Al-Azhar Bulletin of Science Vol. 31, No. 2, (December) 2020, pp. 35-42

PRELIMINARY ACTIVE TECTONIC ASSESSMENT OF WADI GHOWEIBA CATCHMENT, GULF OF SUEZ RIFT, EGYPT, INTEGRATION OF REMOTE SENSING, TECTONIC GEOMORPHOLOGY, AND GIS TECHNIQUES

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ABSTRACT

The Wadi Ghoweiba catchment located at the northeastern part of the western coast of the Gulf of Suez, Egypt has been examined to evaluate the impact of tectonic activity remarks through a significant analysis of the morphotectonic indexes that were calculated using geographic information systems (GIS) technique. Four morphotectonic indexes, including mountain front sinuosity, valley floor width-to-valley height ratio, rock strength, and stream length gradient index were applied and processed for recognition of tectonic activity evidence. The results computed from theses indexes were combined to examine different fracture and/or fault segments of the catchment. The values of the measured morphotectonic indexes were used to evaluate the distribution of the different tectonic signals of the study catchment. The examined catchment mostly reflects low-to- medium tectonic activity signals. From 25 studied segments, only two segments found at the southern Ghoweiba catchment wall record medium-to-high tectonic values which indicate very small significant tectonic activity compared to the whole catchment. Based on these morphotectonic indexes, the southern segments might with respect to the northern segments of the study catchment.

Keywords: Tectonic geomorphology; GIS; Seismic hazards; Wadi Ghoweiba; Gulf of Suez

1. INTRODUCTION

Tectonic activity cycles produce deformed landforms which can be examined by quantitative tectonic geomorphology. Numerous laboratory and field works have been applied to discuss how different morphotectonic indexes record signals along active regions, uplifting blocks, and evolving active faults (El-Hamdouni et al., 2008; Markose and Jayappa 2013; Topal et al., 2016; Khalifa et al., 2018 and 2019; Valkanou et al., 2021). Morphotectonic indexes are very helpful in the evaluation of relative active tectonics of tectonically active regions which undergo different rates of tectonic activities (Keller 1986 and Yıldırım 2014). For example, river drainage analysis is a powerful tool in understanding the morphotectonic evolution of different tectonic elements and features such as faults and fractures (Burbank and Anderson 2000 and Khalifa et al., 2019). Active tectonic landforms, faults, and catchments can be evaluated through detailed calculations of morphotectonic indexes such as mountain front sinuosity (S_{mf}), drainage density (D_d), valley floor width – to – height ratio (V_f), stream length gradient index (S_L), and rock strength levels (Silva et al., 2003 and Keller and DeVecchio 2013).

The Wadi Ghoweiba Catchment (WGC), a morphologically distinct catchment that drains toward the Gulf of Suez (Figure 1). The studied catchment covers the region between the northern scarp of the northern Galala (southern catchment wall) (Hassan 2008 and Abdeen 2009) and Gabal Akheider (northern catchment wall). It occupies a region about 1918 km² which is crossed by a number of roads including Maddi – Sokhna and El – Saf roads. It is bounded by longitudes 31º 45’ and 32º 30’ E, and latitudes 29º 27’ and 29º 50’ N along the western coast of the Gulf of Suez (Figure 1). The region where the catchment is located includes huge industrial and construction projects that aiming for the development of the Ain Sokhna port.

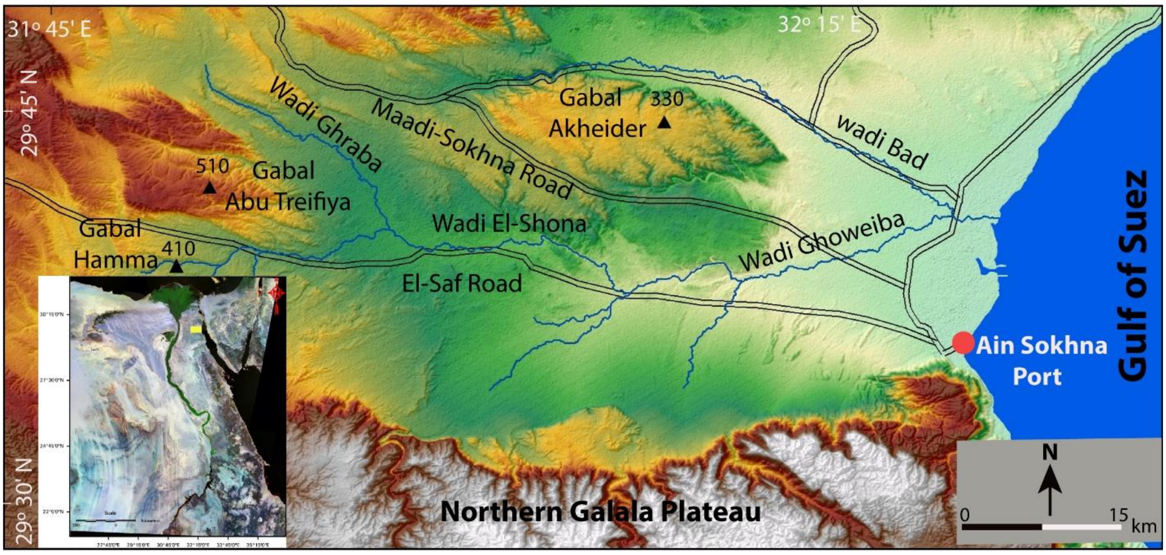

Figure 1. Location map of the study catchment. Inset map and yellow box indicate location of the study region.

The Wadi Ghoweiba region is characterized by two major tectonic elements; the Syrian arc systems and Gulf of Suez rift (Abdeen et al., 2009). It consists of many lithological units including shale, limestone, gravel, dark colored sandstone, and basalt dikes that are ranging in age from Upper Carboniferous to Quaternary. This work aims to apply the remote sensing and GIS techniques in order to evaluate the relative tectonic activity and seismic hazards of the study catchment.

2. GEOLOGY AND STRUCTURE

The geological units of the studied WGC region were examined and mapped within several geological and remote sensed mapping projects (e.g. Sadek 1926; EGSMA 1981; Klitzsch et al., 1987; Abd-Allah 1993; Hassan et al., and Abdeen et al., 2009). They recorded 13 different lithological units and formation that are distributed over the whole studied region (Figure 2). The oldest unit in the study region is the Aheimer Formation which was traced as a narrow strip in the most southeastern part of the area. The Aheimer Formation is composed of shale, dark colored sandstone with limestone (Figure 2). The Aheimer Formation was followed by undifferentiated Early to Middle Jurassic marine deposits. The Cretaceous lithological units are represented by the Late Jurassic – Early Cretaceous, Malha Formation and undifferentiated Late Cretaceous deposits. Abd-Allah (1993) recorded Malha Formation thickness as 70m (Abdeen et al., 2009). Early Eocene is represented by the Thebes Formation which contains well-bedded shelf limestones and other shallow water carbonate deposits. The Mokattam Group are the major units of the study region. They consist of the Observatory Formation (dense, medium-bedded limestone with minor local chert), Giuish Formation, and Gabal Hof Formation (Figure 2). The Late Eocene Maddi Formation is located in the middle and northern parts of the study are and consists of shallow marine shale and limestone. Oligocene is recorded with patchy Gabal El-Ahmar Formation in the central part of the study region which contains vividly colored sand, quartzite, and gravels. Hagul Formation lies in the central and northeastern most parts of the study area and consists of fluviatile sand and gravel. The younger units of the study region are Pliocene deposits and Quaternary wadi deposits (Figure 2).

Several studies stated that the Ghoweiba catchment is a major structural plains that is highly deformed by many sets of normal faults (e.g. Abd-Allah 1993; Abdeen et al., 2009). Generally, the mapped fractures or faults in the study region can be distinguished into three major sets: Suez Gulf-orthogonal trend (E-W),

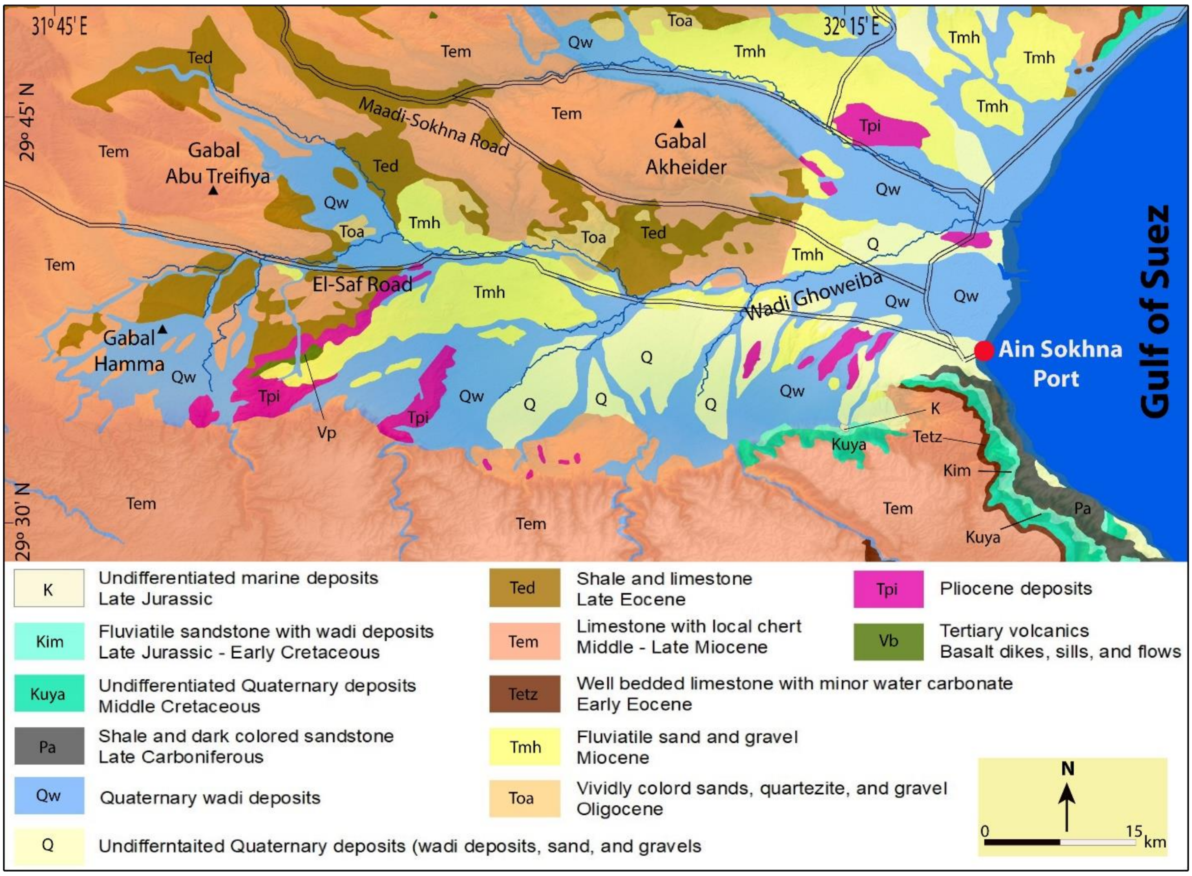

Figure 2. Geological map of the present study region, modified after Klitzsch and Polman (1987).

Suez Gulf-Parallel trend (NW), and Suez Gulf-oblique trend (Sultan et al., 2017). The Suez Gulf-parallel and orthogonal faults are well traced along the northern and southern walls of the Ghoweiba catchment (Hammed and Abdel Khalek 2015).

3. MATERIALS AND METHODS

Digital elevation model (30-m resolution) data (DEM) is extracted and prepared for the various work examinations. The ArcGIS software was utilized for all topographic analyses and calculations. The drainage systems extracted from the DEM through hydrological tool in ArcGIS were used to obtain the morphotectonic indexes values along the entire catchment. In total 25 fracture segments were examined according to the different trends of the fracture or/and faults. Mountain front sinuosity index were applied for each fracture segment of the study catchment.

3-1- Mountain-front sinuosity (S_{mf})

The morphometric mountain front sinuosity index (S_{mf}) is computed as,

$$S_{mf} = L_{mf} / L_s,$$

where L_{mf} represents the length of the mountain gorge front and L_s reflects the mountain straight-line length (Bull and McFadden 1977). Keller (1986) and Bull and McFadden (1977) stated that the S_{mf} values less than 1.4 are tectonically active, while values that are greater than 3 are associated with inactive fronts. The S_{mf} values were extracted from 13 front segments.

3-2- Valley width-to-height ratio (V_f)

The V_f index is used in reading the rate of incision over the uplifted regions. (Keller and Printer, 2002; Silva et al., 2003) proposed V_f, as,

$$V_f = 2V_{fw}/[(E_{ld}–E_{sc})+(E_{rd}–E_{sc})]$$

where V_{fw} measures the valley floor width, E_{ld} and E_{rd} give values of the left and right valley divides, respectively, and E_{sc} represents the valley floor elevation. Azor et al., (2000) proposed that low V_f values suggest regions of high tectonic activity, whereas high Vf values characterized regions with low tectonic signals.

3-3- Rock strength (R_s)

Selby (1980) examined and discussed the relationship between rock hardness and strength that is related to the constituent material and cement playing a scientific role in the resistance to erosion processes. Rock strength is categorized into three classes, low (sand, marl, alluvium, conglomerate, and sandstone), medium (sandy limestone), and high (basalt, gneiss, schist, and quartzite).

3-4- Stream-length gradient index (S_L)

The stream-length gradient index (S_L) was proposed by Hack (1973) in order to evaluate the effect of rock resistance in channels as a case study of south United States. The degree of tectonic activities can be detected using S_L by tracing abrupt changes of river streams gradients along the study zone (Hack, 1973; Keller and Pinter, 2002).

The S_L index is calculated as,

$$S_L = (\Delta H / \Delta L) * L,$$

Where $\Delta H / \Delta L$ indicates stream slopes and L reflects the length of the stream between the drainage divide and the stream midpoint reach which the S_L is calculated. S_L was calculated every 100 m of the streams.

4. RESULTS

The 25 fracture and or/fault segments (FS), recorded S_{mf} values which range from 1.5 into 2.9 (Table 1; Figure 3). The southern Ghoweiba catchment wall comprises fracture and/or faults from 1 to 10, while the rest of the segments were analyzed along the northern Ghoweiba catchment wall. The highest S_{mf} values were recorded for FS-3, FS-6 and FS-21, while the lowest values were calculated for FS-8 and FS-25. The S_{mf} calculations indicate that most of the fracture and/or fault segments give low tectonic activity signals. The V_f index was calculated for 75 spots and provides values from 0.3 into 1.9 (Table 1; figure 4). The highest mean V_f index values were recorded for FSs 6, 11, 13, 21, and 23, while the lowest values are associated with FS-15. The different S_{mf} values point to an mild similarity between mean V_f and The S_{mf} values over the whole catchment zone.

Southern Ghoweiba catchment wall			Northern Ghoweiba catchment wall		
Fracture and/or fault segments	S_{mf}	Mean V_f	Fracture and/or fault segments	S_{mf}	Mean V_f
FS-1	1.7	1.5	FS-11	2.7	1.9
FS-2	2.3	1.8	FS-12	2.6	2
FS-3	2.8	2	FS-13	2.1	1.9
FS-4	2.9	1.1	FS-14	1.9	0.7
FS-5	2.4	1.3	FS-15	2.7	0.3
FS-6	2.8	1.9	FS-16	2.1	1.3
FS-7	2.55	1.3	FS-17	1.8	1.3
FS-8	1.5	0.7	FS-18	1.8	1.1
FS-9	1.65	1.2	FS-19	2.3	1.7
FS-10	2.45	0.8	FS-20	1.8	1.1
			FS-21	2.8	1.9
			FS-22	1.9	1.3
			FS-23	2.1	1.9
			FS-24	2.3	1.5
			FS-25	1.5	1.4

Table 1: S_{mf} and V_f parameters of the study Fracture and/or fault segments.

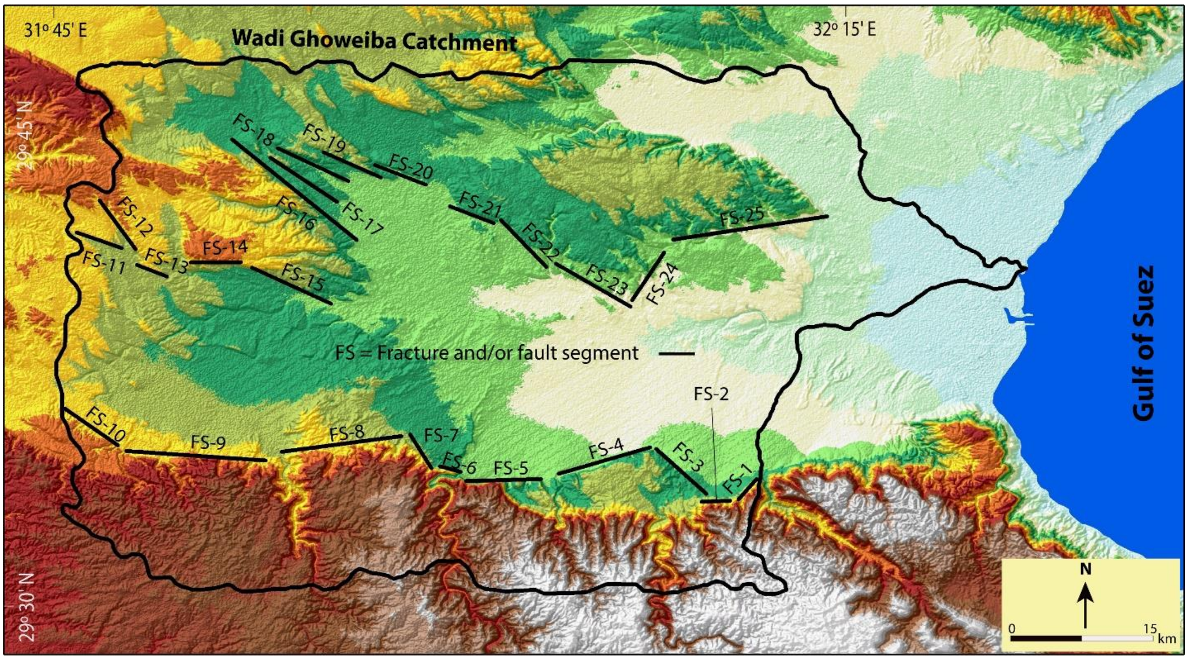

Figure 3. Shaded elevation images show fracture and /or fault segments of the Wadi Ghoweiba catchment.

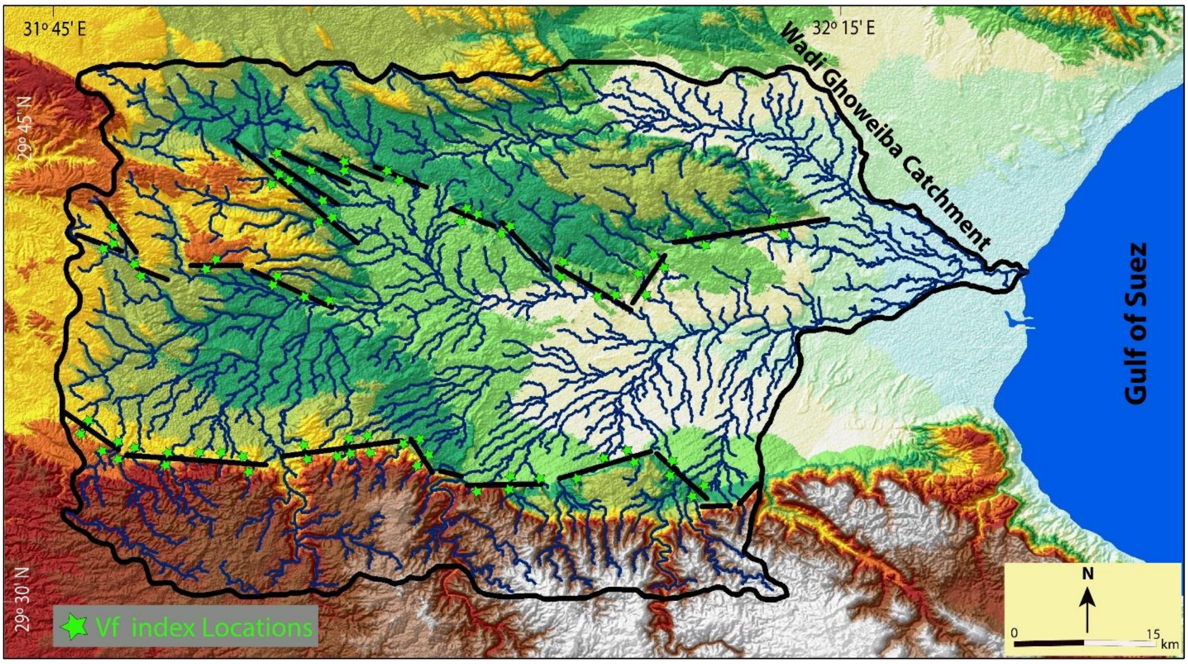

Figure 4. Shaded elevation images show V_f locations of the Wadi Ghoweiba catchment.

The geological map of the WGC is characterized by different types of rock units. The units of the study region include sandstone, shale and limestone, vividly colored sands, quartzite, and gravel, and Quaternary wadi deposits (Figure 2). The lithological distribution indicates that the study catchment has just one rock strength type. According to Selby (1980), all WGC rock types are represented by low level of rock strength. Depending on S_L index calculations, S_L values vary from >50 to 150 along most streams and channels throughout the studied catchment (Figure 5). Generally, S_L values are gradually increase toward the mountain–fronts of the segments. The distribution of S_L values shows anomalous spots

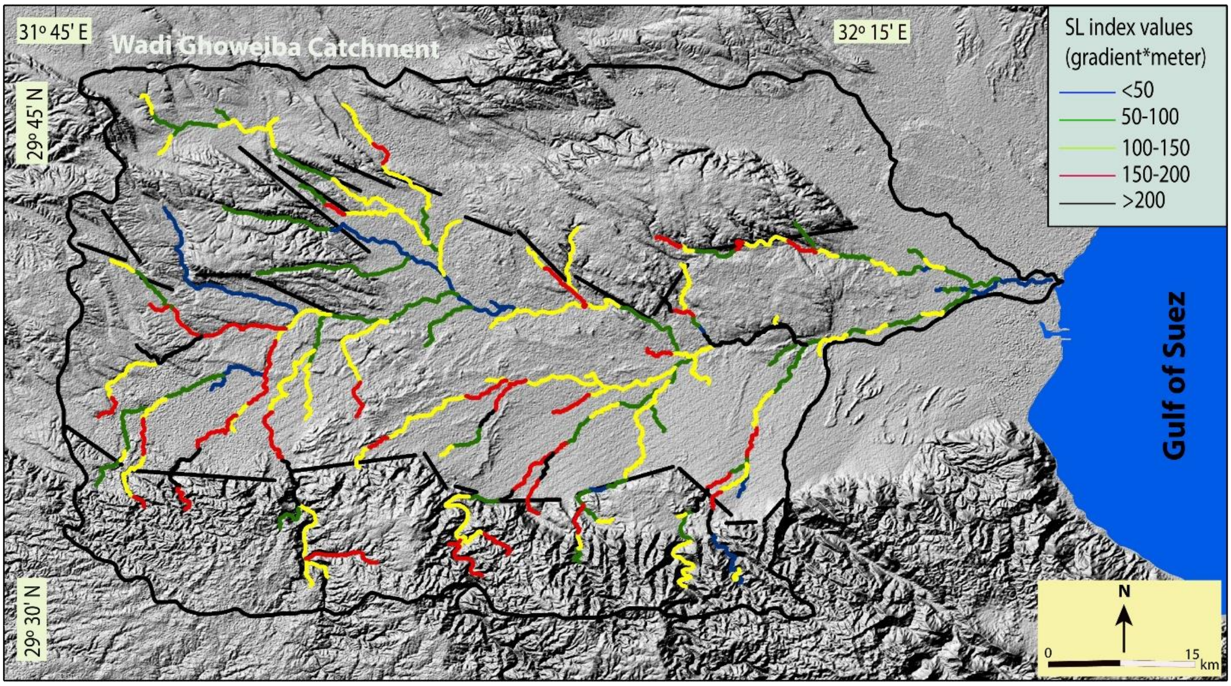

Figure 5. S_L index along the fracture and/or segments of the Wadi Ghoweiba catchment**.**

in some locations of the study catchment, because some high values were recorded on some low strength rock types (Figure 5).

5. Discussion and conclusion

To discuss relative tectonic activity of the major fracture segments, the results of all calculated geomorphic indexes were synthesized. The S_{mf} and mean V_f values are generally high along FSs 2, 3, 6, 11, 12, 13, 21, and 23, respectively with S_{mf} ranges between 2.1 and 2.9, and V_f from 1.8 to 2. The lowest values of the S_{mf} and V_f indexes were only recorded along FS-8 which indicates high to medium activity signal is examined along southern WGC wall. Focusing on the S_{mf} values, southern WGC scarp segments indicate high to medium tectonic activity levels that gradually decrease from east to west except along FSs 8 and 9. Generally, the S_{mf} and mean V_f are discussing medium to slightly high tectonic activity signals along the southern WGC scarp. On the other hand, the S_{mf} and mean V_f values reflect low to slightly medium activities along the northern WGC wall. Many studies were conducted along active landforms using S_{mf} and V_f values (e.g. Yıldırım 2014 and khalifa et al., 2018) and they indicated a consistency between the S_{mf} values and mean V_f values of the majority studied segments. Our study reveals some consistencies and inconsistencies according to the predominant low activity signals that cover the most segments of the studied catchment. Generally, the strengths of rocks partly range from low to very low with changes in S_L values. The only high strength remark is recorded by narrow strips of basalt dikes and sills along the western part of the WGC region. Normally, high S_L values are associated with high strength rocks, while the low rock strengths are characterized by low S_L values. The study examined the rock strength levels and it was found that nearly all rocks indicate a low strength level. For that reason, it can be inferred that the impact of the lithology is negligible and tectonic signals are predominant.

Morphotectonic indexes, including S_{mf}, V_f, Rs, and S_L are used for an in-depth investigation of tectonic geomorphology evolution and tectonic levels of the WGC. Mostly, S_{mf} and V_f values indicate a medium to low level of tectonic activity. The results from S_L index are in agreement with values of S_{mf} and mean V_f. This work indicates that the northern WGC wall mostly reflects low tectonic activity signals, while the southern wall imposes medium activities with some segments. The tectonic activity remarks gradually increase from north towards south and slightly from east to west. In this study, cumulated results can confirm that the seismic signals are slightly poor and there are no significant remarks for any future seismic hazards. This work offers that geomorphic analysis of the whole region of a major structure WGC provides very valuable insights into the region’s tectonic evolution.

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التقييم الأولي للنشاط التكتوني لوادي غويبة, خليج السويس, مصر, دراسة تكاملية تشمل تقنيات الإستشعار عن بعد والجيومورفولوجيا التكتونية ونظم المعلومات الجغرافية

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الملخص العربي:

تناولت هذة الدراسة فحص مورفوتكتوني لمستجمعات مياه وادي غويبة والذي يقع في الجزء الشمالي الشرقي من الساحل الغربي لخليج السويس - مصر. وكان الهدف من هذة الدراسة هو تقييم تأثير ملاحظات النشاط التكتوني من خلال تحليل المؤشرات الجيومورفولوجية السطحية والتي تم حسابها باستخدام تقنيتي الإستشعار عن بعد ونظم المعلومات الجغرافية. في هذة الدراسة تم تطبيق أربعة مؤشرات مورفوتكتونية ، والتي تشمل قياس التعرجات الأمامية للجبال ، ونسبة عرض أرض الوادي إلى ارتفاع الوادي ، ودرجة مقاومة الصخور، ومؤشر التدرج لطول التيار للتعرف على أدلة النشاط التكتوني. وفي هذه الدراسة تم دمج النتائج المحسوبة من القياسات المختلفة لفحص اجزاء النطاقات المشوهة المختلفة والتي تتوزع في الوادي المدروس. ومن ثم تم استخدام قيم المؤشرات المقاسة لتقييم توزيع الإشارات التكتونية المختلفة لمستجمعات الدراسة. وأظهرت نتائج تسجيل مستجمعات المياه التي تم فحصها إشارات النشاط التكتوني المنخفض إلى المتوسط. ومن 25 مقطعًا مدروسًا ، تم تسجيل نطاقين فقط في جدار مستجمعات وادي غويبة الجنوبي واللذان يسجلان قيمًا تكتونية تتراوح من متوسطة إلى عالية والتي تشير إلى نشاط تكتوني صغير جدًا مقارنة بباقي المنطقة المدروسة. بناءً على هذه المؤشرات المورفوتكتونية ، قد تعطي الأجزاء الجنوبية إشارات زلزالية طفيفة بالمقارنة بالأجزاء الشمالية من مستجمعات مياه الوادي المدروس.