Detection and determining landslides hazard potentiality zones in southern Sinai

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1.Abstract

Key Words: Landslide – Hazard Degrees – Southern Sinai – Arid Valley Basins - Weighting Overlay – Model Builder.

Landslides is one of the most important and common natural hazards which facing the Southern Sinai Region. This due to the geological and geomorphological characteristics. That it can have negative impact on infrastructure, especially roads, economic, urban and social projects in the study area.

So, the study aims to determine the locations, their areas, and the exposures degrees to this natural hazard, along the Southern Sinai, generally. For avoiding to these sites or handling with this problem by the best methods, when setting to the development projects.

Accordingly, it was studied many key-criteria which including numbers of sub-criteria. Divided into, topographic criteria as elevations, slope, aspect, climatic criteria including the amounts of rainfalls, temperature, geological and geomorphological criteria which lithology, geological structures, geomorphology of earth's surface, the surface water and groundwater factors where streams, springs, wells, and, the landcover criteria, especially, vegetation and agricultural lands. The (weighting overlay method) has been followed between all of these criteria represented in the form of produced thematic layers, to achieve the aim of the study.

Furthermore, it has been detected the impacts of climate change on the landslide zonation in south of Sinai. By comparing the effects of rainfall and temperature on landslide in the periods 1961: 1998 with their counterpart in 1999: 2021.

For more detailed study, it was made overlay between the arid valley basins map and the landslides map overall the studying area. And, extract the data of each valley, separately. Then, compare between them to know the most and the least exposed valleys to landslides.

Finally, model builder has been designed, illustrates and helps to study the landslides. It can be applied on any region, especially the arid regions.

2. Introduction:

2.1. The location:

The proposed study area occupies 29.363 km2. Which located between Suez and Aqaba Gulfs, at 27˚ 4̀3 23.3“to 29˚ 5̀7 46“N and 32˚ 3̀6 24“to 34˚ 5̀5 10.58“E.

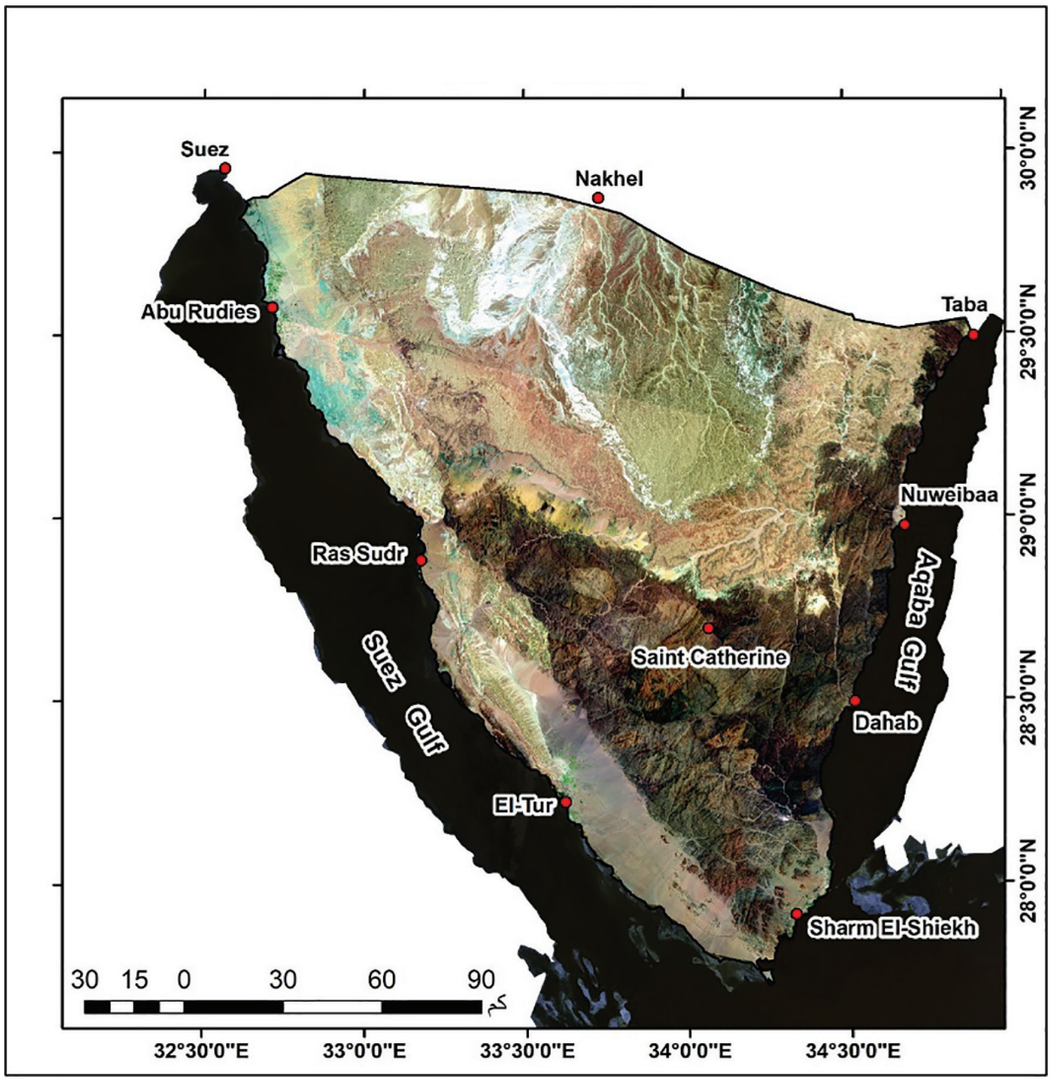

Figure (1) Location map of the study area
(south of Sinai)

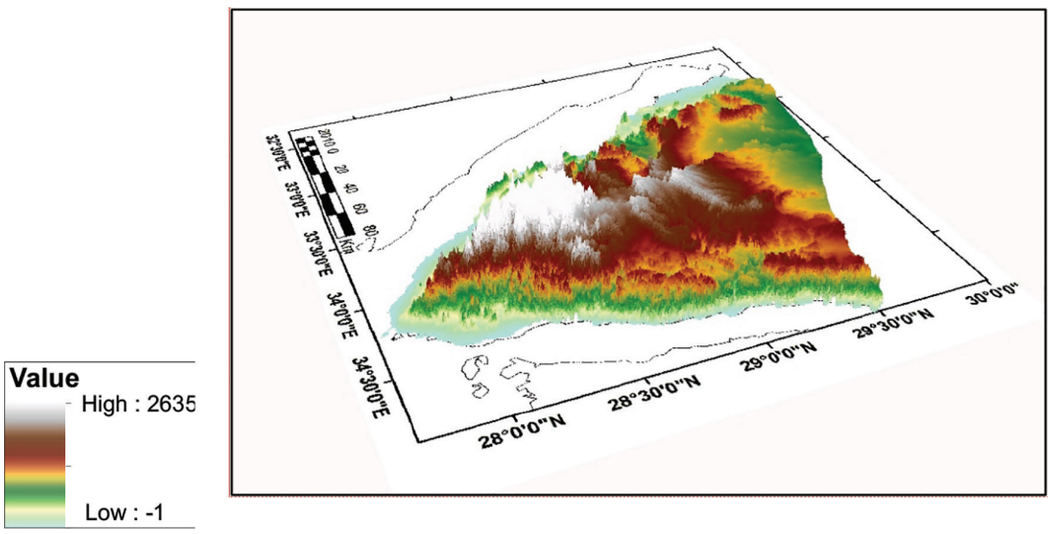

Figure (2): 3D digital elevation model of the study area

2.2. Objective:

The present work aims to study the landslides hazard in south of Sinai. That has been achieved through studying some of criteria as topographic, climatic, geological and geomorphological, surface-water and groundwater, and landcover.

Which resulted in classification of the study area to many classes and zones according to the landslide hazard level. So, it has been able to determine and detect the riskiest sites. And, to determine it in the basins of southern Sinai.

Detect the climate change effects on landslide by depending on two parameters; the precipitation average and temperatures average along to two periods.

To design a model builder, that helping to study the landslide hazard to any region. Especially, the arid regions.

3. Material and Methods:

To determine the landslide potentiality zones, it was depended on eleven factors. Namely, the elevation, slope degree, aspect, rainfall average, temperature average, rock's resistance, drainage network Euclidean, springs and wells Euclidean, and faults density, geomorphology and vegetation density.

Download DEMs from the website https://asf.alaska.edu/. It's ALOS PALSAR with resolution 12.5m. Had been helped to produce the elevation, slope and aspect maps.

The area was classified to nine equal elevation classes with an interval is 300m. The slope layer with an interval is 5˚ except the last class. And, the aspect layer to eight classes.

Climatic data as the average of annual rainfall and temperature were collected in two periods 1961: 1998 and 1999: 2021. To detect the climate change impacts on the landslide hazard.

Structural lineaments were extracted from the geological maps and landsat8. To produce the density of faults and fractures.

Rock units were extracted from the geological maps 1: 250000. And, were collected in four categories according to its resistance to the weathering and erosion factors.

Drainage networks and wadis paths were extracted from the DEM, to design the drainage network's Euclidean layer of the Study area. It's an effective method to reclassify the landform according to the distance near or far the source of surface-water.

Springs and well's locations were extracted from the geological and topographic maps, to design the Euclidean layer of springs and wells in the Study area. Which represent evidence of the groundwater presence.

Geomorphological phenomena of the study area were classified to ten landforms. And, were arranged from the higher to the lower effect on the landslide.

Download Landsat 8 from the website https://earthexplorer.usgs.gov/. for studying the landcover through applied (NDVI) by using the Erdas-imagine 14 program. To distinguish between the value 0, which indicates to the bare rock. And the Values ranging >0: 1, which indicate to vegetation.

Finally, using the weighting overlay method; each thematic layer was given a certain weight according to its effect's degree. And was overlayed to produce the landslide hazard potentiality zones map in South of Sinai.

The landslide hazard map was overlayed on the southern Sinai basins. To identify the landslide hazard zones for each basin, their hazard's degrees and zones area.

4. Geological and geomorphological setting:

The study area is characterized by lithology diversity and density of geological lineaments such as faults, fractures, folds' hinges and dykes.

The basement rocks occupy the southern part which estimated 8.528 km2. Which represented

in four major groups of rocks; Metamorphic rocks including gneiss and metamorphosed volcanic & volcanic-sediments, ultra-mafic rocks, calc alkaline rocks and alkaline rocks. The last type of rock is the youngest and the least resistance to the weathering and erosion in a comparison to the other basement rocks. It takes a mountainous triangle shape which includes faulted and folded mountains in addition to some domes that overlap and surround the triangle.

The sedimentary rocks occupy 20.835 km2. Which is located at the north of the basement rocks. These rocks were Formed in four geological ages; The Paleozoic age; including Cambrian and carboniferous rocks. The Mesozoic age; as Triassic rocks. The Tertiary age; including Paleocene, Eocene, Oligocene, Miocene, and Pliocene rocks. Which formed vast plateaus and because of the tectonic and weathering factors some buttes and mesas occur around these plateaus. The Quaternary age; are Pleistocene and Holocene deposits. These deposits are distributed in wadis that incised the rocks, deltas and fluvial fans in the eastern and western parts of the study area, hamada deposits located at the western of the southern mountainous triangle, fanglomerate and playa deposits which occur in some areas.

The region diverse by the geological structures as faults and fractures. Which have many directions. The most prevalence, the NW-SE as the Suez gulf direction and NE-SW as the Aqaba gulf direction. Mostly, are major-faults. While the least prevalence, is the N-S and E-W directions. Which they are sub-faults. Folds in sedimentary and metamorphic rocks which occur in the second rocks as mesoscopic structures in the texture of rock. Also, dykes that widespread in the region and diverse in their genesis's age and the properties as the direction, chemical composition, color and morphology.

The density of these structural lineaments varies along the study area. Generally, it's very high in the north western part of the southern mountainous triangle and very low in El-Qa'a plain.

5. Results:

5.1. The study thematic layers of the landslide hazard zone:

5.1.1. Topographic criteria:

Elevation: Landslide hazard increases whenever the altitude increases. So, the core of the mountainous triangle is highly risk and it decreases by the direction towards the margins.

Slope: According to the landslide, there are three slopes' major categories. The slopes that value ranging 0˚:15˚ is the least or non-risky, 15˚:30˚ which the landslides widespread and 30˚:90˚ is the riskiest.

Aspect: Generally, the region is classified to four major classes. Graded from the most to the least risky. First, lands which located in the sunny areas, whose aspect degree ranging 0˚:90˚. Second, Semi-sunny areas 90˚:180˚. Third, Semi-shady areas 180˚:270˚. Finally, lands which located in the shady areas, whose aspect degree ranging 270˚:360˚.

5.1.2. Climatic criteria:

Annual precipitation average:

Areas where more rainfall is more susceptible to landslides. This is due to the increased chance of water erosion. So, the more we move from south to north, the greater landslides.

Annual temperature average:

Higher temperature areas are more prone to landslide. Due to the intensity and length of hours' period which they are exposed to solar rays that help the process of rock disintegration. Especially, the internal parts of the study area

are characterized by their continental climate where far from the influence of the sea in temperature adjustment. That is reflected on the increase in the daily temperature variation, which is led to the exposure of rocks to shrinkage and expansion continuous processes and thus increase the rate of disintegration in many parts of our study area.

5.1.3. Geological and geomorphological criteria:
Lithology:

Accordingly, there are three major types of rocks in the area which are sedimentary, metamorphic and igneous. Which the rock type helps to determine the extent resistance of the weathering and erosion factors. So, it has been arranged the rocks according to their hardness from the most rigid as older granite to the least as Cambrian rocks. Noticed, deposits as cobble and boulder are highly risk because ease to transport and rolling from high and steep slopes.

Faults and fractures:

The relationship between the density of faults in square kilometers and landslide hazard has been studied. This is because whenever the structural lineaments were saturated with water, these encourage the rocks for disintegration and sliding processes from the top of slopes.

Geomorphology of the region:

It's an important factor and complement the geology and topography of the region. Each landform of the earth's surface has a role to play in influencing the landslide process. As in the case of high elevated mountains that more risk than plateaus while plains and fluvial fans on the contrary.

5.1.4. Surface water and groundwater criteria:

Wadis: The landslide increases whenever the closer they are to the wadis, despite, they are dry valleys. But they turn to be risk when they are filled with water of rainfalls and floods. Because this helps to move the sediments or dismantling the rock mass of the slopes located near them.

Springs and wells: They are an evidence of groundwater presence. They are effective factors in rock's erosion and sculpture. Especially, when the rainfalls are caused groundwater level raising. Or when sediments are saturated leading to move and transport them to the foot of slopes.

5.1.5 Landcover:

Through the ***study*** and analysis, the NDVI of Landsat 8. Therefore, the image of satellite is divided into two bands:

First band: includes values ranging from -1 to zero. Which it expresses the water bodies and barren lands that prone to landslides.

Second band: includes values ranging from zero to 1. Which it expresses the vegetation whose density varies from place to another. There're the lands which less or no prone to landslides.

- All the previous criteria got into certain classes and arranged according to their importance as mentioned above. Then the weighted overlay method was applied to the eleven thematic layers. As show in table (NO.1).

Table (1): classification the landslides hazard potentiality zones in southern Sinai

Criteria	Thematic Layers	Thematic Layer Weight	Classes		Rank
Topographic criteria	Elevation (meter)	12%	-1:300		9
			300:600		8
			600:900		7
			900:1200		6
			1200:1500		5
			1500:1800		4
			1800:2100		3
			2100:2400		2
			2400:2635		1
	Slope (degree)	12%	0: 5		9
			5: 10		8
			10: 15		7
			15: 20		6
			20: 25		5
			25: 30		4
			30: 35		3
			35: 40		2
			<40		1
	Aspect (degree)	12%	337.5: 360		9
			292.5: 337.5		8
			247.5: 292.5		7
			202.5: 247.5		6
			157.5: 202.5		5
			112.5: 157.5		4
			67.5: 112.5		3
			22.5: 67.5		2
			0: 22.5		1
Climatic criteria	The period		1961: 1998	1999: 2021	
	annual precipitation average (mm)	7%	0: 10	0: 10	5
			10.1: 15	10.1: 15	4
			15.1: 20	15.1: 20	3
			20.1: 25	20.1: 25	2
			25.1: 40	25.1: 40	1
	annual temperature average (C°)	7%	17: 18.9	18.5: 20	5
			19: 20.8	20.1: 22	4
			20.9: 22.7	22.1: 24	3
			22.8: 24.6	24.1: 26	2
			24.7: 26.5	26.1: 27.02	1

Geological and geomorphological criteria	Lithology and it's resistance degree to erosion	12%	Hamada and fanglomerate deposits	9
			Wadis deposits	8
			Calc-alkaline rocks Older granite (GI) (Granodiorite, quartz-diorite and tonalite)	7
			Calc-alkaline rocks Younger granite (GII) (Monzogranite and syenogranite)	6
			Alkaline rocks Younger granite (GIII) (Alkaline granite, riebeckite, syenite and quartz-syenite)	5
			Metamorphosed rocks (gneisses, schist, phyllite)	4
			Metamorphosed volcanic and volcanic-sediments rocks	3
			Sedimentary rocks (Limestone and cretaceous rocks)	2
			Cambrian rocks	1
	Faults and fractures (km/km2)	12%	0: 0.0915	9
			0.0916: 0.183	8
			0.184: 0.275	7
			0.276: 0.366	6
			0.367: 0.458	5
			0.459: 0.549	4
			0.550: 0.642	3
			0.642: 0.732	2
			0.733: 0.842	1
	Geomorphology	12%	Fluvial fans	9
			Plains lands	9
			wadis	8
			Small sedimentary plateau	7
			Sedimentary medium height landforms	6
			Rugged terrain dissected by dykes	5
			large sedimentary plateau	4
			Folded landform	3
			Faulted domes and mountains	2
			High elevation mountains	1

Surface-water and groundwater criteria	Distance near of Wadis (km)	6%	<9	5
			6: 9	4
			3: 6	3
			1: 3	2
			0: 1	1
	Distance near of springs and wells (km)	4%	<9	5
			6: 9	4
			3: 6	3
			1: 3	2
			0: 1	1
Landcover	vegetation	4%	vegetation	9
			Barren lands	1

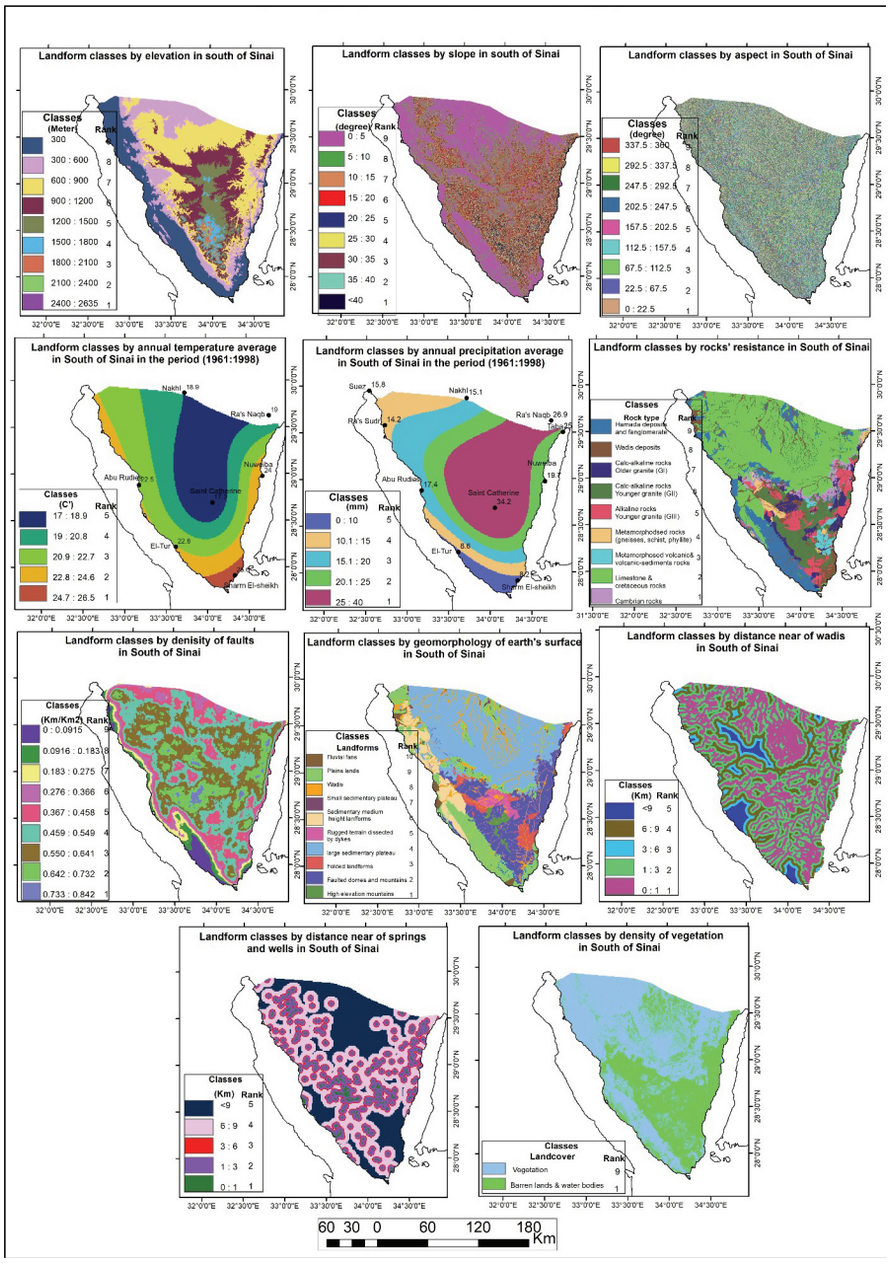

Figure (3): Landslides hazard potentiality zones in South of Sinai

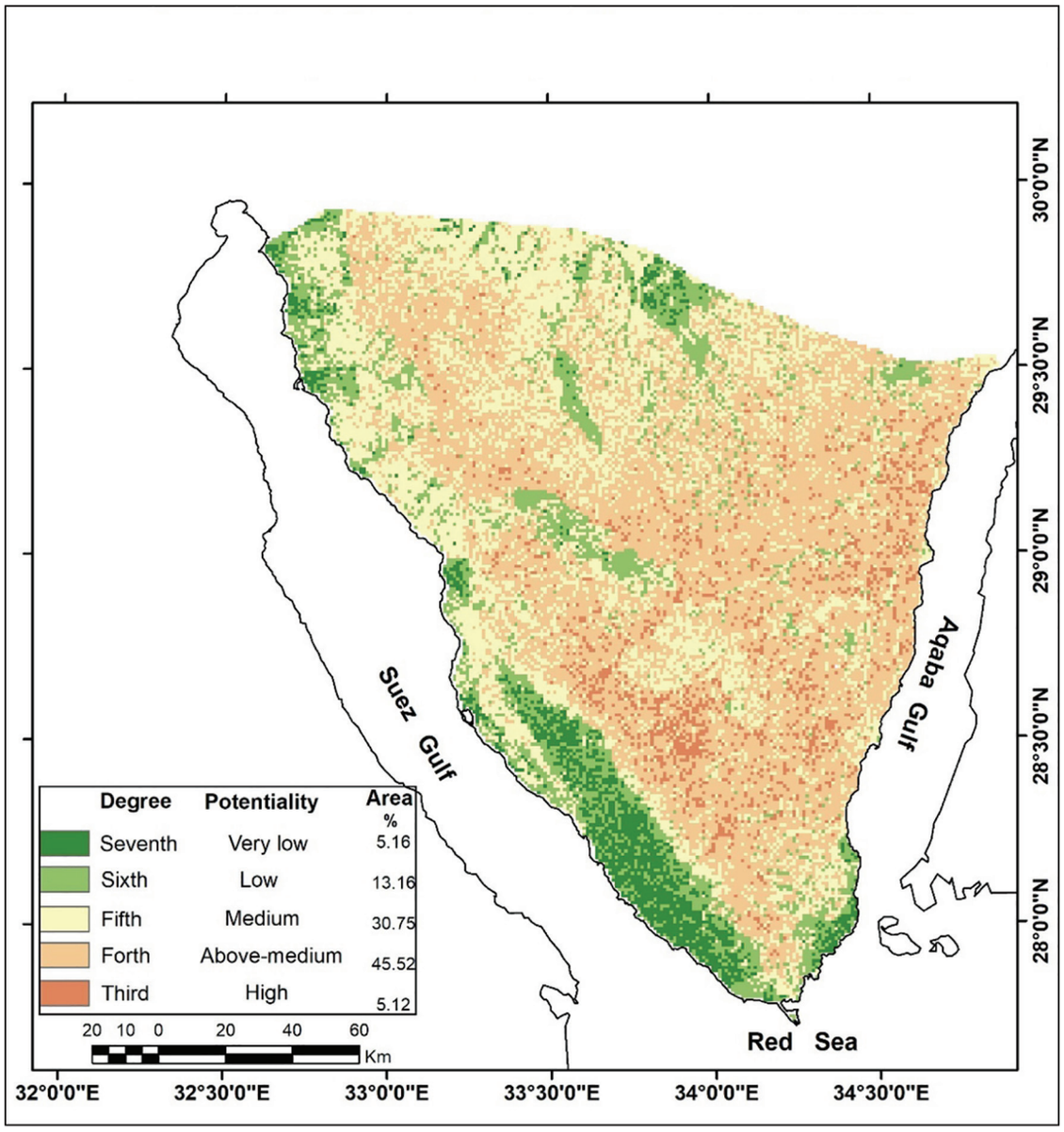

Figure (4): Landslides hazard potentiality zones in South of Sinai
According to annual temperature and precipitation averages in the period (1961:1998)

5.2. Detecting change in the area of landslide zones:

- Rising temperatures also lead to an increase in water vapor in the atmosphere which is reflected in increased rainfall and negatively affects the hazard of landslides. Sometimes, in arid regions such as the study area, the climate causes more drought or more vegetation so that the landslide becomes unblurred. It will be clarified whether climate change has affected landslide zones areas or not.

- Therefore, the extent of the change in landslides was studied, by comparing the extracted data depending on precipitation and temperature averages in the period 1961: 1998 with its counterpart in the period 1999: 2021. As shown in table (No.2).

- Based on the study of the landslide hazard in south of Sinai in the first period. So, the region is classified to five zones. Graded from the most to the least suffering zones. There is a high suffering zone has an area of 5.12% (a very highly unstable), above-medium zone of 45.52% (highly unstable), medium zone of

30.75% (moderately unstable), low zone of 13.16% (moderately stable), a very low zone of 5.16% of the total area of South Sinai (a stable zone).

- On the contrary, landslides in the second period, are classified into six zones. Although there are no obvious differences in the two data, but the area of the above-medium zone has increased 1% and there is a new zone emerged but has a small area. Therefore, there is a very suffering zone that is forming a critical zone has an area 82.5m^2 currently.

Table (2): Landslides hazard potentiality zones in south of Sinai and their areas

Rank	potentiality		Zone	Total area (1961-1998)		Total area (1999-2021)	
				Km^2	%	Km^2	%
7	Seventh degree	very low	Stable	1.492	5.16	1.521	5.22
6	Sixth degree	low	Moderately Stable	3.883	13.16	3.859	13.24
5	Fifth degree	medium	Moderately Unstable	8.884	30.75	8.811	30.23
4	Fourth degree	Above medium	Highly Unstable	13.152	45.52	13.538	46.44
3	Third degree	high	Very Highly Unstable	1.481	5.12	1.416	4.86
2	Second degree	Very high	Critical	----------	----------	0.082	0.003

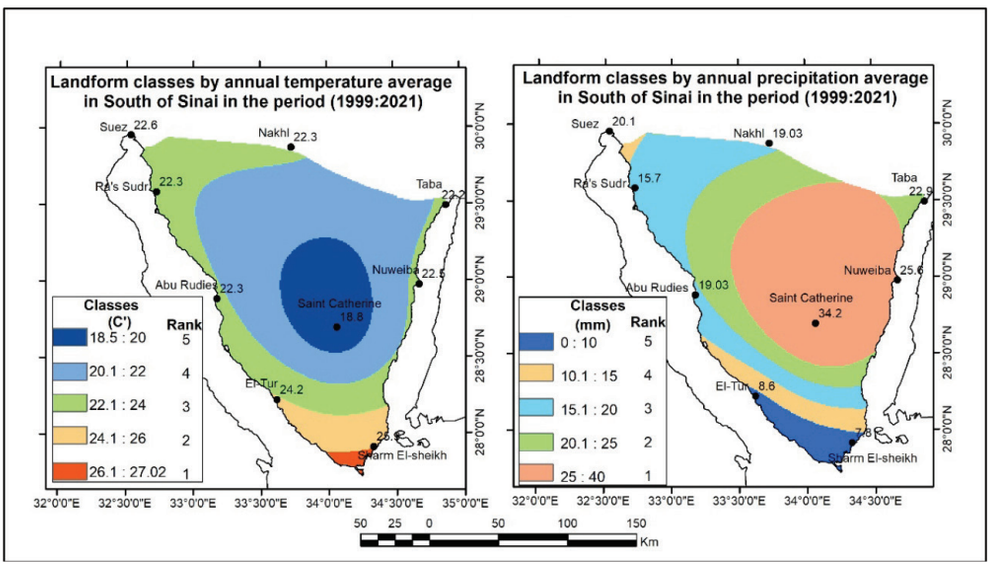

Figure (5): Climate data's South of Sinai in the period (1999:2021)

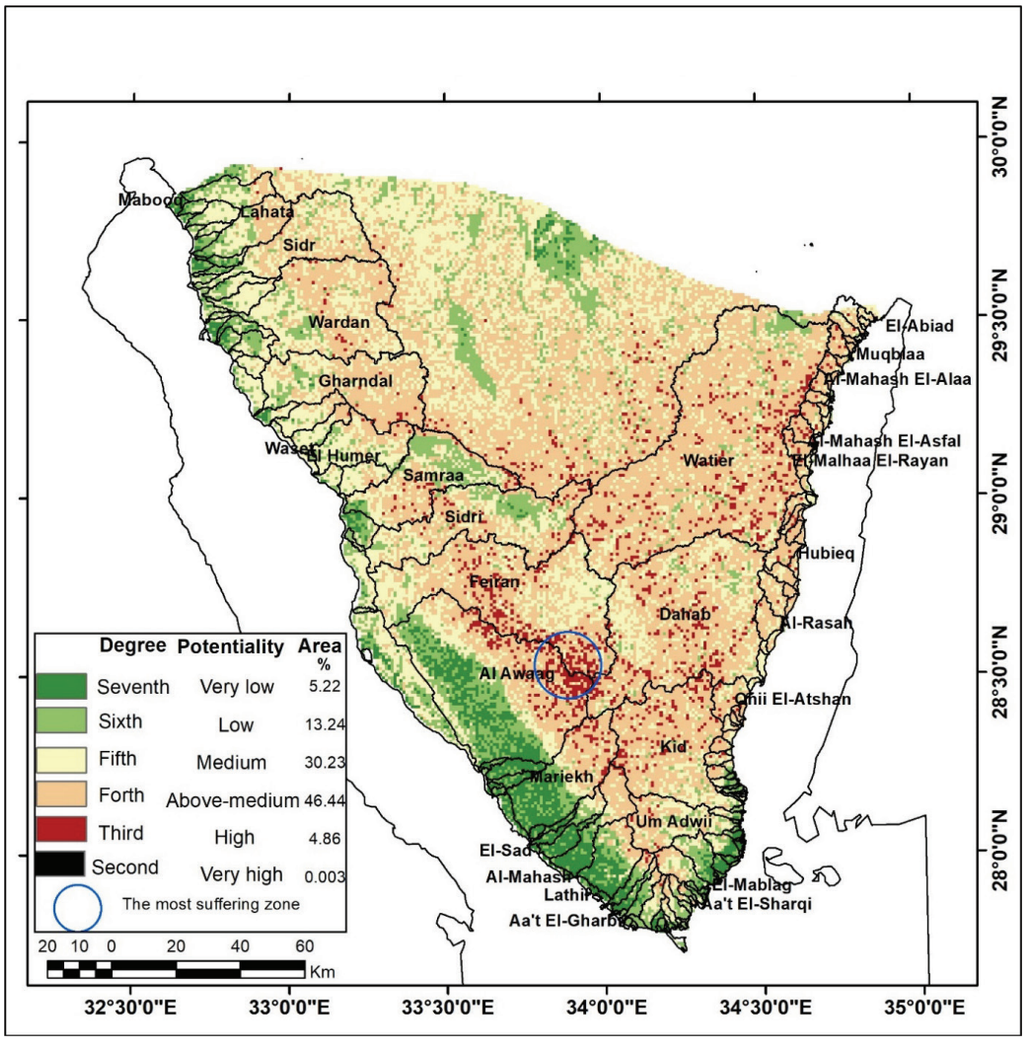

Figure (6): Landslides hazard potentiality zones in South of Sinai
According to annual temperature and precipitation averages in the period (1999:2021)

5.3. Analysis of the landslide zones:

The critical and very highly unstable zones are impossible to work their urban and economic development.

The highly unstable area can be modified to be suitable for human habitation by creating barriers and restricting the discharge of surface and groundwater through the construction of dams and wells.

The moderately unstable zone is stable now but when extremely runoff occur or the groundwater level rise, it may prone to landslide.

The moderately stable and stable zones is very appropriate for human activities and region development

5.4. The landslide hazard zones in basins South of Sinai:

- Areas of the potentiality landslide hazard zones of the basins in south of Sinai were determined and calculated as shown in table (NO.3).

Table (3): Areas of the potentiality landslide hazard zones of the south of Sinai basins

No		Basins	Area	The areas of landslides hazard zones (%)					
				Very high	High	Above Medium	Medium	Low	Very low
			Km^2	Second	Third	Fourth	Fifth	Sixth	Seventh
1	Eastern Basins	El Abiad	37.6	–	2.4	58.5	31.7	7.3	–
2		Muqblaa	49.5	–	10	78.3	11.7	–	–
3		Mahash Alla	31.3	–	13.1	73.7	13.1	–	–
4		Mahash Asfal	46.2	–	18.7	69.6	17.8	1.8	–
5		Malha El-Rayan	52	–	17.5	77.8	3.2	1.6	–
6		Watier	3508.6	–	8.7	70.6	15.9	4.8	0.02
7		Hubieq	63.5	–	6.5	73.6	15.6	1.3	–
8		El Rasash	75.5	–	1.06	71.3	27.6	–	–
9		Dahab	2068.2	–	9.5	60.6	26.4	3.4	–
10		Qnii El-Atshan	97.3	–	5.9	61.9	29.7	2.5	–
11		Kid	1055.7	–	10.06	67.4	19.1	3.2	0.07
		Average	–	–	9.40	69.39	19.25	3.24	0.045
12	Western Basins	Mabooq	179.4	–	0.9	20.3	44.8	28.9	5.2
13		Lahatta	279.3	–	0.9	36.8	36.8	22.6	2.9
14		Sidr	642.8	–	0.5	48.6	42.1	8.7	–
15		Wardan	1151.8	–	1.6	51	37.3	9.8	0.14
16		Gharndal	857.6	–	1.4	57.1	33.6	7.2	0.7
17		Waset	108.5	–	0.7	25.7	57.6	14.4	1.5
18		El Humer	370.6	–	1.3	32.7	50.7	15	0.2
19		Samraa	735.2	–	4.8	38.2	28.1	27.6	1.2
20		Sidri	1077.7	–	4.7	45.3	32.4	16.9	0.6
21		Feiran	1780.9	0.05	11.8	53.2	31.1	3.1	0.05
22		Awaag	1924.1	–	9.7	29.8	18.02	23.8	18.7
23		Mariekh	632.9	–	7	35.1	11.8	17.5	28.6
		Average	–	0.05	3.77	39.48	35.36	16.29	5.43
24	Southern Basins	Um Adwii	361.9	–	3.4	47.3	37.9	10.9	0.45
25		El mablag	114.9	–	–	7.3	25	45.6	22.05
26		Aa't El Sharqi	109.9	–	2.2	39.8	32.3	21.8	3.7
27		El Sad	95.1	–	12.4	26.5	34.5	26.5	–
28		El Mahash	251.8	–	3	39.6	10.9	15.5	33
29		Lathii	275.9	–	0.6	20.3	12.2	38.3	38.5
30		Aa't El Gharbi	58.2	–	16.1	11.8	57.3	14.7	–
		Average	–	–	6.28	27.51	30.01	24.7	19.54

- By studying the landslides hazard zones in 30 basins as study samples. It turned out that, the eastern basins which pour in the Aqaba gulf are characterized by the increasing of fourth-degree landslides with the absence of the seventh-degree landslide approximately. This indicates the lack of degradation and leveling processes, and the slow progress of slopes. Due to its composition from basement rocks. The most basins that prone to the high and above medium landslides are the Mahash Asfal, Malha El Rayan, Mahash Alla, Muqblaa, Kid and Dahab.

- While the western basins which flow into the Suez gulf, the area of the third-degree zone converge with the area of fourth-degree landslide zone with the appearance of the seventh degree. This refers to the activity of degradation processes and the slopes are more progress than the previous. This is primarily due to the high density of structural lineaments along with other factors such as the retreat of rift edge away from the Suez coast and large areas of the north western basins are composed of sedimentary rocks. The basins most susceptible to severe landslides are Feiran, Awaag and Mariekh.

- In addition to, the southern basins which flow into the red sea are characterized by the convergence fourth, fifth- and sixth-degree landslides areas. So, their slopes in an intermediate stage of progress compared to eastern and western basins. The riskiest basins are Aa't Gharbi, El-sad and Um Adwii.

5.5. The produced Model Builder to determine the landslide hazard zones:

- It has been designed a model builder by using ArcGIS program, which showing the method that is followed in the present study to determine the landslide hazard potentiality zones. Which it can be applied on any study area. As shown in figure (NO.7).

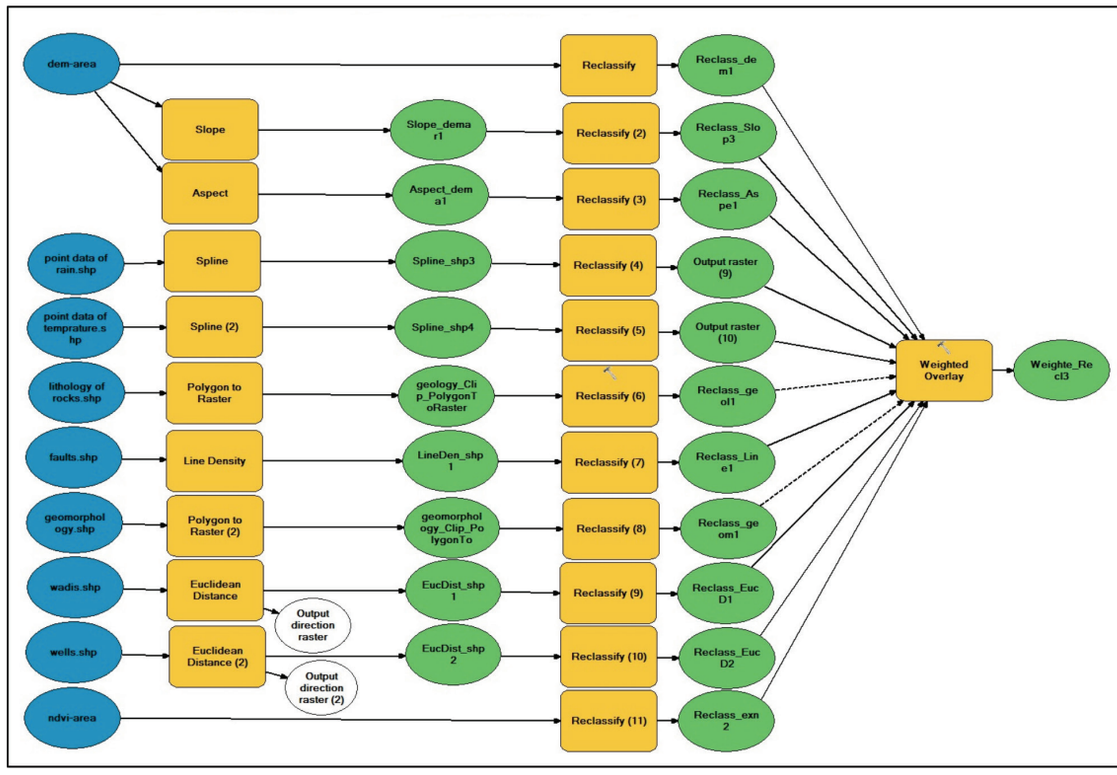

Figure (7): Model Builder for determining and detection the landslide hazard potentiality zones

6. Conclusion:

The very high potentiality hazard zone occupies 82.5 m2 which located in saint Catherine province. And the very low potentiality zone occupies 1,521 km2 which represented in Qa'a plain, fluvial fans of northwestern and southeastern basins.

In general, and according to study 30 basins in south of Sinai. The eastern basins are high risk, then the southern and finally the western basins. This is shown by studying the values of the average landslides of the second and third degree. But, in especial, the most suffering zone is in the middle of the study area. Which occupies the eastern of Feiran and Awaag and small area in western of Dahab basin.

By comparing the landslide zones maps that were designed depending on the periods 1961: 1998 and 1999: 2021, the progress of the slopes is very slow and may be limited in many sites to debris flow, debris mud, small slide and few rock falls.

All these important results must be taken into account in the formulation of development plans in the region. To deal with this problem in the best ways.

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2. https://earthexplorer.usgs.gov/

3. https://www.meteoblue.com/en/weather/historyclimate/change