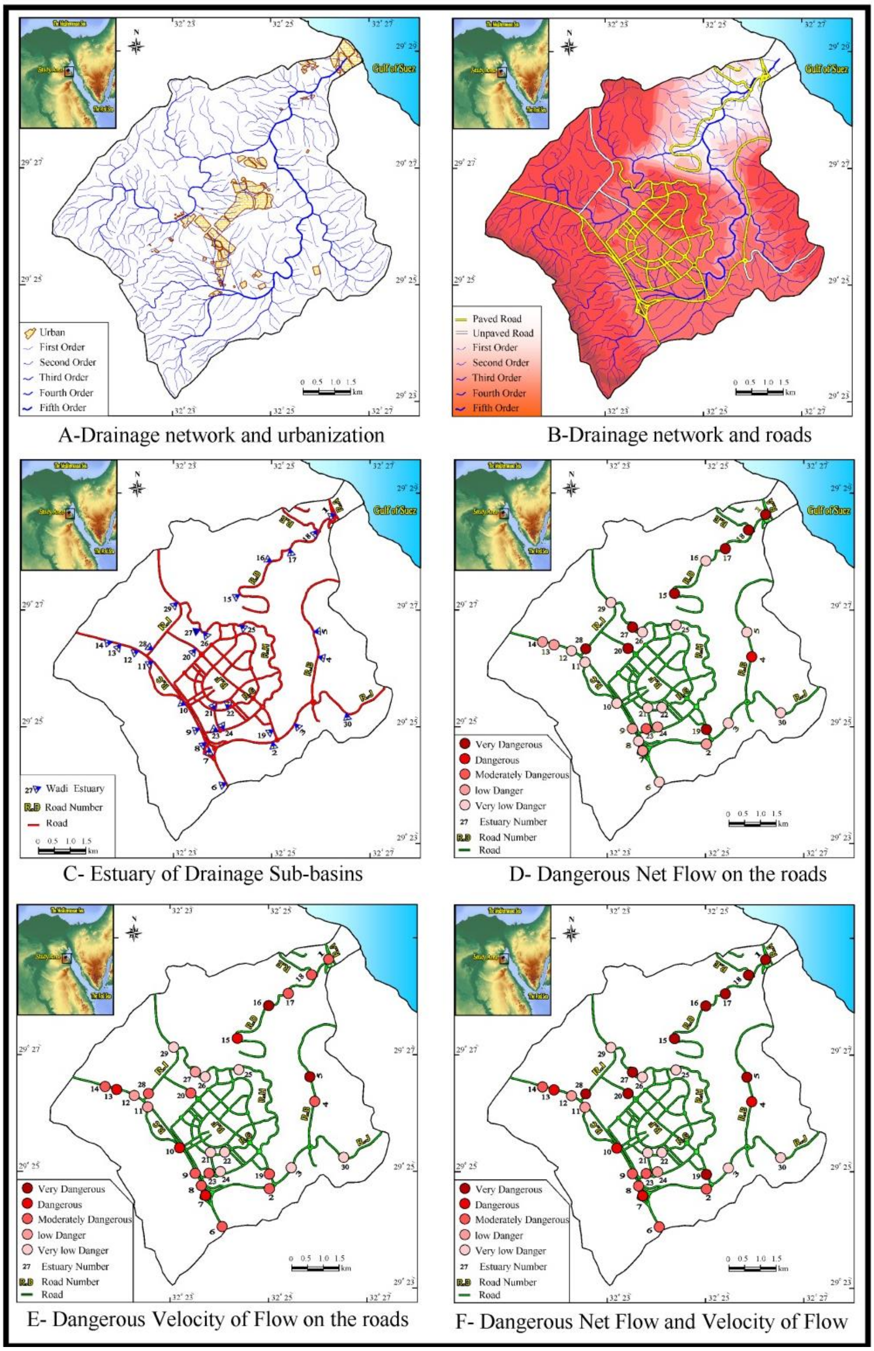
Table (4): Danger of Net Flow and Velocity of Flow on the Roads in Wadi Abu Daraj

Road and Village Name	Drainage Basin Name	Velocity of Flow Rate Km/H	Degree of Danger	Net Flow M^3	Degree of Danger	Total Degree of Danger
R.A	W.A.1	8.91	Moderately Dangerous	3311698	Very Dangerous	Very Dangerous
R.B	W.B.2	7.94	Moderately Dangerous	151472	Moderately Dangerous	Moderately Dangerous
	W.B.3	1.94	Very low Danger	29631	Very low Danger	Very low Danger
	W.B.4	8.50	Moderately Dangerous	365150	Dangerous	Dangerous
	W.B.5	13.12	Very Dangerous	40625	Very low Danger	Very Dangerous
R.C	W.C.6	8.03	Moderately Dangerous	55535	Very low Danger	Moderately Dangerous
	W.C.7	10.42	Dangerous	166095	Moderately Dangerous	Dangerous
	W.C.8	6.18	Moderately Dangerous	57051	Very low Danger	Moderately Dangerous
	W.C.9	8.37	Moderately Dangerous	145618	Moderately Dangerous	Moderately Dangerous
	W.C.10	9.55	Dangerous	61720	Very low Danger	Dangerous
	W.C.11	5.21	low Danger	39645	Very low Danger	low Danger
	W.C.12	4.48	low Danger	30713	Very low Danger	low Danger
	W.C.13	9.16	Dangerous	116204	Moderately Dangerous	Dangerous
	W.C.14	8.62	Moderately Dangerous	139106	Very Dangerous	Moderately Dangerous
R.D	W.D.15	10.50	Dangerous	1355617	Very Dangerous	Very Dangerous
	W.D.16	21.22	Very Dangerous	72732	Very low Danger	Very Dangerous
	W.D.17	6.45	Moderately Dangerous	3008481	Very Dangerous	Very Dangerous
R.E	W.E.18	8.92	Moderately Dangerous	3329078	Very Dangerous	Very Dangerous
R.F	W.F.19	8.27	Moderately Dangerous	996270	Very Dangerous	Very Dangerous
	W.F.20	7.70	Moderately Dangerous	739650	Very Dangerous	Very Dangerous
R.G	W.G.21	2.28	Very low Danger	71637	Very low Danger	Very low Danger
	W.G.22	2.71	Very low Danger	49325	Very low Danger	Very low Danger
R.H	W.H.23	8.18	Moderately Dangerous	287392	Moderately Dangerous	Moderately Dangerous
	W.H.24	2.30	Very low Danger	147395	low Danger	low Danger
	W.H.25	1.17	Very low Danger	23556	Very low Danger	Very low Danger
	W.H.26	2.76	Very low Danger	47169	Very low Danger	Very low Danger
	W.H.27	4.93	low Danger	783416	Very Dangerous	Very Dangerous
R.I	W.I.28	7.87	Moderately Dangerous	540620	Very Dangerous	Very Dangerous
	W.I.29	1.99	Very low Danger	72807	Very low Danger	Very low Danger
R.J	W.J.30	2.59	Very low Danger	71581	Very low Danger	Very low Danger
Tolip Resort El Galala	W.V.1	9.19	Dangerous	3301177	Very Dangerous	Very Dangerous

Source: Based on appendix (3).

A. Velocity of Flow:

Studying the velocity of flow is one of the most important hydrological parameters in determining the degree of danger of the basins to human activity. The higher the velocity of flow, the greater the ability to erosion and transport, and thus the destructive power of flash floods increases (Saber, 2016).



Source: Topographic Maps, 1:50000, 2006 using Auto CAD Civil 3D and Field Study, 2022

Figure (21): Hazards of Flash Floods on Engineering Facilities in Wadi Abu Daraj

Based on Table (4) and Fig. (21), the danger degrees of the drainage basins are classified according to the values of the velocity of flow as follows:

- **Basins of very low danger:** Their velocity of flow is less than 3 km/h, and they include eight basins, representing 25.8% of the total number of basins. They are represented in W.B.3, W.G.21, W.G.22, W.H.24, W.H.25, W.H.26 and W.I. 29 and W.J.30 basins, and the low velocity of their flow is due to the high time of their concentration, and the low degree of their slope, as most of them stems from gentle slope areas.
- **Basins of low danger:** Their velocity of flow ranges between 3 and 6 km/h, and they include only three basins: W.C.11, W.C.12 and W.H.27. Their low danger is due to two reasons: the decrease in the vertical distance and the rate of slope and this applies to the first and second basins. As for the third basin, its length led to the length of time required for the water to reach the estuary, so the velocity of flow decreased.
- **Basins of moderate danger:** Their velocity of flow ranges between 6 and 9 km/h, and they include thirteen basins, representing 41.9% of the total number of basins. They are represented in W.A.1, W.B.2, W.B.4, W.C.6, W.C.8 and W.C.9, W.C.14, W.D.17, W.E.18, W.F.19, W.F.20, W.H.23 and W.I.28. This category includes medium and large basins. Increasing the area increases the time period for water to reach the estuary, which increases losses by evaporation and leakage, and consequently the velocity of their flow decreases.
- **Dangerous basins:** Their velocity of flow ranges between 9 and 12 km/h, and they include five drainage basins, representing 16.1% of the total number of basins. They are represented in the W.C.7, W.C.10, W.C.13, W.D.15 and W.V.1 basins. In the first three basins, their danger is attributed to the decrease in the time of their concentration. As for the other two basins, despite their large area, the velocity of their flow increases due to the high relief characteristics.
- **Very dangerous basins:** Their velocity of flow is 12 km/h and more. They are represented in only two basins, W.B.5 and W.D.16, due to the low concentration time, which does not

exceed 0.10 hours. The shorter the time, the greater the danger as a result of large quantities of water reaching the estuary shortly after the rainfalls, in addition to the fact that highest degree of slope recorded is in this category, reaching 22.5 and 19.25 respectively.

B. Net Flow:

It is one of the important hydrological parameters on the basis of which the probability of the occurrence of flash floods is determined, and it is represented in the actual volume of water that reaches human use, and therefore the selection of the most appropriate methods to protect it is in proportion to the volume of this water. Accordingly, the basins of the study area are divided as follows:

- **Basins of very low danger**: Their net flow is less than 100 thousand m^3, and they contain 14 drainage basins, representing 45.2% of the total number of basins. They are represented in W.B.3, W.B.5, W.C.6, W.C.8, W.C.10, W.C.11, W.C.12, W.D.16, W.G.21, W.G.22, W.H.25, W.H.26, W.I.29 and W.J.30 basins. This category is characterized by the small area of its basins, which does not exceed 1.22 km^2.
- **Basins of low danger:** Their net flow ranges between 100 and 200 thousand m^3, and they include six basins, representing 19.4% of the total number of basins. They are W.B.2, W.C.7, W.C.9, W.C.13, W.C.14 and W.H.24 basins. This category is also characterized by areas of basins smaller than the previous category.
- **Basins of moderate danger:** Their net flow ranges between 200 and 300 thousand m^3, and they include one basin W.H.23, representing 3.2% of the total number of basins, with a net flow of 287 thousand m^3.
- **Dangerous basins:** Their net flow ranges between 300 and 400 thousand m^3, and they include one basin W.B.4, representing 3.2% of the total number of basins.
- **Very dangerous basins:** Their net flow is 400 thousand m^3 or more, and they include nine basins: W.A.1, W.D.15, W.D.17, W.E.18, W.F.19, W.F.20, W.H.27, W.I.28 and W.V.I,

representing 29% of the total number of basins, and including basins of large areas.

The study groups both the velocity of flow and net flow together in order to determine the realistic levels of danger (Fig.), and the following is found:

- Nearly half of the study area basins are dangerous and very dangerous, which represents a danger to the roads of the study area and its exposure to the hazards of flash floods.
- The R.D road is considered one of the most vulnerable roads to flash floods, as it intersects with the estuaries of three basins, all of which are very dangerous. What increases their danger is that they are located along the road from its beginning to its end. Besides, on its eastern parts, which are linked to R.E road and R.A road, intersect two very dangerous estuaries.
- The northern and southern parts of the R.F road are affected by the danger, due to the intersection of two estuaries of the basins that are very dangerous with them, and they are like the boundary that surrounds the city. As for the parts of the road that cuts through the city, they are safe from any impact of the danger of flash floods.
- The R.C road, along its length from north to south, is exposed to the danger of flash floods, but in a different way, due to the occurrence of nine estuaries of basins of varying degrees of danger along its length. Therefore, it is exposed to extreme danger in three places: the north, center and south, and the rest of its parts range between low and moderate danger of flash floods.
- The eastern parts of the R.B road are exposed to the danger of flash floods, as two estuaries of dangerous and very dangerous wadis intersect with them, while its western parts range between low and moderate danger.
- The R.H road, which borders El-Galala city from the east, is characterized as safe and of low danger of the occurrence of flash floods in most of its parts, except the northernmost part

of it, where the estuary of Wadi W.H.27, which is a very dangerous basin, is located.

- The R.I road is safe in most of its parts except for the westernmost part of it because of the fact that Wadi W.R.I basin, which is a very dangerous basin, is perpendicular to it.
- The rest of the roads in the study area, represented by the R.G and R.J roads, are characterized by the fact that all their parts range between safe and low danger in regard to the danger of flash floods.

Fourth: Results and Discussions.

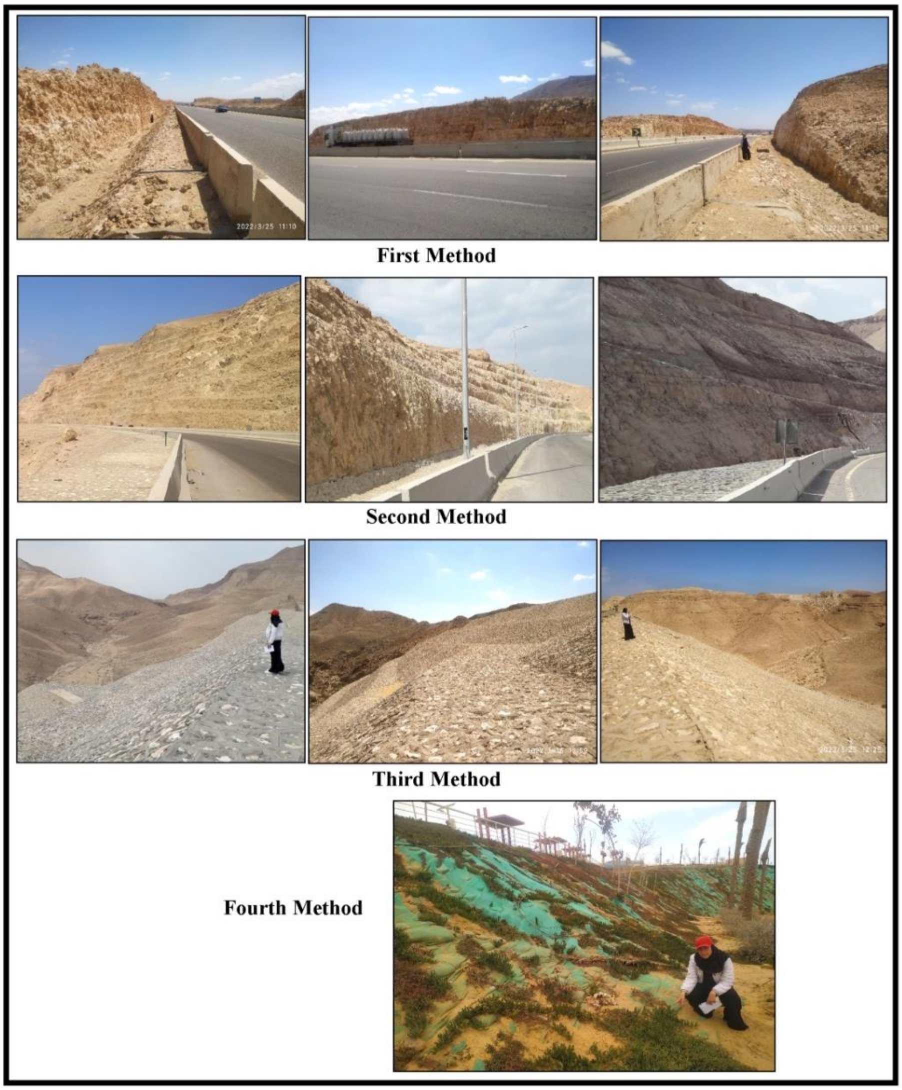
The Geotechnical Assessment process is a very important mechanism in placing development projects within their sound environmental and economic framework (Ghoneimy, 2000). The assessment process of the current methods of protection aims to identify the extent of their effectiveness for engineering facilities and development projects, and whether they are actually sufficient and achieve their purpose or not. What follows is an explanation of what is concluded:

1- Geotechnical Assessment for the Methods of Protection against the Hazards of Slopes:

The methods of protection from the dangers of movement of materials on the slopes vary, which poses a threat to the movement of transportation on the roads of Wadi Abu Daraj. Four methods of protection have been monitored (Fig. 22):

- **The first method:** It is converting the slopes located at a level higher than the road level, which represent a danger, into vertical cliffs (90 degrees) for low levels, whose height ranges between 2 and 6 m, with an average of approximately 4 m.
- **The second method:** It is converting the slopes located at a level higher than the road level, which are characterized by extreme height and exceed 6 m, into terraces. The height and width of the one terrace varied from one place to another, as the height ranged between 3 and 6 m, and the width between 0.5 and 1.0 m. The maximum height and minimum width

were recorded in very hard rocks, while the minimum height and maximum width were recorded in weakly hard rocks, particularly those containing a shale. This design is based on a sound scientific basis, as it corresponds to the degree of disintegration and fragmentation process, movement of materials and road safety and security.

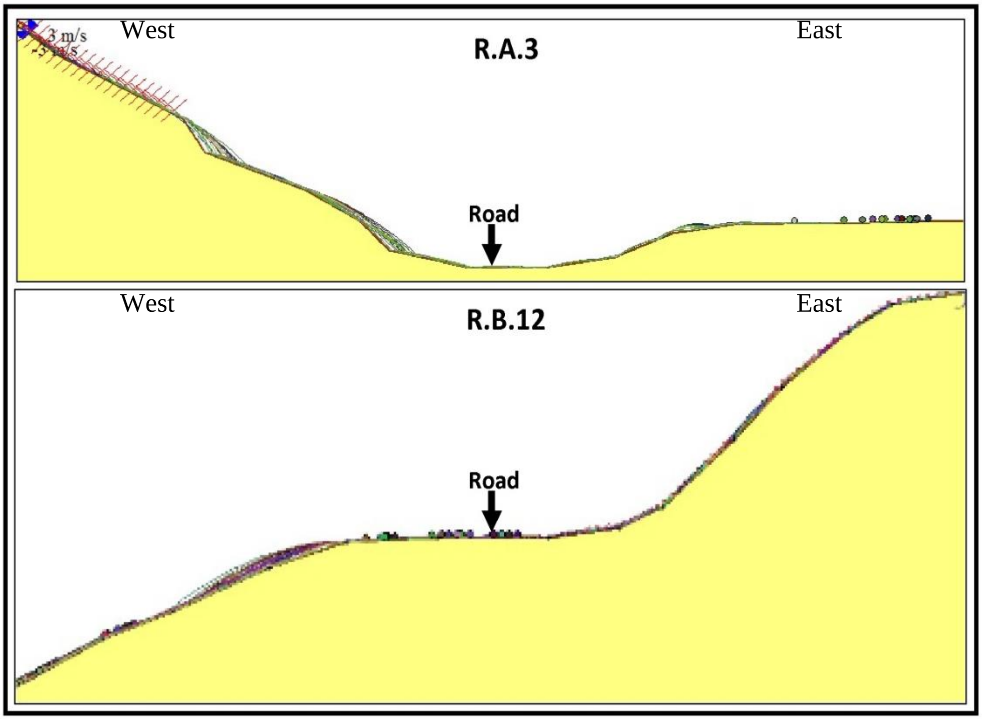


Source: Field Study, 2022

Fig. 22: Methods of Protection against the Hazards of Slopes in Wadi Abu Daraj

- **The third method:** It is the use of revetments, whether straight or in the form of terraces. This method is used to cover the backfill used to raise the level of roads in areas that are extremely lower than the general level, represented by the beds of the tributaries of Wadi Abu Daraj basin that intersect with the path of the roads. Their height exceeds 10 m in most locations, and the vast majority take the form of terraces, but at great distances.
- **The fourth method**: It is the use of bags packed with sand, and fixed to the edge. This method was used on the edge of R.H road with a length of approximately 200 m. The field study monitored its water saturation, as a result of the leakage resulting from the use of water in human activities in the city of El-Galala. This helped the growth of the Mesembryanthemum plant, which had a role in increasing the cohesion of the edge and keeping it from collapsing or falling off.

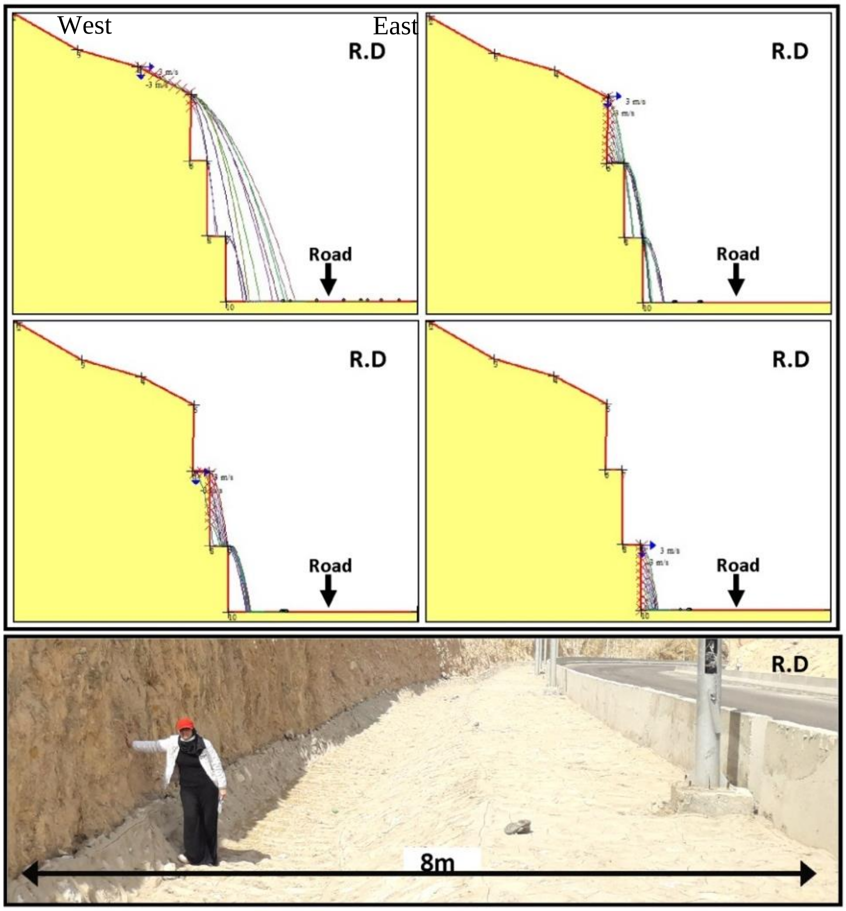
Based on GeoRock 2D software to model the expected trajectories for the movement of rocky materials on the slopes, it is observed from Fig. (23) that most of Wadi Abu Daraj roads are exposed to the process of Talus Creep. This process is monitored in 23 out of 44 sectors with a percentage of 52%, and it spreads in R.B, R.D and R.A roads in particular. However, with the use of the first and second methods of protection against the danger of material movement, the steep slopes and cliffs in the areas that are cut through by the roads were transformed into straight edges or into the form of terraces, and this modification led to a change in the material movement from creeping to falling. Fig. (23) indicates that the expected trajectory of the separated masses from the edge and their falling point depends on the location of the separation, as there is a direct relationship between them: the higher the separation location, the farther the falling point from the edge.



Source: Based on GeoRock 2D program.

Fig.23: A Model of the Trajectories of Material Movement and Talus Creep Formation on the Roads of Wadi Abu Daraj

It is evident from Fig. (24) that the farther point that the separated (falling) rock masses can reach does not exceed 8 meters from the edge, and it decreases significantly in the case of their falling from the first and second terrace, as it does not exceed 4 meters, which is already taken into account in the methods used to protect the roads from the material movement in Wadi Abu Daraj. With the increase in the height of the vertical edges, the safe distance between the beginning of the road and the edge is increased.



Source: Based on GeoRock 2D program.

Fig.24: A Model of the Scenarios of Rockfall and the Geotechnical Assessment of Protection Methods on the R.D Road

The following is an assessment of the methods of protection against the hazards of slopes, according to the degrees of danger of each profile separately, so as to assess and suggest the appropriate methods of protection for the safety and security of roads, as follows:

- **R.A Road:** A proportion is found between the places of danger and the number and type of the suitable methods of protection, and the number of terraces reaches 2, and the revetments 2.
- **R.B Road:** the number of methods of protection is proportional to the places of dangerous and above dangerous profiles. The

number of terraces was ten, most of which are distributed to the right of the road, except for the end of the road on both sides. As for the places where the road level rises on both sides due to the backfilling process, all of them have been covered.

- **R.D Road:** The places of the terraces are suitable for the dangerous and extremely dangerous parts along the road (seven places). As for the second method, which is the revetment, it spreads in many places, as a result of the intersection of many tributaries with the road. However, the lowest part of the road in the direction of the tourist village has not been covered, and areas on both sides of the road in its lower sector have been leveled and constructed, and have become at a low level to the road, with the lack of methods of protection for them. In addition, there are places that do not have revetment despite the high level of the road and need to speed up their construction, and perhaps this is attributed because the study area is still under construction and development.
- **R.E Road**: The proportion of the danger places, and the number and type of the methods of protection are confirmed. The number of terraces reached 5 and the revetment spreads in most of its parts, particularly the places where it rises from the neighboring lands.
- **R.J Road**: It is an unpaved road where construction is still going on, but the terraces have been completed by 4 terraces. As for the revetment processes, they have not yet been completed, and it was noted that the construction of flash flood drains precedes the protection methods for the slopes, and this applies over the entire study area, not just this road.

2- Geotechnical Assessment for the Methods of Protection against the Hazards of Flash Floods:

The study dealt with 31 drainage basins that were identified on the basis of their intersection with human activities, particularly with roads, and many of them represent a danger, whether caused by velocity of flow or net flow. Several methods of protection against flash floods have been used in 22 out of 31 locations, which represent the meeting points between human activity and the estuary of the drainage basin. These methods differed in their shape and dimensions from one basin to another, as the methods of protection used on the highest roads are limited to creating side openings on the road. In the case of flash floods, their water is drained into low areas that were built on both sides of the road as flash flood drains so that the road is not affected (Fig. 25). As for the methods of protection down the road, two types of culverts were used: square concrete tunnels, and pipes. For the accuracy of the assessment process and the confirmation of the extent to which it is related to the actual reality and the net flow in the basins of the study area, it was relied mainly on the field study (Table 5) and (Fig. 26), which can be explained as follows:

Source: Field Study, 2022

Fig. 25: Methods of Protection against the Hazards of Flash Floods on the Roads of Wadi Abu Daraj

Table (5): Methods of Protection against the Hazards of Flash Floods on the Roads of Wadi Abu Daraj

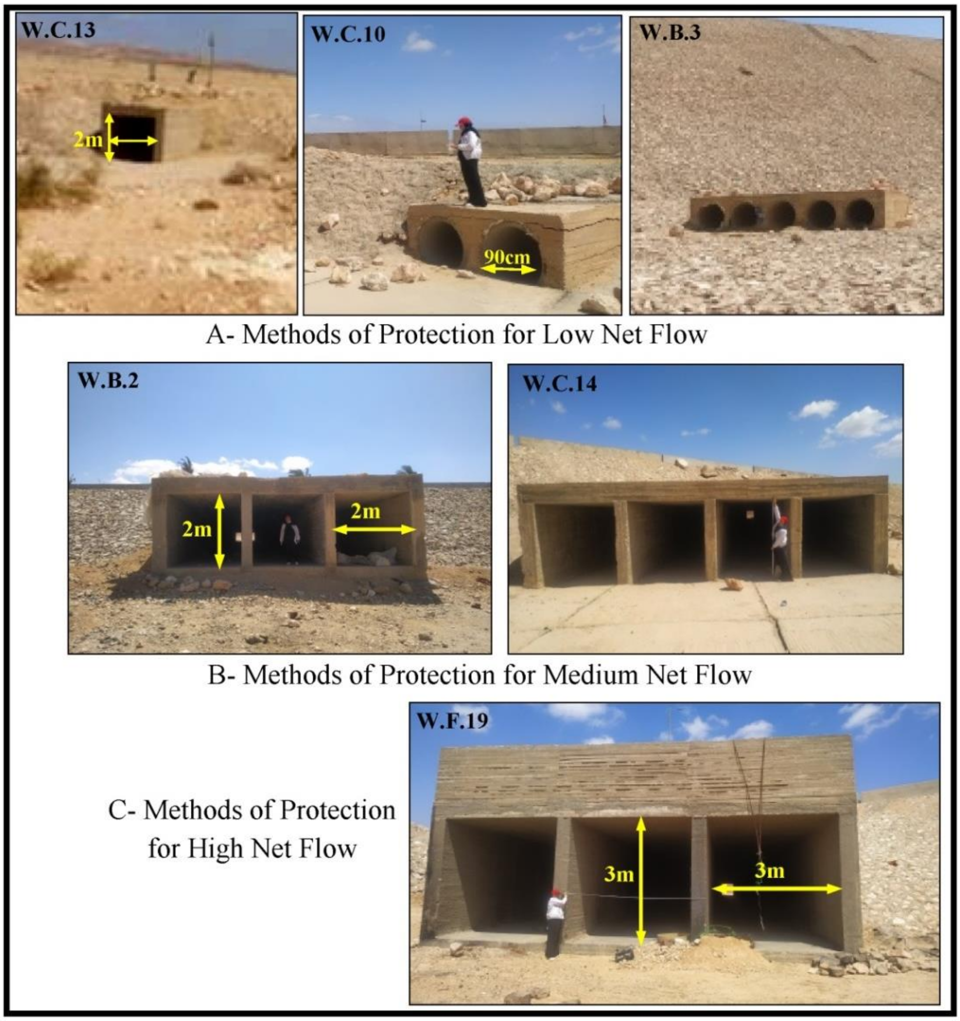
Name	Basin	Protection Method	Height (m)	Width (m)	Diameter (cm)	Number of Slots	Net Flow Million M^3
R.A	W.A.1	Concrete Tunnels	3	3	-	3	3.3
R.B	W.B.2	Concrete Tunnels	2	2	-	3	0.15
	W.B.3	Pipes	-	-	90	5	0.03
	W.B.4	Concrete Tunnels	2	2	-	3	0.37
	W.B.5	Concrete Tunnels	2	2	-	1	0.04
R.C	W.C.6	Pipes	-	-	90	2	0.06
	W.C.7	Concrete Tunnels	2	2	-	3	0.17
	W.C.8	Pipes	-	-	90	2	0.06
	W.C.9	Concrete Tunnels	2	2	-	3	0.15
	W.C.10	Pipes	-	-	90	2	0.06
	W.C.11	Pipes	-	-	90	2	0.04
	W.C.12	Concrete Tunnels	2	2	-	1	0.03
	W.C.13	Concrete Tunnels	2	2	-	1	0.12
	W.C.14	Concrete Tunnels	2	2	-	4	0.14
R.E	W.E.18	Pipes	-	-	90	4	3.3
R.F	W.F.19	Concrete Tunnels	3	3	-	3	1.0

Source: Field Study, 2022.

The following is evident from the analysis of (Table 5) and (Fig. 26):

- Basins with a net flow of less than 0.13 m. m^3: These are the basins that are connected to methods of protection represented by pipes with a diameter of 90 cm, and their number varies depending on the net flow between 2 and 5 openings. Concrete tunnels with one opening were also used in some basins, and this is consistent and proportional with the low net flow, and they has been monitored in 9 locations.
- Basins with a net flow between 0.13 and 0.4 m. m^3: Their method of protection is concrete tunnels. The number of openings ranged between 3 and 4, with dimensions of 2x2 meters. They are spread in areas where R.B and R.C roads meet with W.B.4, W.C.7, W.C. 9 and W.C.14 basins.
- Basins with a net flow of 0.4 m. m^3 or more: This category is related to the largest dimensions of the three-opening concrete tunnels, with dimensions of 3x3 meters, and was used at the meeting points of the R.F road with W.F.19 basin, and the R.A. road with the W.A.1 basin.

Lakes of small areas have also been established in front of some protection methods, which do not have revetments, with an average depth of 2m, width of 5m, and length of 5m. This is in order to facilitate the leakage of water to recharge the groundwater reservoir, as in W.C.11 and W.C.13 (Fig. 27).



Source: Field Study, 2022

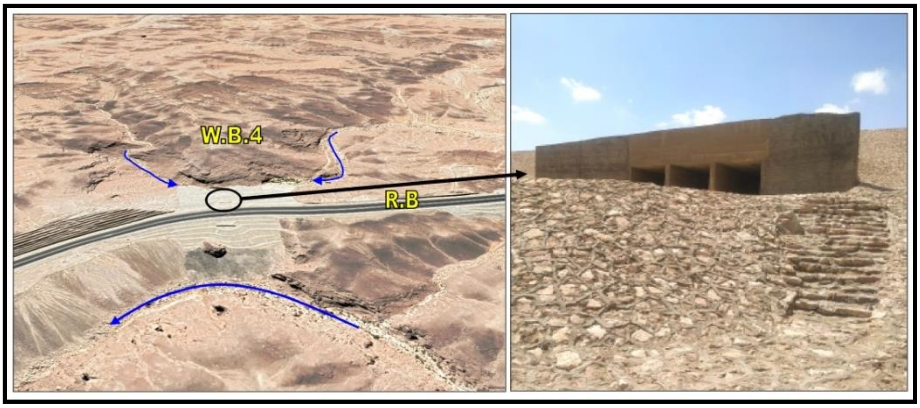
Fig. 26: Methods of Protection against the Hazards of Flash Floods down the Roads

Source: Field Study, 2022

Fig. 27: Construction of Artificial Lakes in Front of Some Flash Flood Drains in Wadi Abu Daraj

It is worth noting that the field study observed deviations from the previous classification, which is as follows:

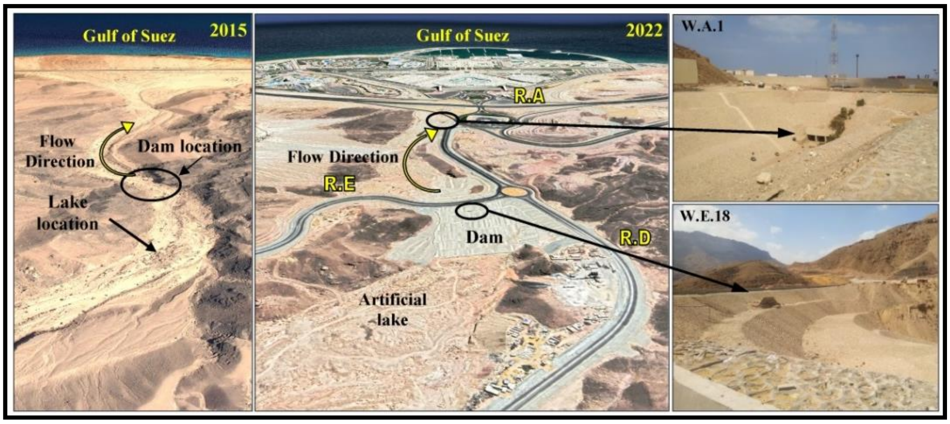
- The net flow of the W.B.4 basin was twice the net flow of the wadis located in the moderate category. Despite this fact, the method of protection is the same one used in the moderate category with the same dimensions, but at a higher level than the level of the bed of the stream. The reason is that it was designed above a dam to reduce the force of the water rush resulting from the flash floods due to the extreme steepness and the storage of water in front of it in the form of an artificial lake (Fig. 28).



Source: Google Earth Pro & Field Study, 2022

Fig. 28: Methods of Protection against the Hazards of Flash Floods of W.B.4 Basin

- The net flow of the W.E.18 basin amounted to 3.3 million m^3, and it falls within the very high category. Despite this fact, four pipes with a diameter of 90 cm were used, which is a method that does not completely fit with this volume of water. However, it turned out that this method was built at a large height as happened in W.B.4, where the distance between the bed of the stream and the pipes (culvert) was approximately 25 m. Accordingly, a concrete dam was constructed near the estuary of Wadi Abu Daraj (the main) to create an artificial lake to collect the flowing water. This contributes to slowing down its flow and so as to protect the coastal tourist villages on Wadi Abu Daraj fan, and to conserve wasted water and benefit from its water to feed the underground tank, and reuse it in various human activities in order to create new, stable urban communities next to permanent water sources. The rest is drained (excess water) through pipes in W.A.1, which is located above the dam (Fig.29).
- The net flow in the W.A.1 basin amounted to 3.3 million m^3, which is a large amount of water. Despite this fact, concrete tunnels with three openings and dimensions of 3x3 meters were used. This engineering design of the method of protection in this wadi is not proportional with the net flow, and the explanation of this is related to the former method. It is assumed the entire quantity reaches the location, but it is reserved in front of the dam at the intersection of W.E.18 with the R.E. road, and the amount that will be discharged is very small and therefore commensurate with the actually constructed method.



Source: Google Earth Pro & Field Study, 2022

Fig. 29: Methods of Protection against the Hazards of Flash Floods of W.E.18 and W.A.1 Basins

- Eight locations lack methods of protection in their wadis that intersect with those roads, and they are eight wadis (W.G.21, W.G.22, W.H.24, W.H.25, W.H.23, W.F.20, W.I.28, and W.I.29), and the reason is due to the following:
  - The intersection of Wadis W.G.21, W.G.22, W.H.24 and W.H.25 with the R.H and R.G roads: It was found that all these basins are located in the area of the engineering facilities (El-Galala City) on the flat surface of the plateau. They are basins of small area, and their degree of slope does not exceed 3.5. Besides, they are completely levelled, and no longer need any protection.
  - The intersection of Wadi W.H.23 with the R.H road: It turns out that R.H road is located on the same level as the bed of the stream.
  - The intersection of Wadis W.F.20, W.I.28 and W.I.29 with the R.I and R.F roads: It is shown that these roads are unpaved, and that the methods of protection have not yet been implemented.

Based on the aforementioned, the study suggests the following:

- Applying methods of protection for the three wadis W.I.29, W.F.20 and W.I.28 so that the area is completely safe. It is recommended to construct concrete tunnels with dimensions of 3x3 meters with three openings in each of W.F.20 and W.I.28 to be commensurate with their net flow of 0.74 and 0.54 $m.m^3$ respectively. As for W.I.29, the appropriate method with its net flow (0.07 $m.m^3$) is the construction of a concrete tunnel with one opening and dimensions of 2x2 m.

- Replacing the pipes with concrete tunnels because of their highest quality, even if they are with one opening. This is mainly because of the spread of weeds and vegetation in front of the pipes, and the accumulation of large and coarse sediments inside the pipes due to their small diameter, which reduces the efficiency of the method of protection in passing water flow (Fig. 30).
- Purifying and maintaining the flash flood drains on the sides of roads, particularly after each flash flood (Fig.30).

Source: Field Study, 2022

Fig. 30: Lack of Purification and Maintenance of Protection Methods against Flash Floods from Sediments and Vegetation on the Sides of Roads in Wadi Abu Daraj

Appendices:

Appendix 1: Morphometric Characteristics of Relief Profiles in Wadi Abu Daraj

R.A.1	Left	Right	**R.A.2**	Left	Right	**R.A.3**	Left	Right	**R.B.1**	Left	Right	**R.B.2**	Left	Right
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)
0-2	88.7	43.9	0-2	12.1	64.5	0-2	7.7	73.8	0-2	11.4	115.4	0-2	45.5	126.3
3-5	10.5	35	3-5	27.3	0	3-5	0	0	3-5	31	19.7	3-5	105.1	0
6-10	12.8	63.8	6-10	11.1	33.9	6-10	0	37.7	6-10	110.2	21.5	6-10	3.8	17.8
11-18	21.9	7.9	11-18	40.5	55.3	11-18	11.4	40.4	11-18	0	0	11-18	0	8.9
19-30	18	0	19-30	39.8	0	19-30	61.4	0	19-30	0	0	19-30	0	0
31-45	0	0	31-45	29.4	0	31-45	94.1	0	31-45	0	0	31-45	0	0
45-90	0	0	45-90	0	0	45-90	0	0	45-90	0	0	45-90	0	0
Total	151.9	150.6	Total	160.2	153.7	Total	174.6	151.9	Total	152.6	156.6	Total	154.4	153

R.B.3	Left	Right	**R.B.4**	Left	Right	**R.B.5**	Left	Right	**R.B.6**	Left	Right	**R.B.7**	Left	Right
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)
0-2	67.5	93.7	0-2	104.9	102.1	0-2	84.7	76.2	0-2	52.1	62.4	0-2	35.2	22.4
3-5	55.5	41.8	3-5	24.6	53.9	3-5	13.7	13.8	3-5	35.5	52.8	3-5	0	0
6-10	29.5	19.4	6-10	23.2	0	6-10	36.5	62.7	6-10	34.4	21.9	6-10	0	22.6
11-18	11.5	0	11-18	0	0	11-18	19.5	0	11-18	0	18.7	11-18	32.7	108.2
19-30	0	0	19-30	0	0	19-30	0	0	19-30	30.3	5.4	19-30	72.6	0
31-45	0	0	31-45	0	0	31-45	0	0	31-45	0	0	31-45	19.4	0
45-90	0	0	45-90	0	0	45-90	0	0	45-90	0	0	45-90	0	0
Total	164	154.9	Total	152.7	156	Total	154.4	152.7	Total	152.3	161.2	Total	159.9	153.2

R.B.8	Left	Right	**R.B.9**	Left	Right	**R.B.10**	Left	Right	**R.B.11**	Left	Right	**R.B.12**	Left	Right
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)
0-2	15.7	30.8	0-2	10.2	44.7	0-2	80.6	27.7	0-2	0	9.4	0-2	49.2	15
3-5	29	28.2	3-5	13.2	38	3-5	0	15.2	3-5	8.9	31.4	3-5	0	0
6-10	58.5	17.9	6-10	45.2	40.8	6-10	9.3	10.5	6-10	8.8	20.8	6-10	0	46.4
11-18	10.9	41.2	11-18	42.8	29	11-18	30	11.4	11-18	66.4	29	11-18	0	0
19-30	0	25.1	19-30	20.9	0	19-30	32.5	76.1	19-30	75.1	62.8	19-30	82.8	16.1
31-45	22.1	12.8	31-45	7.8	0	31-45	0	25.5	31-45	0	0	31-45	31.2	47.4
45-90	25.3	0	45-90	22.8	0	45-90	0	0	45-90	0	0	45-90	0	50.7
Total	161.5	156	Total	162.9	152.5	Total	152.4	166.4	Total	159.2	153.4	Total	163.2	175.6

R.B.13	Left	Right	**R.B.14**	Left	Right	**R.B.15**	Left	Right	**R.B.16**	Left	Right	**R.B.17**	Left	Right
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)
0-2	12.2	11	0-2	60.1	42.7	0-2	12.9	10.8	0-2	10	38.2	0-2	78.1	21.5
3-5	0	0	3-5	0	24.7	3-5	31.8	0	3-5	0	25.6	3-5	12.7	0
6-10	29	0	6-10	20.2	0	6-10	0	14.9	6-10	53.2	4.7	6-10	0	8.2
11-18	45.6	0	11-18	0	17.4	11-18	0	39.2	11-18	46.3	24	11-18	0	21.4
19-30	70.9	75.8	19-30	86	37.5	19-30	87.8	67	19-30	31.6	63.1	19-30	33.2	92.5
31-45	0	65.1	31-45	0	17.3	31-45	30.7	25.2	31-45	0	0	31-45	41.1	24.4
45-90	0	20.2	45-90	0	17.3	45-90	0	9	45-90	22.7	0	45-90	0	0
Total	157.7	172.1	Total	166.3	156.9	Total	163.2	166.1	Total	163.8	155.6	Total	165.1	168

R.D.1	Left	Right	**R.D.2**	Left	Right	**R.D.3**	Left	Right	**R.D.4**	Left	Right	**R.D.5**	Left	Right
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)
0-2	69	9.9	0-2	6.7	28.7	0-2	66.6	9	0-2	56.6	0	0-2	77.7	25.1
3-5	24.6	0	3-5	0	0	3-5	26.4	0	3-5	45.4	6.1	3-5	0	0
6-10	56.4	51.7	6-10	36.8	34.9	6-10	0	25.6	6-10	22	0	6-10	0	23.5
11-18	0	29.4	11-18	65.5	78.9	11-18	44	75	11-18	0	0	11-18	27.7	0
19-30	0	66.8	19-30	46.8	10.1	19-30	0	38.6	19-30	0	81.5	19-30	21.8	85.6
31-45	0	0	31-45	0	0	31-45	15.8	8	31-45	31	69.7	31-45	28.6	27.7
45-90	0	0	45-90	0	0	45-90	0	0	45-90	0	16	45-90	0	0
Total	150	157.8	Total	155.8	152.6	Total	152.8	156.2	Total	155	173.3	Total	155.8	161.9

R.D.6	Left	Right	**R.D.7**	Left	Right	**R.D.8**	Left	Right	**R.D.9**	Left	Right	**R.D.10**	Left	Right
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)
0-2	16.9	0	0-2	0	0	0-2	7.4	18.3	0-2	5.1	9.7	0-2	26.9	21.5
3-5	0	14.1	3-5	0	0	3-5	29.1	0	3-5	25.4	84.8	3-5	66.4	6.7
6-10	19.9	54.2	6-10	8.8	32.1	6-10	0	18	6-10	33.7	13	6-10	0	24.7
11-18	77	20.5	11-18	75.6	25.8	11-18	12.4	30.4	11-18	47.6	32.5	11-18	0	0
19-30	16.8	66	19-30	73.4	80.7	19-30	108.5	57.7	19-30	25.6	11.4	19-30	23.3	18.3
31-45	27.3	0	31-45	0	19.7	31-45	0	38	31-45	19.8	0	31-45	40.4	41.6
45-90	0	0	45-90	0	0	45-90	0	0	45-90	0	0	45-90	0	63.8
Total	157.9	154.8	Total	157.8	158.3	Total	157.4	162.4	Total	157.2	151.4	Total	157	176.6

Appendix 1 (Continuation): Morphometric Characteristics of Relief Profiles in Wadi Abu Daraj

R.D.11	Left	Right	R.D.12	Left	Right	R.D.13	Left	Right	R.E.1	Left	Right	R.E.2	Left	Right
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)
0-2	24.4	38.4	0-2	54	58.2	0-2	15.3	100.5	0-2	40.8	6.7	0-2	0	0
3-5	0	0	3-5	44.5	0	3-5	13.1	14.2	3-5	0	13	3-5	4.5	30.1
6-10	93.7	36	6-10	13.7	21.1	6-10	37.7	20.5	6-10	0	45.8	6-10	98.3	26.7
11-18	32.7	25.5	11-18	0	16.4	11-18	31.2	15.3	11-18	33	11.8	11-18	48.7	57.3
19-30	0	54	19-30	16	47.6	19-30	57.8	0	19-30	39.8	0	19-30	0	41.6
31-45	0	0	31-45	28.6	12.8	31-45	0	0	31-45	41.6	54.3	31-45	0	0
45-90	0	0	45-90	0	0	45-90	0	0	45-90	12.3	48.5	45-90	0	0
Total	150.8	153.9	Total	156.8	156.1	Total	155.1	150.5	Total	167.5	180.1	Total	151.5	155.7
R.E.3	Left	Right	**R.H.1**	Left	Right	**R.J.1**	Left	Right	**R.J.2**	Left	Right	**R.J.3**	Left	Right
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)
0-2	5.3	8.4	0-2	0	9.0	0-2	30.6	116	0-2	20.9	18	0-2	48.4	0
3-5	0	28.4	3-5	0	43.0	3-5	30.9	34.2	3-5	0	52.5	3-5	5.3	2.4
6-10	0	0	6-10	0	53.0	6-10	44.4	0	6-10	67.1	53.4	6-10	27.4	0
11-18	87.3	10.4	11-18	0	49	11-18	45.9	0	11-18	50.1	28.2	11-18	13.1	102.2
19-30	40.8	95.2	19-30	38	0.0	19-30	0	0	19-30	15	0	19-30	60.7	52.2
31-45	26.1	21.6	31-45	75	0.0	31-45	0	0	31-45	0	0	31-45	0	0
45-90	0	0	45-90	127	0.0	45-90	0	0	45-90	0	0	45-90	0	0
Total	159.5	164	Total	240	154	Total	151.8	150.2	Total	153.1	152.1	Total	154.9	156.8
R.J.4	Left	Right	**R.J.5**	Left	Right	**R.J.6**	Left	Right	**R.J.7**	Left	Right			
Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)	Range	Length (M)	Length (M)			
0-2	0	52	0-2	15	2.7	0-2	27.1	15	0-2	14.5	3.7			
3-5	24.3	43	3-5	0	0	3-5	8.2	0	3-5	21	31.6			
6-10	33.8	2.4	6-10	53.8	0	6-10	12.4	53.8	6-10	36.2	32.1			
11-18	31.4	9.1	11-18	55.6	98.6	11-18	18.2	55.6	11-18	38.7	19.8			
19-30	67.7	49.3	19-30	14.5	57	19-30	63.9	14.5	19-30	44.7	68.9			
31-45	0	0	31-45	15.8	0	31-45	29.7	15.8	31-45	0	0			
45-90	0	0	45-90	0	0	45-90	0	0	45-90	0	0			
Total	157.2	155.8	Total	154.7	158.3	Total	159.5	154.7	Total	155.1	156.1			

Source: Google Earth Pro, Topographic Maps, Scale 1:50000, 2006 and Field Study, 2022 (Total Station)

Appendix 2: Average Slope Degree of Relief Profiles in Wadi Abu Daraj

Sector No.	Degree			Sector No.	Degree			Sector No.	Degree		
	Left	Right	Average		Left	Right	Average		Left	Right	Average
R.A.1	7.6	5.3	6.5	R.D.1	4.9	13.9	9.4	R.H.1	41.0	7.6	24.3
R.A.2	15.5	7.3	11.4	R.D.2	12.6	8.9	10.8	R.J.1	7.4	1.5	4.5
R.A.3	27.3	6.9	17.1	R.D.3	9.6	15.0	12.3	R.J.2	11.3	6.7	9.0
Average	16.8	6.5	11.7	R.D.4	10.4	27.1	18.8	R.J.3	11.6	15.2	13.4
R.B.1	2.6	2.8	2.7	R.D.5	12.9	15.4	14.2	R.J.4	15.7	13.6	14.7
R.B.2	3.3	3.2	3.3	R.D.6	14.3	11.6	13.0	R.J.5	12.4	16.4	14.4
R.B.3	4.6	2.7	3.7	R.D.7	16.1	17.9	17.0	R.J.6	14.7	8.3	11.5
R.B.4	2.7	1.9	2.3	R.D.8	12.8	18.1	15.5	R.J.7	11.7	12.4	12.1
R.B.5	4.3	3.2	3.8	R.D.9	13.3	8.5	10.9	Average	12.1	10.6	11.4
R.B.6	6.8	6.2	6.5	R.D.10	18.6	22.4	20.5				
R.B.7	16.8	8.8	12.8	R.D.11	8.9	10.0	9.5				
R.B.8	16.9	12.2	14.6	R.D.12	12.3	13.4	12.9				
R.B.9	20.5	6.5	13.5	R.D.13	10.8	4.0	7.4				
R.B.10	13.2	17.9	15.6	Average	12.1	14.3	13.2				
R.B.11	16.3	12.0	14.2	R.E.1	24.0	26.2	25.1				
R.B.12	17.0	27.0	22.0	R.E.2	9.1	14.3	11.7				
R.B.13	15.1	27.8	21.5	R.E.3	19.0	20.4	19.7				
R.B.14	14.7	21.1	17.9	Average	17.4	20.3	18.9				
R.B.15	16.4	21.6	19.0								
R.B.16	15.0	13.1	14.1								
R.B.17	15.5	16.9	16.2								
Average	11.9	12.1	12.0								

Source: Google Earth Pro, Topographic Maps, Scale 1:50000, 2006 and Field Study, 2022 (Total Station)

Appendix 3: Some Morphometric and Hydrological Characteristics of Drainage Basins in Wadi Abu Daraj

Name	Basin	Area (km^2)	Total precipitation (m^3)	Total losses (m^3)	Basin Length (km)	length of the main stream (Km)	Gradient degree	Discharge time (hour)	Concentration time (hour)	Lag Time (hour)	Stream lengths (km)	Drainage density (Km/km^2)	Vertical Distance
R.A	W.A.1	65.56	4368263	1064091	11.589	15.826	5.74	0.24	1.30	0.78	277.434	4.23	1108
R.B	W.B.2	2.46	163909	12507	3.413	3.085	6.63	0.06	0.43	0.26	10.610	4.31	370
	W.B.3	0.48	31982	2356	0.931	0.553	3.87	0.02	0.48	0.29	2.223	4.63	60
	W.B.4	5.87	391118	26165	2.975	3.510	11.13	0.07	0.35	0.21	26.595	4.53	280
	W.B.5	0.62	41310	688	1.312	0.627	22.55	0.01	0.10	0.06	2.966	4.78	312
R.C	W.C.6	0.86	57301	1774	1.445	1.018	13.52	0.02	0.18	0.11	5.103	5.39	320
	W.C.7	2.63	175236	9191	3.126	2.783	11.55	0.04	0.30	0.18	13.947	5.30	602
	W.C.8	0.89	59300	2258	1.421	0.820	8.96	0.02	0.23	0.14	3.925	4.41	200
	W.C.9	2.30	153249	7675	2.344	2.660	11.74	0.04	0.28	0.17	11.881	5.17	450
	W.C.10	0.97	64631	2934	2.197	2.620	10.41	0.05	0.23	0.14	4.702	4.85	380
	W.C.11	0.62	41310	1671	1.303	0.765	8.97	0.02	0.25	0.15	3.279	5.29	160
	W.C.12	0.49	32648	1940	1.703	1.034	6.00	0.02	0.38	0.23	2.851	5.82	160
	W.C.13	1.84	122599	6439	2.566	2.553	11.25	0.05	0.28	0.17	9.995	5.43	377
	W.C.14	2.20	146586	7480	2.156	1.361	10.18	0.02	0.25	0.15	9.085	4.13	341
R.D	W.D.15	23.27	1550480	196643	6.508	10.117	8.82	0.16	0.62	0.37	97.363	4.18	817
	W.D.16	1.11	73959	1232	2.122	0.919	19.25	0.01	0.10	0.06	4.252	3.83	680
	W.D.17	61.88	4123064	1120798	9.990	13.510	6.48	0.21	1.55	0.93	361.337	5.84	1078
R.E	W.E.18	64.69	4310295	988333	10.880	14.824	6.11	0.23	1.22	0.73	274.312	4.24	1108
R.F	W.F.19	16.65	1109390	113757	4.798	5.212	9.18	0.08	0.58	0.35	76.668	4.60	638
	W.F.20	12.46	830209	91155	4.620	5.474	8.16	0.10	0.60	0.36	57.475	4.61	457
R.G	W.G.21	1.21	80622	9002	1.663	1.120	3.27	0.03	0.73	0.44	5.502	4.55	80
	W.G.22	0.82	54636	5330	1.624	1.624	3.42	0.05	0.60	0.36	3.610	4.40	90
R.H	W.H.23	4.62	307830	20548	3.107	2.986	10.87	0.05	0.38	0.23	23.971	5.19	460
	W.H.24	2.63	175236	27904	2.393	1.839	2.76	0.05	1.04	0.62	11.273	4.29	110
	W.H.25	0.40	26652	3100	0.912	0.578	2.55	0.02	0.78	0.47	2.096	5.24	40
	W.H.26	0.77	51305	4143	1.463	0.716	5.00	0.02	0.53	0.32	4.469	5.80	110
	W.H.27	14.26	950143	167682	4.929	7.447	7.43	0.14	1.0	0.60	94.776	6.65	477
R.I	W.I.28	8.78	585011	44685	3.307	3.905	10.78	0.07	0.42	0.25	41.322	4.71	417
	W.I.29	1.22	81288	8499	1.355	1.083	4.50	0.03	0.68	0.41	4.235	3.47	90
R.J	W.J.30	1.19	79289	7725	1.634	1.422	5.53	0.03	0.63	0.38	5.440	4.57	140
Tolip Resort	W.V.1	66.39	4423566	1130328	12.590	16.492	5.44	0.25	1.37	0.82	278.916	4.20	1148

Source: Based on WMS and Topographic Maps, Scale 1: 50000, 2006, using the AutoCAD Civil 3D, and the following equations:

- $TL = KI\ (A)^{0.3} / [\ sa\ / Dd\ ]$ **(Khidr, 1997)**
  TL = Lag Time. A = Area of the basin (km^2). sa = Gradient degree. Dd = Drainage density.
  KI = Constant Coefficient (0.4 for limestone surfaces, and 0.25 for sand and gravel surfaces).
- $Tc = 1.67\ TL$ **(Geriesh, et al., 2004)**
  Tc = Concentration time. TL = Lag Time.
- $Td = (0.305\ L\ )^{1.15} / 7700(\ 0.305\ H\ )^{0.38}$ **(Saeid, 1989)**
  Td = Discharage Time. L = Along the main stream (m). H = Vertical difference between the highest and lowest levels.
- Runoff Velocity = The length of the basin (km) / Concentration time (hour). **(Salama, 2004)**
- Net Flow = total precipitation - total losses. **(Mahsoub, 2003)**.

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