

Geo-Informatics Application in Determining, Analyzing, Evaluating and Mitigating Landslides Hazards in the Slopes of the Canyon of Watier Valley, Southeastern Sinai, Egypt

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Abstract Landslides in the Canyon slopes of the lower reach of Watier Valley represent one of the great hazards, which threaten the highway users that extends along the canyon bed between Newieba marine port and the rest of the country, for more than 50 km. In addition, the other human activities inside this reach are susceptible for the landslides hazard, especially, the electric, water networks and scattered Bedouins communities. This study tries to highlight the landslides hazard issue along the canyon reach. In order to analyze, evaluate and mitigate the hazard, a combination of data acquired, manipulated and implemented in the form of geo-informatics package. Fieldwork measurements for the canyon sides slope by using non-prism Total-Station and high-resolution quick-bird images were the main data sources. A GIS Model designed and applied for manipulating, processing and conducting these data. The application of this approach give the opportunity to create a Risk Zones Map for the canyon reach and revealed three main points: 1-Elevation, very steep slopes and rock structure are the main precondition factors and the earthquakes, while, the heavy rain-falls and seismic movements are the triggering main factors for that cause the landslides hazards. 2-The rock fall, toppling, rock sliding and debris flow are the main landslides movement forms. 3- The study suggested some appropriate mitigation methods to reduce the risk of landslide movements and rock stability along the canyon.

Keywords: landslides, hazard, geo-informatics, gis model, mitigation

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1. Introduction

Landslides are among the most widespread Environmental hazards worldwide, they are causing properties damage, people killing, and many other threaten types for human activities. South Sinai is subject to many of these environmental hazards like: torrential floods, earthquakes, droughts and landslides. Watier Valley is one of the largest valleys in Sinai Peninsula. The valley basin and its network occupy the northern eastern part of south Sinai. The main stream of the valley runs from north to south and to southeast to reach Aqaba Gulf at Nuweiba marine port, where the valley mouth is located. The lower part of the main valley stream extends with length of about 50 km and penetrates through high mountainous and faulted terrain block, which consists mainly of basement igneous rocks. This mountainous block has been affected by extensive tectonic movements as a part of El Aqaba Gulf and Red Sea graben. These characteristics formed the main stream as a deep narrow

bed canyon, with very high steep slope sides. Inside the canyon reach extends the most important highway road in the area, which connects between Nuweiba marine port on the Aqaba Gulf with the other parts of Sinai Peninsula and Nile Delta cities. In addition, many small villages, some human activities, and the infrastructure were located on both sides of the highway inside the canyon reach. The highway and the human activities are susceptible to landslides that move from both valley sides of the canyon, where, the steep slopes cause a significant risk along the Canyon reach. The moving materials may cause blocking to the highway road, people killing, cars damaging and many other threaten types for the highway users and the area residents.

Regardless to varying classifications of landslides, and based on field work data, the moving of the material to down slopes of rock and soil, can classified into different types on the basis of movement type and the material forms. The main types of landslides are rock fall, rock toppling, rockslide and debris flow. There are number of factors that cause movement of materials, earthquakes,

heavy rains, human excavations and the massive trucks movements on the road represent the most triggering factors and consequently, the main causes of the landslides movement on steep slopes of valley sides. The risk of landslides movements are expected to increase in the near future with increasing the human activities inside this area of the valley lower reach. So, need for assessing, evaluating and mapping of the risk are vital in mitigating the hazard, [12]. Planning for mitigating of this hazard raised and became an urgent request. No inventory or previous official records for past landslide events in this area, only the Bedouin people who represent the region residences, have a collective memory of like these bad events, especially, after the seismic shakes and intensive rainfalls. In addition, no procedures were performed to prevent or avoid or reduce the hazard, at the same time no study for any of the landslide hazard forms has been conducted along the Canyon reach in the last period.

In recent years, researchers in geomorphology and other fields have become increasingly interested in using Geographical Information Systems, Remote Sensing and Surveying methods, [3,4,35], that became used as one package under the Geo-informatics term in mitigating the slopes hazards. Implementation of this combination of Geoinformatics method, helped in assessing, evaluating, manipulating and mitigating the landslides hazard in the study area, [24]. The field measuring of the Canyon slopes reach has been implemented to conduct mapping and modeling of vulnerability magnitude. Also, to evaluate,

delineate the risk grades in a Risk Zones Map that depended on GIS Model. In addition to give, some suggestions of appropriate mitigation methods, in order to, reduce the hazards impact.

This work used a new useful a tool in slope measuring, that save time, effort and money, by using non-prism Total-station that used before but only in rock-fall monitoring, in the very steep and high elevation slopes [34]. In addition, application of slope modeling, may consider one of useful recent methods that can be developed and promoted for more applications in the following landslides works, in order to get trustworthy accurate results. There are many researchers have been used this approach, and have high accuracy results, [23,25,26].

2. The Study Area Location

The study area covers the lower part of the main stream of Watier valley, which lies in north eastern of South Sinai Governorate. It forms a deep canyon extends between lat: $29^{\circ}.00' - 29^{\circ}.10' N$. and long: $34^{\circ}.30' - 34^{\circ}.40' E$. (Figure 1). The Canyon reach extends for about 50 km., from Shiekh Attia inside the area, at the northeast of the reach, to Nuwieba marine port city at Aqaba Gulf in the east and south east at the end of the Canyon, where the valley mouth is.

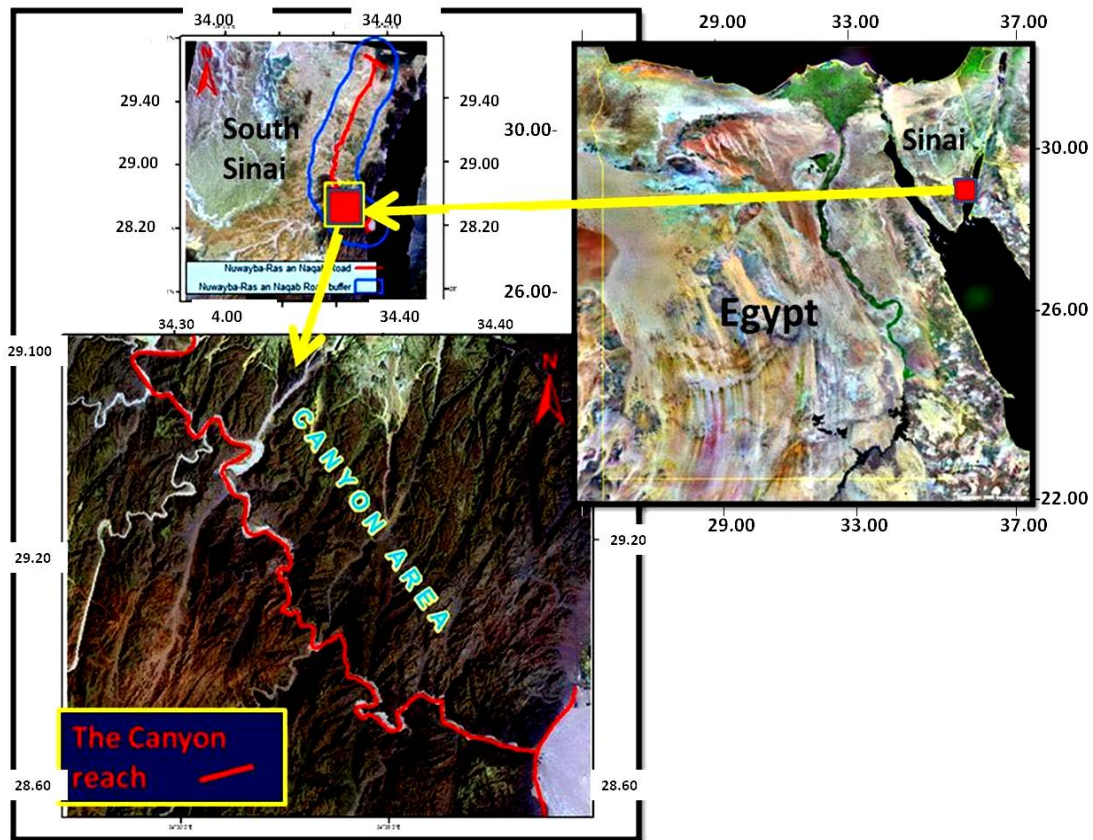


Figure 1. Location of the canyon reach at the lower part of Watier valley

3. The Study Objectives

The main objectives of this research are:

a- To delineate, determine, analyze and assess the hazard of landslides along the canyon reach at the lower part of Watier Valley. In addition, to determine the vulnerable and susceptible parts through application of Geoinformatics approach.

b- To suggest appropriate methods for managing and mitigating the hazard risks along the canyon reach, in order to minimize and reduce the hazard risks impacts.

4. Physical Characteristics

Geologically, the lower part of Watier Valley, consists mainly of basement rocks of old coarse and medium grain size Granite and some lenses of Metamorphic rocks of Rhyolite and Quartzite, which interrupted by some small dykes of recent Igneous rocks

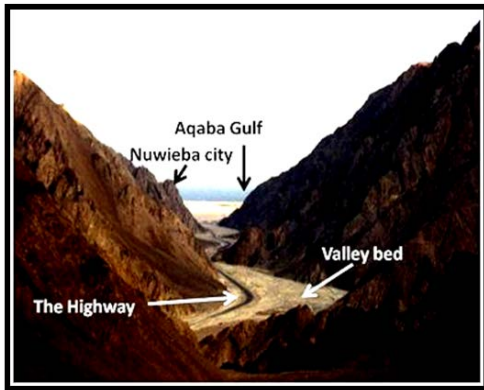


Figure 2. Form of the canyon lower part

Morphologically, the canyon cuts its reach through a mountainous and hilly dissected area of the basement rocks, so it forms deep, narrow stream with very steep and high vertical sides, (Figure 2). In addition, the area is subject to earthquakes that generate and concentrate in

Aqaba Gulf, which represents a part of Red Sea Graben (Figure 12).

Climatologically, the area lies in extreme hot desert region, so the mean annual and the range of temperature are very high, it ranges between 25 – 32 C. in a year. On the opposite side, the mean annual rainfall is very low, only few inches, about 3-4 inches yearly and they fall randomly temporally and spatially. Most rains types are frontal or convectional. The frontal thunderstorms cause short duration and intensive rainfalls that cause very dangerous flash floods, and slope material movements.

5. Materials and Methods

In order to measure and analyze the very high steep mountainous slopes with high elevations, a new field method implemented. This method relies on using of non-prism Total-station and GPS devices. Application of this method, in measuring, cross-sections of the valley sides, in integration with high resolution remote sensing data of Quick-Bird images, Topographic maps and other physical data, gave the possibility to design and create a GIS Model (Figure 3). GIS Model used in determining and evaluating the slopes vulnerability of the hazard risk. In addition, used in conducting the susceptibility and hazard assessment to get the risk grades along the two sides of the canyon reach in a Risk Zones Map. The GIS Model, the Risk Zones Map and fieldwork data helped in determining and assessing the hazard magnitude for the valley sides slope. In addition, they helped in designing and managing, appropriate mitigation suggestions and sustainable treatment for area, [7,21].

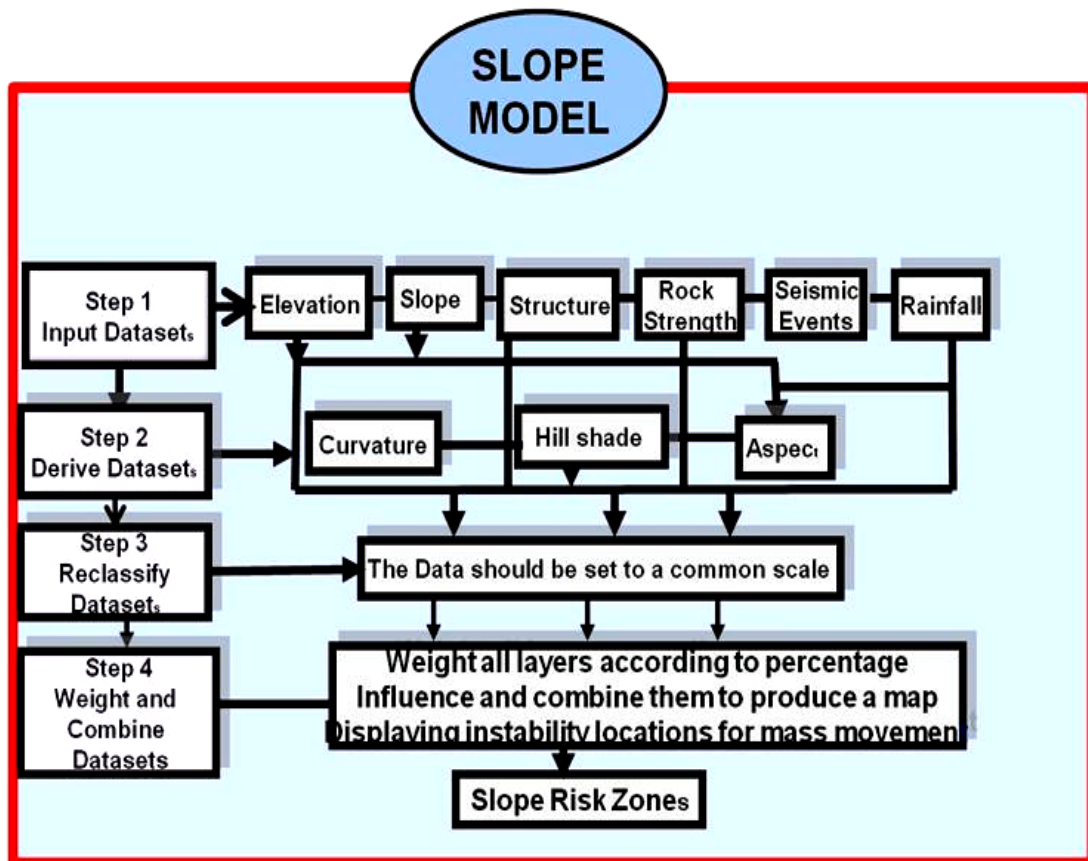


Figure 3. Slope GIS Model chart

The data sets of Slopes were used in designing and conducting a GIS Model, based on GIS, RS data and techniques of fieldwork are represented in a flow chart (Figure 3). All the measured and analyzed data added to the data that acquired from the previous sources are considered as a group of variables or factors that affect on landslides movement process. They conducted and manipulated in four steps by the Slope GIS Model (Figure 3).

6. Landslides Affecting Factors

All the managed and derived datasets that cleared in Figure 3 considered as main factors that affect and cause landslides movement process along the canyon reach. These factors divided into 2 categories, [16,21]:

- a. Precondition factors are elevation - slope - rock strength – curvature – structure – hill shade – aspect.
- b. Triggering factors are seismic shakes and Intensive rainfall. In addition, the impact of large tracks movement that runs on the high way, should be taking into account.

The following paragraph will explain the impact of these factors on the landslides process:

6.1. Precondition Factors

a. Elevation:

The data of elevation and slopes of 10 valley sides, which, measured in the field by using a Total-Station and

GPS were located on Quick-Bird images (Figure 4). These data managed to generate DEMs (Figure 5), in the 10 cross-sections locations. DEMs are one of the most important variables, which affect and describe slopes accurately but their accuracy depends on the DEM data resolution [32]. Here, the DEMs derived from the Quick Bird high resolution images (Figure 5).

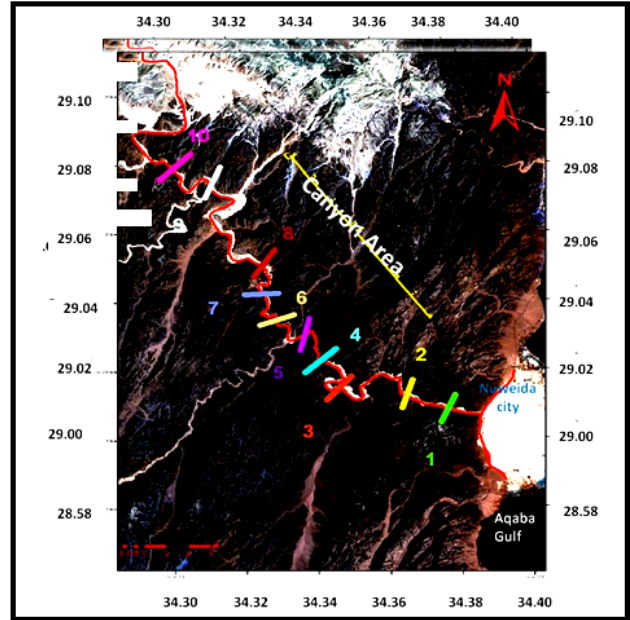


Figure 4. Locations of cross-sections along the Canyon reach

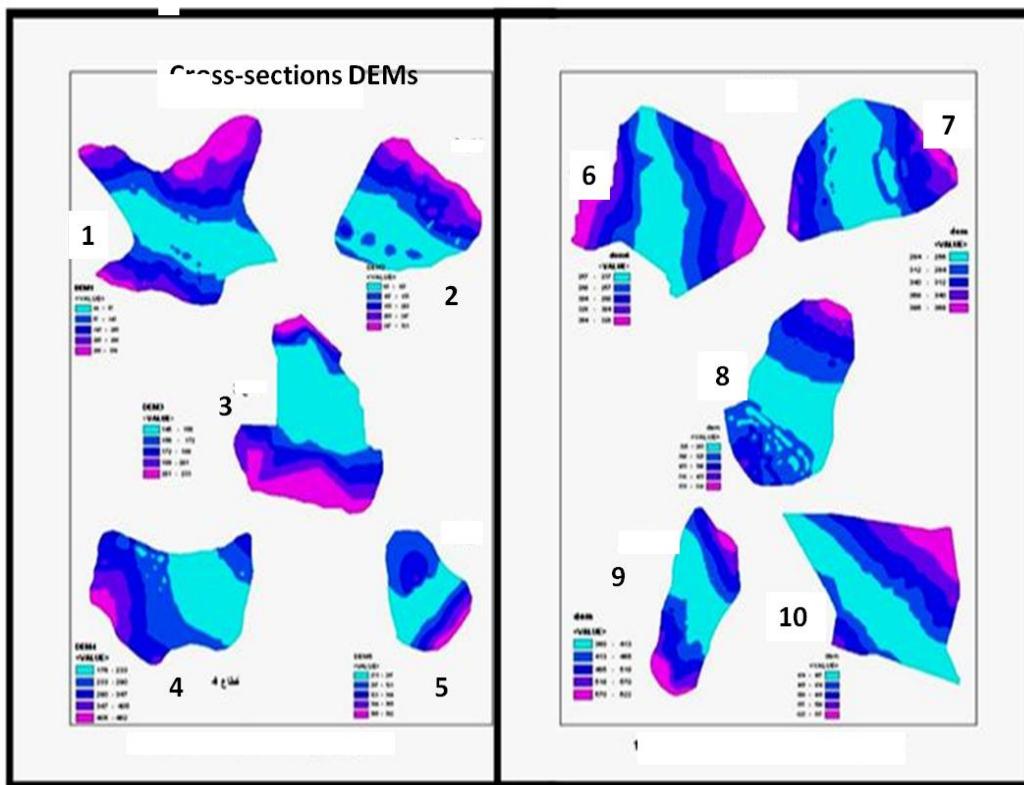


Figure 5. Cross-sections DEMs

b. Slope:

The slope variable considered as the master factor that affect on materials movement on slopes, Therefore, the field measurements by using non-prism Total-station for all cross-section slopes have been managed to include the

three dimensions, X, Y, Z. for every point, measured at every slope cross-section. These data helped in designing the forms of the valley cross-sections accurately (Figure 6) and gave an idea for the materials movement form.

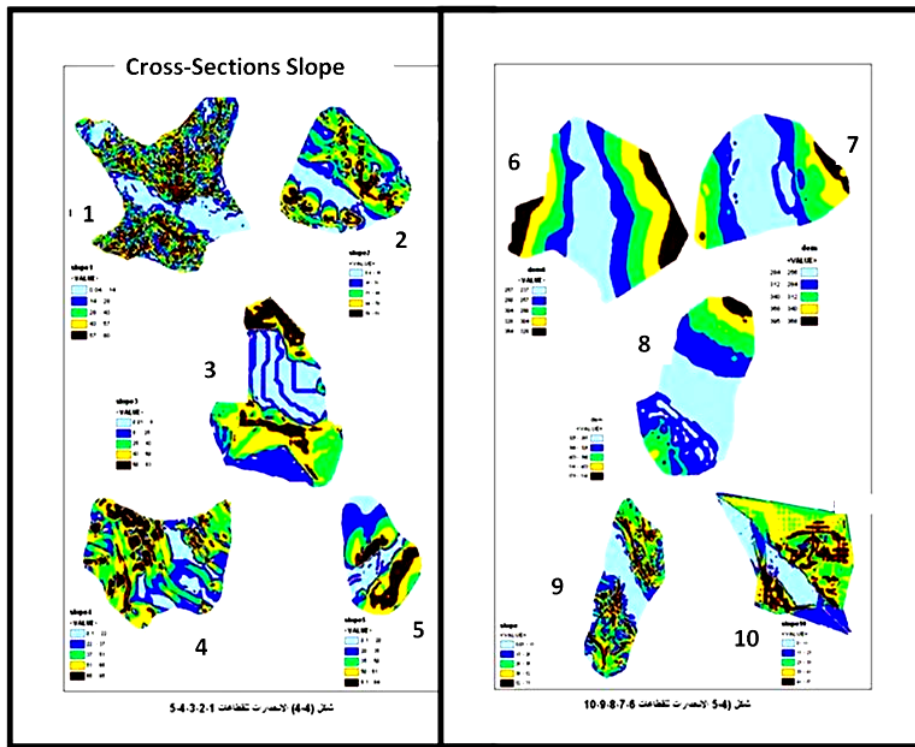


Figure 6. Slopes of cross-sections

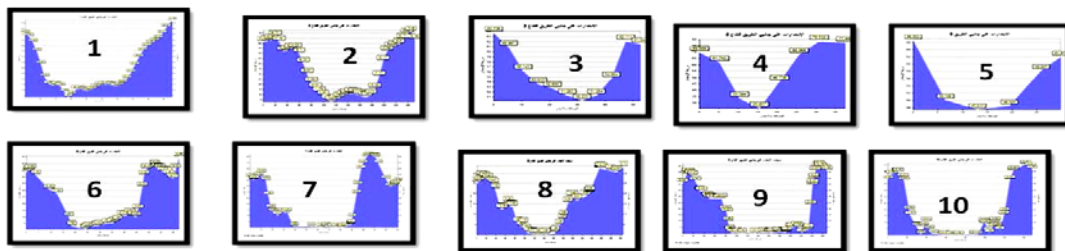


Figure 7. Forms of cross-sections

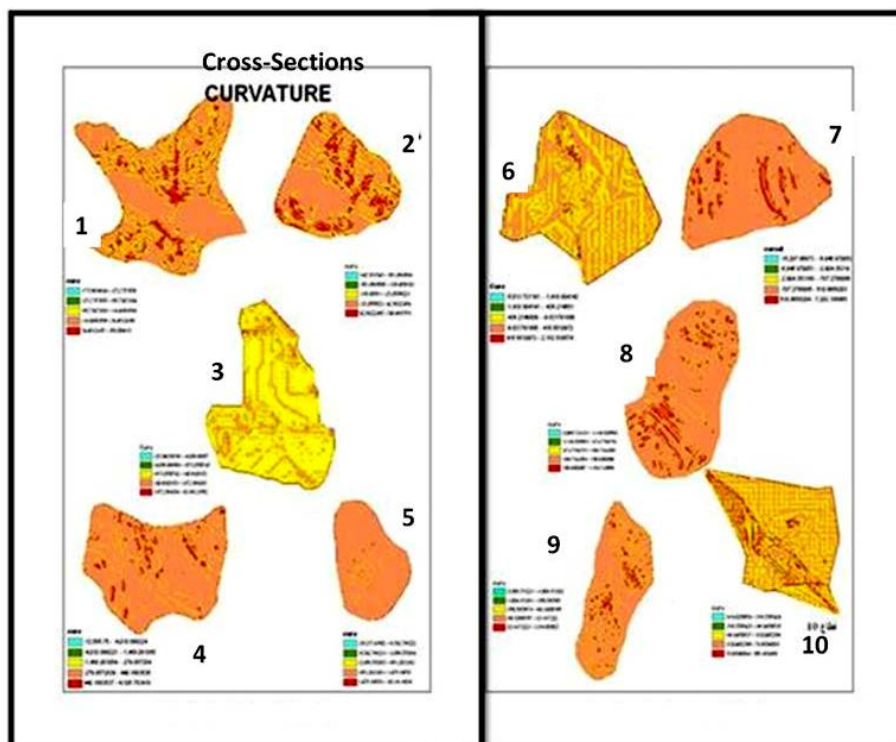


Figure 8. Curvature of cross-sections

The forms of the cross-sections (Figure 7) show high elevation and very steep slopes in both sides along the Canyon reach. These factors play an active part in landslides process.

c. Rock Strength

Analysis of Compressive Strengths and Unit Weight Density for six rock samples that collected from the measured some cross-sections locations, have been analyzed, in order to show the characteristics and strength of the rocks in measured slopes. The analysis showed that the mean of compressive strength is 197 MN/m². This number reflects, high strength and high resistance in the most rocks of slopes. The analysis showed also, that the mean of unit weight density is 2.76 kg/m³, where the rest numbers ranged between 2.63 to 2.90 kg/m³. These numbers reflect high rock density. These characteristics show low susceptibility for the rock movement.

d. Curvature

Curvature of slopes has been derived by spatial analyst from the integration between the field-measured data and the Quick-bird images. The curvatures reflect that most of the slopes start at the crest point with convex element, sequenced by strait long segment in a cliff form, which represents the main source of the susceptible rock falling or sliding. The lower part of the slope mostly, form concave element, which represent the area of talus cones and fragments cumulating, while the large-sized materials move farther away towards the road (Figure 8). Based on this situation, they represent the core of the problem.

e. Structure

Structure map of the area (Figure 9) entered as a digital map and used as variables in the GIS Model. The rock structure affect on the slope stability and landslides. In addition, the fractures and joints that measured in the field (Figure 10), added to the derived data from the high-resolution photographs, and Remote Sensing Images, were used to determine the form of blocks separation and their movement trends [27]. In addition, they helped in discrimination and estimation of the hazard magnitude at the vulnerable slope parts.

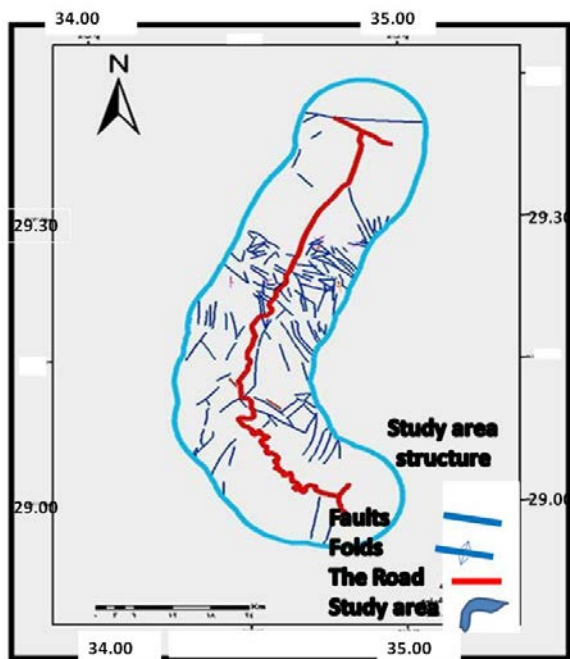


Figure 9. Structure of the study area



Figure 10. Rock structures

f. Hill-Shade

The hill-shade is one of the elements that reflect the slope form; it increases as the slope steep increases, so it helps in determining the susceptible areas for movement. The hill-shade derived from the field measured data and high-resolution remote sensing images at the cross-sections locations (Figure 11).

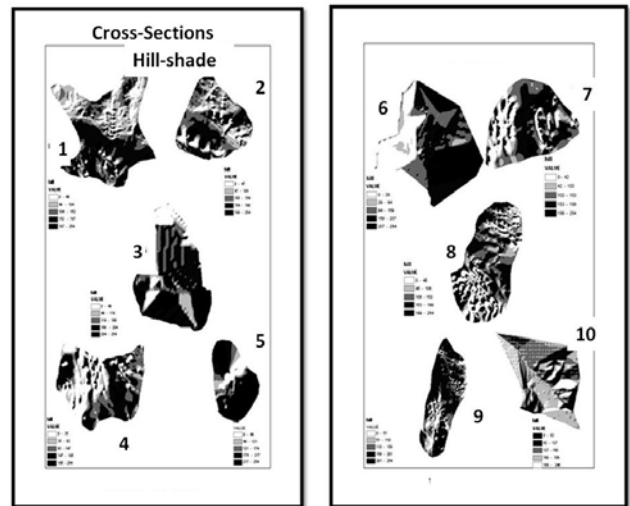


Figure 11. Hill-shade of cross-section

g. Aspect

The aspect (Figure 12) reflects the steepness orientation downward of the slope. Their study showed that the orientation of the slope sections are mostly toward the surface of the high way road and low areas in slopes feet. Consequently, most of the landslides processes would be occur toward the road and urban areas. These areas still represent the most susceptible parts for high hazard risk.

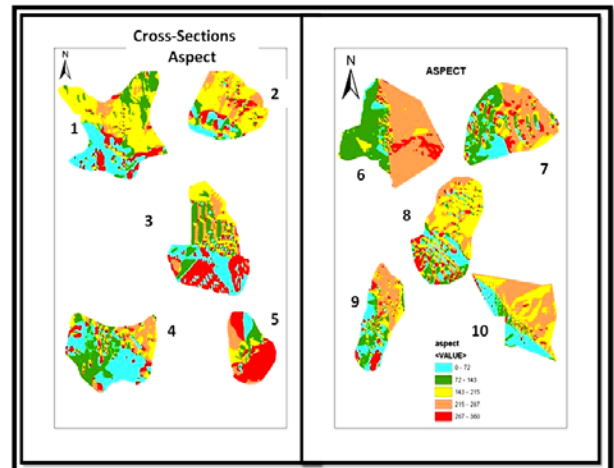


Figure 12. Aspect of cross-sections

6.2. Triggering Factors

a. Seismic factor

Earthquakes are a major trigger for instability of rocks, consequently, the materials movement. Presentation and management of seismic data by using a GIS package would provide a landslide hazard map and vital results for the hazard magnitude [17,35].

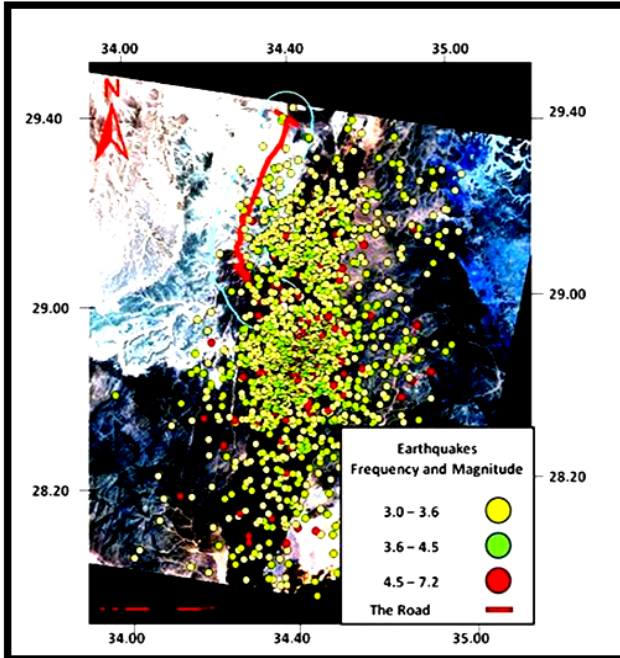


Figure 13. Earthquakes frequency and magnitude

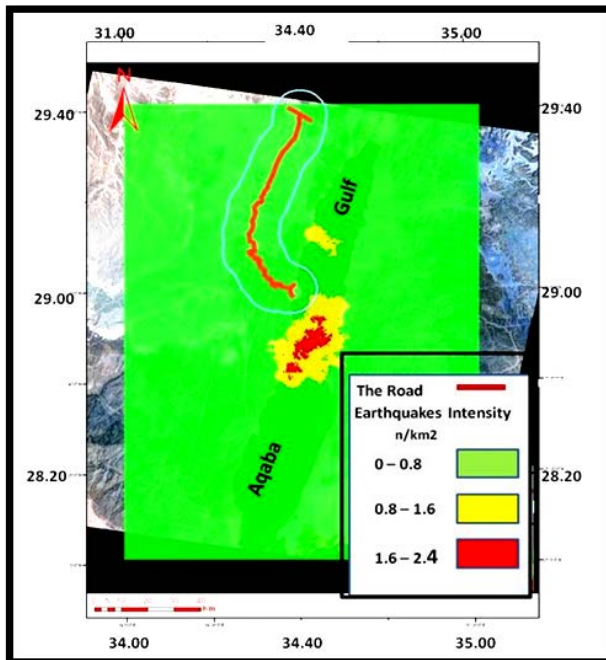


Figure 14. Earthquakes Risk Map

The data of earthquakes events and their characteristics: the earthquakes number, frequency and magnitude along El Aqba Gulf, for the period of 1900 – 1995 have been collected, managed and mapped. Aqba Gulf represents the main source of the seismic movements in the area and also, in the neighboring areas. Figure 13 shows, the earthquakes frequency and magnitude in study area. The data

management shows a great concentration for the earthquakes movements in the area of the valley mouth and along the canyon. Figure 14 shows the earthquakes risk map. It's clear that the canyon area has high intense of the earthquakes of high magnitude and high risk, Consequently, the earthquakes impact will affect on landslides movements process along the canyon area as the main triggering factors.

b. Intense Rainfalls

The rainfall intense of low duration represent one of the main characteristics of the desert rainfall, it falls as great concentrated showers, so they could consider as one of triggering factors that affect directly on the rock movement. Increasing of rain quantity in low duration and the seepage process, will cause increasing in the pore pressure inside the rocks and decreasing in their friction, these conditions will lead to the rock moving into the slope downward, according to the increase of rock blocks, [9,10,19,33]. Figure 15 Shows the intense of rainfall that fallen on the area for the period 1985-2002.

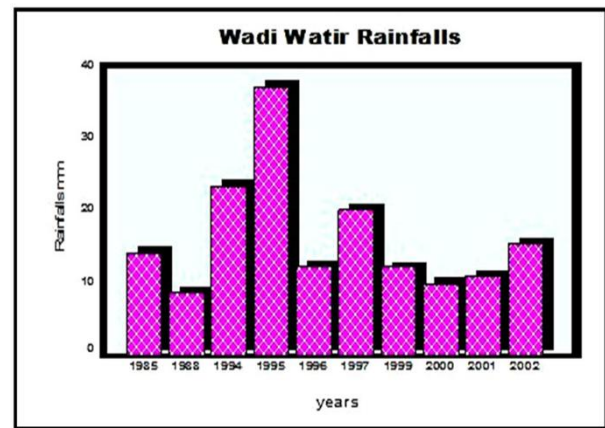


Figure 15. Wadi Watir intense Rainfall 1985-2002

6.3. The Risk Zones Map

The final evaluation of the Slope GIS Model shows that all the cross- sections slopes have high susceptibility to landslides and material movements, so the road and other human activities are considered more vulnerable to very high risk, along most of the canyon parts. On basis of managed variables, it is clear that there is partly difference in the impact between cross-sections. The combination of affecting variables package with fieldwork data, helped in the model of the final Risk Map creation (Figure 16). According to, the previous scientific works on slopes, hazard mapping is one of the main concerns of researcher in landslides studies [14,15,28].

The Risk Map divided the landslides hazard magnitude into three risk categories, (Figure 16):

a. The very high risk zone, it covers most of the middle area of the canyon reach, where, the canyon segment is very narrow, the valley width not more than 18 m., the valley side slopes are very steep or vertical, forms long cliff slopes and their elevation is very high for the rest of the canyon region.

b. The high-risk zone, it covers two areas before and after the previous area (Figure 16). These areas are characterized by more wide width than the last segment, their wide are not more than 40 m, and they less in the slopes steep.

c. The moderate risk zone. It covers the area at the end of the canyon inside Sinai, where the valley width maybe up to more than 100 m, and less steep slopes and elevation are the main characteristics of this segment (Figure 16).

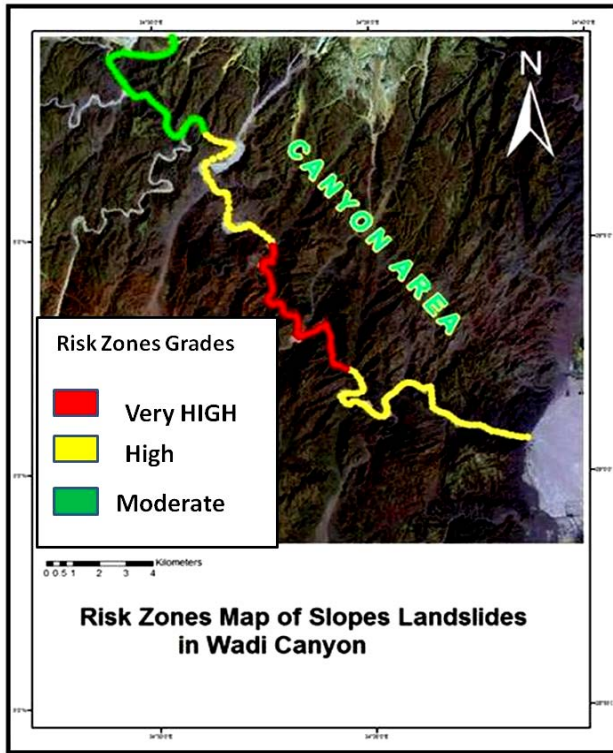


Figure 16. Canyon Risk Zones Map

7. Landslides Types

The field study and the slopes measurement data explain and interpret the material movement form on the cross-section slopes. The movement mostly occurs in various forms, according the impact of affecting variables. These forms can summarize in three processes as the following:

7.1. Rock Fall

Occurs, when the rocks detached from the very steep slopes or cliff face and move abruptly with high speed downward to the slope base. The falling materials may be rock blocks or small pieces of rock fragments, (Figure 17). The falling blocks can be rolling for a long distance after falling to reach the surface of high way road; this movement can harm the road cars and the user people. Therefore, this type represents the highest hazard risk form that occurs in the very high-risk zone, especially, it is the common type of the movement at in the very high elevation and very high steep slopes that characrizze long segments along the canyon.

7.2. Rock Toppling

Occurs where the vertical fractures became often prevalent, so the mass of rock move forward down slope slowly or in high speed, as the separated rock blocks affect by triggering factors. This type of landslides movement can be extremely destructive, especially, when the failure of rock blocks is sudden and/or the velocity is

rapid. This kind of landslides occurs where; there are vertical fractures coupled with vertical slopes in the valley sides (Figure 18).

7.3. Rockslide

This type of movement, occurs when the rock mass is moving down slope on surfaces of rupture or on relatively thin zones of intense shear strain and move. This type of movement is common in talus and cones of unconsolidated material that accumulated on slope base. The intense of rainfall can lead to saturation hens, moving take place. This type of slide can also be earthquake-induced. This can cause extreme damage to infrastructures, road, and lifelines, it will be low risk in the case of the movement of the block is slow (Figure 17).

7.4. Debris Flow

It occurs in the large amounts of fine loose soil that accumulate on the slope base, especially, when concentrate in the gullies stream mouths under the intensive rainfalls and run off of flash floods [1,22]. Where they can cause road blocking and consequently, harm the road users (Figure 17).

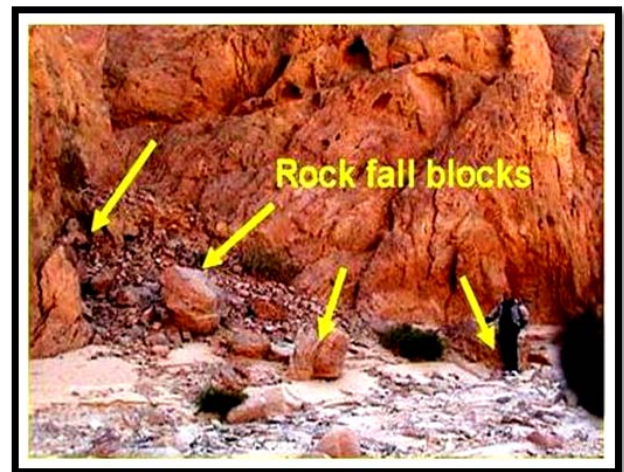


Figure 17. Rock fall blocks

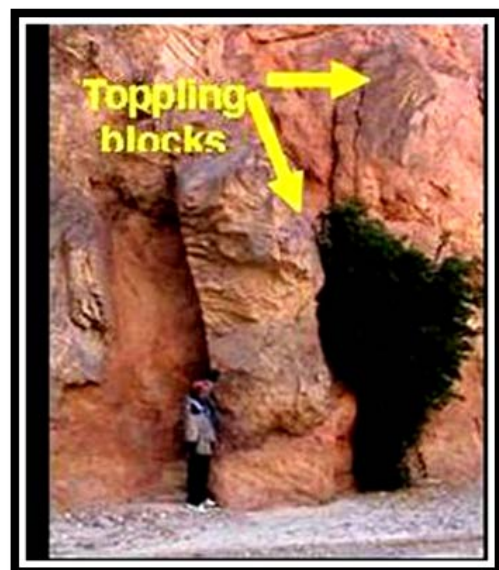


Figure 18. Susceptible toppling blocks

8. Mitigation Methods

In order to improve the slope stability and reduce the risk degree; a mitigating prescription must be designed to fit the condition of the specific slope under study. In addition, it must identify the most important controlling process that are affecting the stability of the slope; and determining the appropriate technique to be sufficiently applied to reduce the influence of that process. The following points introduce some techniques that can be used to increase slope stability and reduce the risk of landslide movements in the canyon reach.

1. Reducing the elevations of the high, vertical slope parts mechanically. Especially, in the narrow width of the canyon where the valley side slopes stand directly on the road edge. This method is only moderately efficient in increasing stability, and a complete solution may involve additional modifications of the slopes. The modification by reconstructing the slope face into benches or steps would be more effective in reducing the rock failure hazard. Bench faces can be constructed steeper than the overall slope angle, as rocks that fall will likely remain on the benches.
2. Rock blocks, which susceptible to fall forward, must be removing before they fall and cause a danger. Removing these blocks can be used and implemented in the loose, unstable, and/or overhanging blocks of rock, which may pose a danger to passing traffic on the road.
3. Strengthening Slopes by using synthetic soil and reinforcement materials or plastic meshes, in particular, where the joints and dense fractures increase in slope rock faces. It is known that cracks at tops of slopes are good indicators of the initiation of failure. It should take into consideration that, the application of this method gave outstanding results at many similar areas.
4. Rock and concrete fences are fairly easy to install and can restrain small rocks from falling or moving onto the road or houses, but it does not stop rocks that bounce out over the top of the fence barrier. So this method can be implemented in the wide reaches of the canyon with very steep slopes. A variety of engineering techniques can be implemented to help and mitigate the effects of rock falls.
5. At the reaches of wide bottom and low steep slopes, most of the moved materials accumulate at the slope base in the form of talus, cones and small fans, these forms can move under the heavy rain showers and causing road blocking, the steel meshes and reinforced earth wall are the most effective methods to reduce like these hazards.
6. Warning writing signs are very necessary and recommended for awareness and guiding the drivers and the road users. As a simple example stopping or parking under hazardous cliffs should be warned against.
7. General, exploratory examination or survey must be done periodically for the main risk features of a region particularly, susceptible and high vulnerability usually preliminary to a more detailed survey. Same work system must implement after Earthquakes and

heavy rainfalls events, in order to discover and predict the probability of hazard occurrence [10].

8. Establishing a complete database supported with high resolution Remote Sensing and GIS for the area will help homeowners, communities and emergency managers, and decision makers to take the positive step of encouraging awareness of available options and recourse in regard to landslide hazard. This database can connect with alarm system.
9. Instrumental monitoring devices to detect movement and the rate of movement can be implemented for very high-risk points. In addition, it will be very useful for using alarm system in spite of that the landslide hazard prediction and warning is still a difficult problem and hot topic in the research of landslide hazards [1,18].
10. The main and the simplest means of dealing with landslide hazards are to avoid construction on steep slopes and existing landslides areas. Therefore, high-risk areas mapping and ground monitoring became very necessary and urgent work, [6,20,31].
11. In addition, a good strategy suggested as a national framework by USGS in 2003, [28,30]. Also, an attempt to unify the landslides definitions and terminology must be taken into account for the possibility to international use and by the same way standardization of description of the types and levels of landslide zoning and the risk degree, will help in the exchange of information and experiences among researchers [8].

9. Conclusion

Through the application of the Geoinformatics method which consists of a combination of recent techniques that include, using of the Total-Station, GPS in the measurement of the very steep slopes of the high mountainous sides of the canyon reach, and link their data with Quick-Bird high resolution images data. Using GIS modeling application gave opportunity to manage these data and consequently, got accurate results and helped in determining, analyzing, evaluating and mitigating the landslides problem. The Risk Zones Map consider one the most important results, which covers one of the study goals. New researches have followed the same method and got accurate results.

The study revealed that the Canyon reach is vulnerable to high risk under the landslides movement hazard. The landslides movements are subject to precondition factors and triggering factors. The movements of the materials on slope sides differ in their forms, speed and magnitude, so they move in the form of rock-fall, rock toppling, rockslide and debris flow. These forms of the movement cause differences in the type and the size of the risk and differences in the form and size of moved rock materials.

In order to improve the slope stability and reduce the risk grade and magnitude; a mitigating prescription has been designed. These proposed treatments took into account the environmental condition as they will be useful for both planner and decision maker.

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