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Evolution in seismic monitoring system and updating seismic zones of Egypt

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ABSTRACT

On 3 September 2015, an unexpected earthquake with magnitude MB = 4.5 occurred in a completely silent area, located at 40 km south El Alamein city north western desert, where there are ~ 20 million pieces of unexploded ordnance. This study aims to: i) review and interpret the widespread seismic activity in Egypt during the last three decades, and ii) delineate the active seismic source zones map of Egypt based on realistic assumptions. These assumptions include only the real and accurate seismic events from the whole earthquake catalogue of Egypt. The idea based on the accuracy of the monitoring system, magnitude size of earthquakes, and detailed structure elements map of Egypt. The seismic catalogue of Egypt was updating to the end of 2019 including the historical and instrumental earthquakes since −2200 BC. The seismicity map of Egypt was outlined along five interval periods based on the significant evolution in the seismic monitoring system. The advanced monitoring period in the detection and location of seismic events in entire Egypt was supposed to begin in 2003 where the ENSN almost accomplished. Seismicity of advanced monitoring period 2003–2019 can be used as a tracer of real seismicity boundaries entire Egypt. Active seismic source zones map was delineated based on the advanced monitoring period and the unified Mw ≥ 4.5 instrumental catalogue from 1900 to 2019. To validate the seismic zones model, it compared with the structural elements map and given a rational matching. The new local seismic spots entire Egypt was discussed because of the invention in the seismic monitoring system entire Egypt and attributed to the misdetection and/or dislocation events due to the lack of monitoring system before the accomplished of ENSN. In conclusion, a validated active seismic zones map of Egypt was delineated using real and accurate seismic and geologic data based on powerful assumptions.

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1. Introduction

On September 3rd, 2015, El Alamein earthquake of MB 4.5 occurred in northwestern Egypt, approximately 40 km south El Alamein city north western desert, at depth of 18 km. It was felt in Alexandria and Cairo as well.

The occurrence of the El Alamein earthquake in the uncommon seismic area of north Egypt was the motivation to judge the present-day seismicity because of seismo-tectonic and seismic monitoring invention along the historical and instrumental periods. Egypt has known as a moderate seismicity region, while it threatened to frequent damaging earthquakes along 4200 years. Most of the historical earthquakes were documented around the Nile valley where the ancient civilisation took place, south Sinai and north offshore of the Nile Delta where strong earthquakes occurred. The recent damaging earthquakes vary in size from moderate magnitude 5.8 such as the Aswan earthquake 1981 and Cairo earthquake 1992 to great magnitude 7.2 such as the Aqaba earthquake 1995. Instrumental seismicity has been started since 1899 with one seismic station installed south Cairo and increase gradually with time until 1997.

After the occurrence of Cairo Earthquake on 12 October 1992, which caused huge damage in wide cities of Greater Cairo north Egypt, Egypt has a plan to instal Egyptian National Seismic Network ENSN configured entirely in the country. The ENSN operation started in 1997 with a local seismic network in the epicentral area of Cairo earthquake west Cairo and almost accomplished to cover all the country in 2003–2010. After accomplishing the advanced ENSN, significant changes in the present-day seismicity of Egypt were distinguished. One of these changes is the widespread of seismic activity to include uncommon seismic sites such as the El Alamein earthquake 2015. Figure 1 displays the epicentral distribution map of historical and instrumental earthquakes from 2200 BC to 2019. The seismicity of Egypt was studied by many authors, (Papaiouannou and Papazachos, 2000; El- Sayed et al., 2001; Fat-Helbary and Tealeb 2002; Badawy 2005; Abou Elenean 2010; Deif et al. 2011; El-Amin 2011; Mohamed et al. 2012; El-Hadidy 2012; Sawires et al. 2014), to understand its mechanisms, and to delineate the seismic source zones as a step to assess earthquake hazards. The seismic source model of Egypt differs from author to author and from

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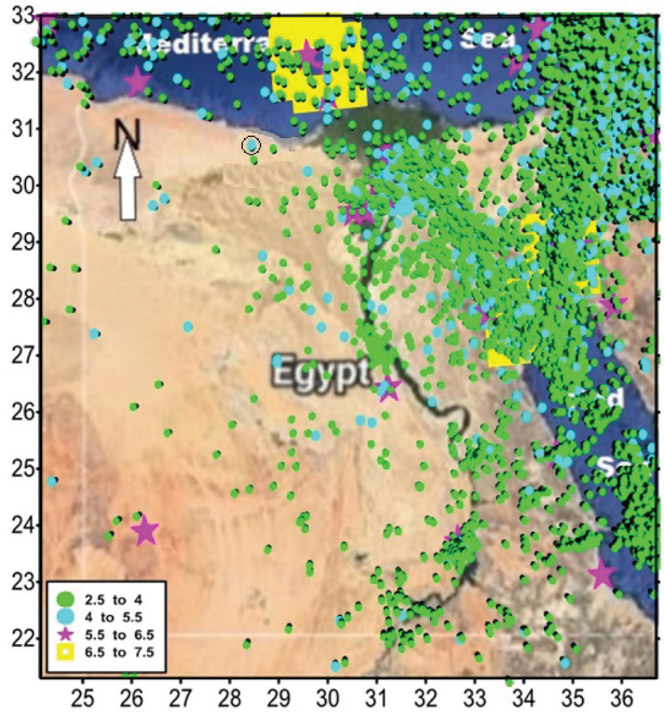


Figure 1. Seismicity map of Egypt through 2200 BC to 2019 period. Black ellipse indicates to the El Alamein earthquake site.

the same author along the invention stages of the monitoring system.

This study aims to judge the widespread seismic activity in uncommon seismic areas delineate the active seismic source zones of Egypt. The seismicity map of Egypt was plotted along the stages of the significant invention of the monitoring system to appreciate the reason for widespread present-day seismicity. The present-day seismicity map was used as a tracer to delineate the seismic source zones compared with the structure elements map.

2. History of seismological observations in Egypt

2.1. Historical seismicity

Egypt is one of the few countries that have a long history documented earthquakes. The historical earthquakes in Egypt cover a long period extended from a very old civilisation of 2200 BC (before Christ) to 1899. These historical earthquakes are collected and studied by many authors over the national and international (Sieberg 1932a, 1932b; Maamoun and Ibrahim 1978; Maamoun1979; Poirier and Taher 1980; Ambraseys et al. 1994; Badawy1999).

Almost eighty earthquakes were documented as felted in Egypt during this historical period ~ 3900 years. Most of them are lies along with north Egypt close to Cairo and some of them located in the Mediterranean Sea. Figure 2 shows the epicentral distributions of the documented historical earthquakes. Some of them caused huge damage to Alexandria and Cairo provinces. Their maximum intensity ranged from V to IX as Modified Mercalli Intensity scale (MMI). Although the historical period is very long, the number of documented earthquakes can be ignored relative to that of a very short instrumental period ~ 100 years.

2.2. Instrumental seismicity

The instrumental seismic observation in Egypt has been started since 1899 with a single component station located in south Cairo at Helwan, the place of NRIAG now. The evolution in the seismic monitoring was developed gradually from one station in 1899 to more than 70 seismic stations. It includes a short period, broadband, and very broadband seismometers. The abrupt changes in the monitoring system of Egypt were done after the occurrence of the Cairo 1992 earthquake which left the worst effect on people and their properties during the instrumental period. The real changes in the instrumental seismic observation period can be divided into four main stages based on the number and distribution of seismic stations over the country. The evolution in the monitoring and seismicity distribution maps was shown over each instrumental stage as below.

2.2.1. First instrumental stage 1900-1974

The Instrumental monitoring system started in 1899 with a single seismic station Milne horizontal pendulum east component, located in Helwan, south Cairo, where NRIAG was built. It upgraded later to three Components and named as HLW (Figure 3). In

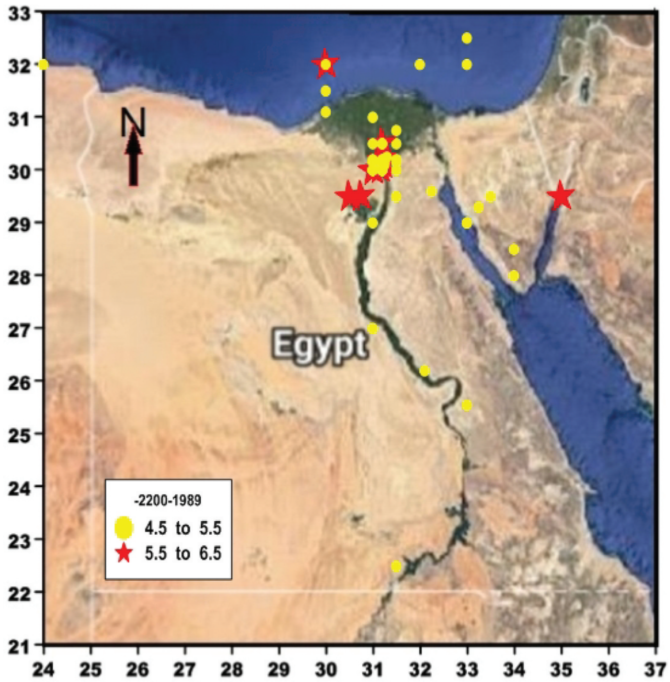


Figure 2. Epicentral distribution map of the historical earthquakes in Egypt.

1964, a World Wide Standard Seismic Network of six components (Long and Short period) was added to HLW. The first station with analog visual filtering was added to HLW in 1972.

Although only one monitoring seismic station was run along with the 1900–1974 period, the seismicity map shows significant changes in the epicentral distribution in the Lower Egypt in comparison with historical event distributions (Figure 3). On the other hand, there was no detection of any event located in Upper Egypt.

2.2.2. Second instrumental seismicity stage 1975–1996

During this instrumental period, three more stations in addition to the local seismic network were installed in the south and north regions of Egypt. In 1975 three seismic stations, Kimos type (three components) installed in Aswan, Abu Simple, Marsa Matrouh, named ASW, ABS, and MAT respectively (Figure 4). In 1982, after the occurrence of the Aswan 1981 earthquake, 13 seismic stations were installed and deployed in Aswan as a local seismic network. Few weeks before the occurrence of the Cairo 1992 earthquake the first broadband station named KEG was installed east of Cairo.

Figure 5 shows the instrumental distribution effect in the epicentral earthquake distribution through the seismicity period < 1997. More detection through Upper Egypt and clusters earthquakes can be appreciated during this significant instrumental period.

2.2.3. Third instrumental seismicity stage 1997-2002

This stage represents the first real changes in the quantity and quality of the monitoring system in

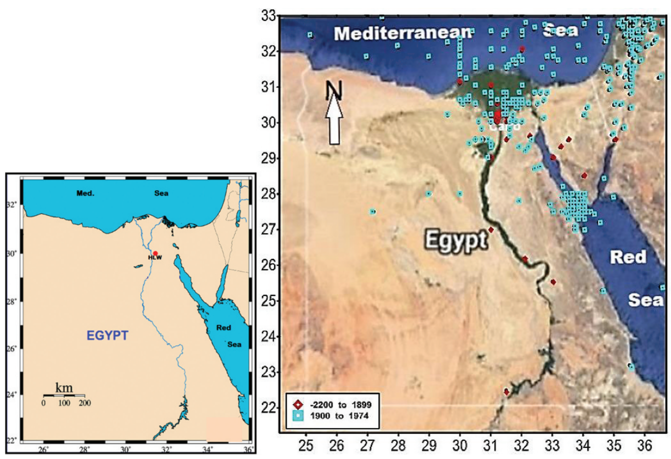
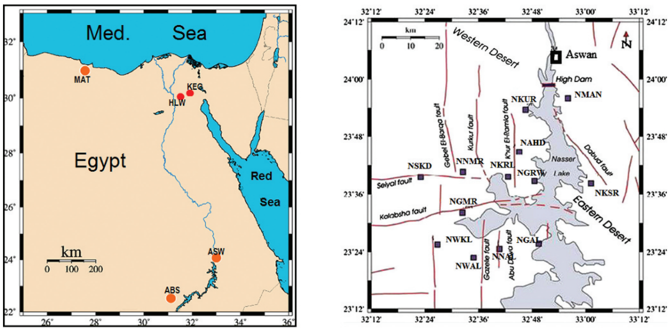


Figure 3. Left, First instrumental seismic station HLW (red circle). Right, epicentral earthquake distribution map< 1975.



A) B)

Figure 4. Second instrumental stage. A) Aswan (ASW), Abu Simple (ABS), Marsa Matrouh (MAT), and Kotamia (KEG) observations. B) Aswan local seismic network includes 13 stations.

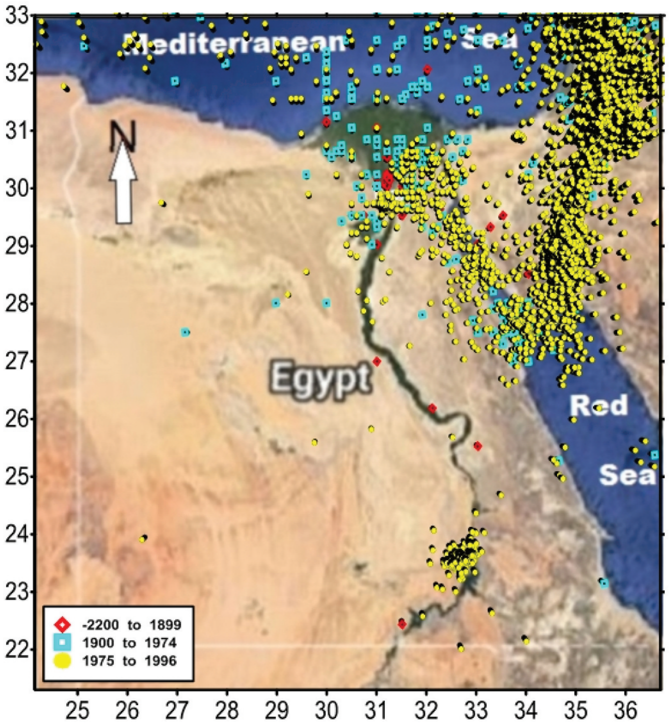


Figure 5. Seismicity map of Egypt up to period <1997.

Egypt. After the occurrence of the Cairo 1992 earthquake, the decision of installing and deploying the Egyptian National Seismological Network (ENSN) covered all the country was taken from the formal government. ENSN initiated to cover the active seismic regions around Cairo, Gulf of Suez, the northern Red Sea, and Gulf of Aqaba (Figure 6). Seven seismic stations were installed around Cairo in 1997. ENSN was extended along both sides of Gulf Suez in 1999. In 2001 it continued to cover the eastern part of Aqaba Gulf, Sinai, and northern part of the Red Sea.

Figure 7 shows the seismicity map through the instrumental monitoring system evolution up to < 2002 period. More monitoring stations means more detection and good covering. Additional detection can be noted in the North West Egypt and good covering

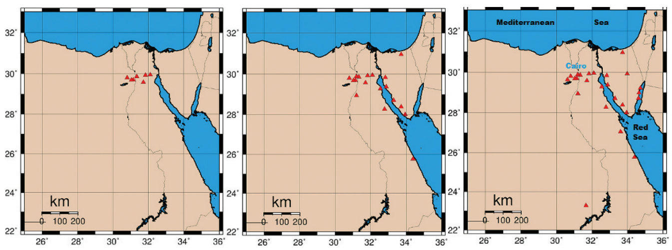


Figure 6. ENSN evolution through 1997 to 2002 period. From left to right, Local Cairo network, Gulf of Suez, and Gulf of Aqaba.

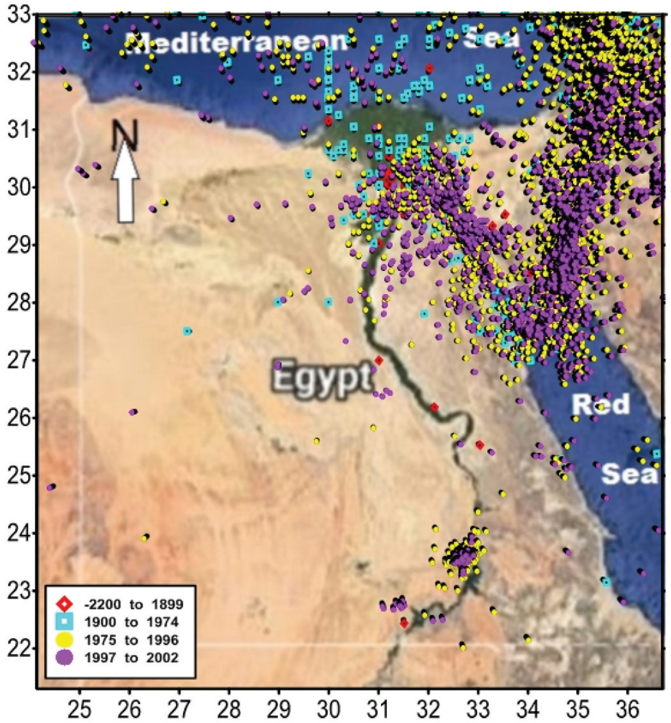


Figure 7. Seismicity map of Egypt up to period < 2003.

through the north Red Sea, Gulf of Aqaba and Suez Gulf.

2.2.4. Final instrumental seismicity stage 2003-2019

This is the comprehensive and advanced monitoring period in Egypt. During this period, ENSN is completely achieved to include more than 100 of different types of short, broadband, very-broadband and accelerogram stations covering all the Egypt country from south to north and west to east (Figure 8(a, b)). It works with highly advanced transfer and analysing data techniques. During this period the ENSN extended to cover the eastern desert, the eastern side of the Red Sea, western desert, and northern Egypt along the Mediterranean shore. The very broadband stations were distributed in the low noise sites and compensated any the areas of few stations. Generally, we can see seismic instruments covered all Egypt with concentrations in the hazardous seismic active areas. This dense distribution is enhanced by using more short-period stations in the early stage of installing ENSN, and finally, this produces a good control in events location through a wide range of earthquakes. On the other hand, the very broadband and broadband instruments were designed to detect all magnitude scales at long distances based on the signal/noise ratio of each station.

Figure 9 outlines a real seismicity map of Egypt after a full covering of seismic monitoring through all the country. Although the period is short, it guides to distinctive and localising seismic zones and shows extended seismicity in rare seismic areas through the eastern and western desert. This extended seismicity could not be ignored with the advanced monitoring system which means better detection, accurate identification, and location of the events in a wide range of magnitude. The extended seismicity indicates active seismic areas. This extended activity may be attributed to a new local/regional seismic regime in the areas of dislocation in the earlier 2003 monitoring system.

3. Data processing and data analysis

3.1. Delineating seismic source zones

Although Egypt has a long history catalogue, the rare occurrence of large events and inaccuracy location of events lead to a considerable error in the configuration seismicity map. Before the period before completing ENSN there is some defection in the accurate delineation of different active seismic source zones through all Egypt until installing ENSN in 1997–2010. As a step to assess probability seismic hazards, many authors attempt to delineated the seismic source zones for Egypt (Maamoun and Ibrahim 1978; Kebeasy 1990; El-Sayed and Wahlistrom 1996; Abou Elenean 1997, 2007, 2010; Riad et al. 2000; El-Sayed et al. 2001; Sawires et al. 2014) delineated seismic source zones model for Egypt.

The seismic source zones model can vary slightly from author to author or from model to model, but it was varied largely before and after installing the advanced monitoring system of ENSN by the same author. Figure

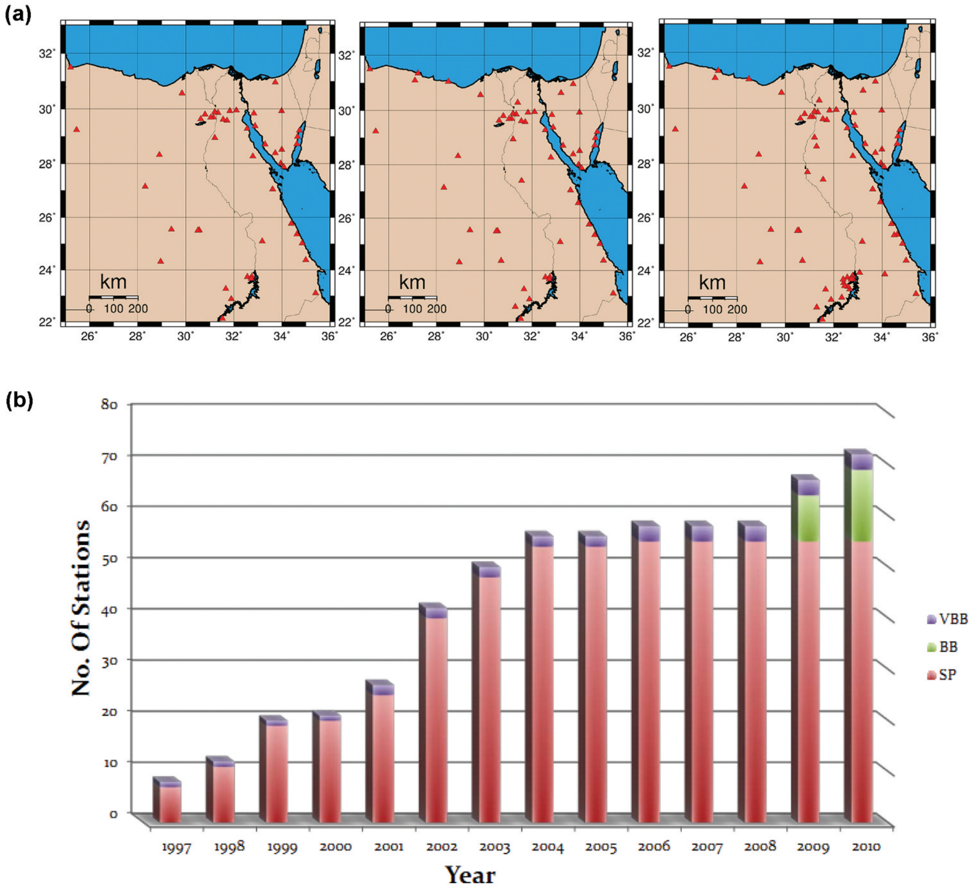


Figure 8. (a).Evolution in ENSN through 2003, 2008, and 2010 period from left to right. (b).Gradual Evolution in the number and types of ENSN stations.

10 shows significant variations in the number and lateral distribution of the delineated seismic source zones delineated by Abou Elenean (1997, 2010) before and after operating ENSN. This variation can be attributed to the dislocations and misdetections of small and moderate events before operating ENSN. From the previous

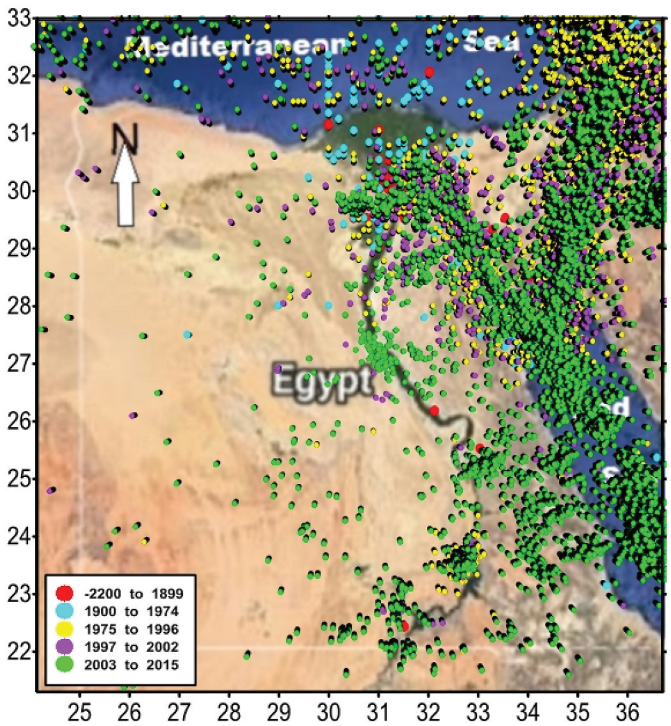


Figure 9. Periodic seismicity map of Egypt along 2200 BC to 2019 through the evolution monitoring system.

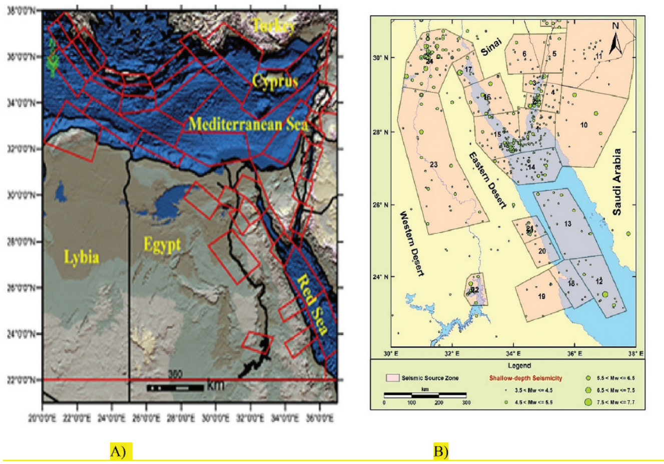


Figure 10. (a)The seismic zones in Egypt (Abou Elenean 2010). (b) The seismic zones in Egypt, (Sawires et al. 2014).

section, the seismicity distribution is highly affected by the distribution and number of seismic stations as shown in Figures 2–9. This means that depending on the historical/primary instrumental seismicity can guide to an inaccurate seismic model. However, increasing the number of observation sites with good lateral distribution make a good covering for all seismic activity and detects all magnitude sizes of events.

In this study, we apply a new idea to delineate active seismic source zones using the high-quality background seismicity, earthquakes size, and structure elements map. The idea based on eliminating the effects of scattering, dislocation, discrimination, and misdetection seismic events using the high-quality observation period of the seismicity catalogue. Plotting seismicity maps along successive periods of considerable evolution in the seismic observation system (Figures 2–8) shows the period 2003–2019 of the catalogue is the highest quality observation period. Where a full covering, stable, and advanced monitoring system of ENSN makes a good localisation of seismic active zones and detect new active seismic sites such as the El Alamein area in north Egypt. The high-quality seismic observation period with magnitude Mw > 2 was used to trace the seismic source zones along with high seismic activity sites and the instrumental catalogue 1900–2019 with magnitude Mw ≥ 4.5 were integrated to outline the active seismic sources map (Figure 11).

Finally, this seismic source zones model was compared with the structure elements map to verify the delineated seismic source zones map of Egypt (Figure 12). There is a good matching between delineated seismic source zones and the structural elements that can be used to identify the active faults in Egypt.

4. Discussion and conclusion

The seismicity of Egypt was outlined along the reasonable evolutionary stages of the monitoring system to judge the new detected seismicity sites and delineate the active seismic source zones. The evolution in the monitoring system of Egypt passed through five effective stages, one historical and four instrumentals as shown through the Figures 2, 3, 5, 7, 9. The historical period is longer in documenting felt earthquakes in Egypt. However, almost 60 events were documented along ~4000 years and their locations were affected by the inhabitant's distribution along the Nile Valley (Figure 2). Although this historical period is very long compared with the instrumental period, it could not draw the real seismicity of Egypt.

The first instrumental seismicity was begun at the end of 1989 until 1974 with one seismic station located south of Cairo (Figure 3). The local small events and the regional large earthquakes had been recorded. The seismicity distribution map is affected by the location of the monitoring station, where most of the seismicity is concentrated around it but the distant seismicity to the south or west was not detected. The second instrumental stage was begun in 1975 until 1996 by increasing the number of seismic stations to four stations (Figure 4) to cover the northwest and south-east Cairo in addition to the south Aswan network. The seismicity map was abruptly changed during this period (Figure 5) where absent seismicity regions in the previous monitoring periods were outlined.

In the third instrumental period, which extended from 1997 to 2002, meaningfully increasing in the number of seismic stations was done (Figure 6), as the first stage of installing ENSN, to cover the west, south and east Cairo, Gulf of Suez and Gulf of Aqaba in addition to Aswan network in the south. Although the number of seismic stations increased during this period, its distribution was not covered all active seismic regions of Egypt. There is no consistent change in seismicity map of this period in comparison with the previous instrumental period despite the scattering is less in this period (Figure 7) where the location accuracy increased with increasing the number of seismic stations. In the latest evolution monitoring stage,

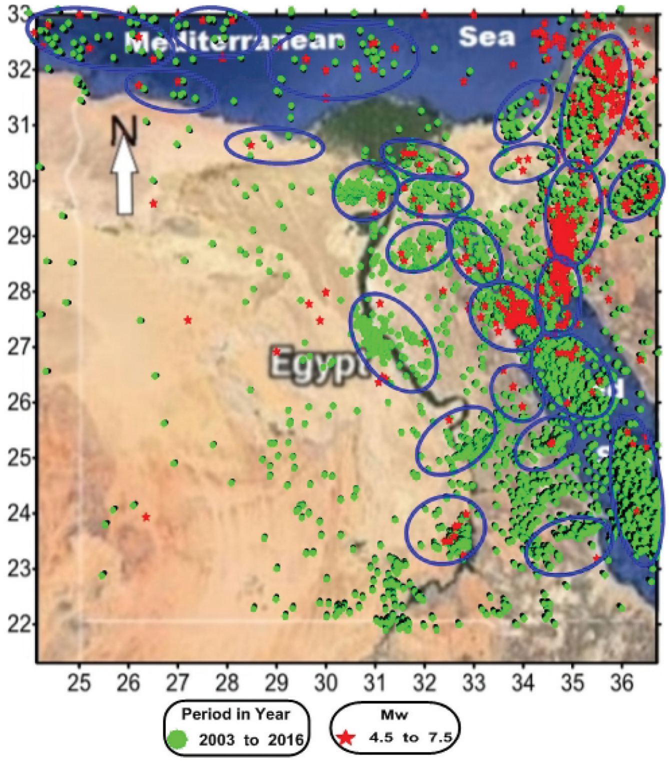


Figure 11. Seismic source zones map outlined in blue ellipses. High-quality background seismicity period Jan, 2003-Jan, 2016 in green colour and the instrumental period 1900–2019 with Mw≥4.5 in red colour.

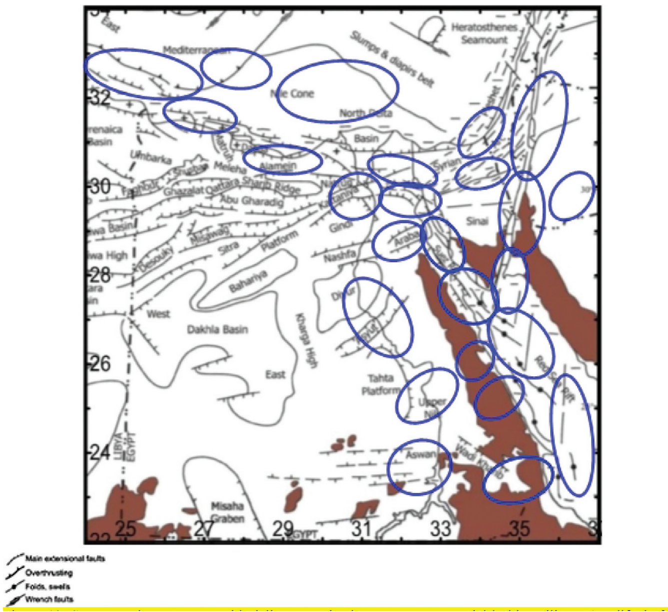


Figure 12. Structure elements map with delineates seismic source zones model in blue ellipses (modified after Sestini 1995).

which extended from 2003 to 2010, the big number of short, broadband, and very-broadband seismic stations were operating in a harmony monitoring system distributed all in entire Egypt country (Figure 8). This accomplished advanced monitoring system during this and previous period is known as the ENSN where all old stations were replaced by new and advanced instruments. The seismicity of this period is characterised by a high ability to detect events of all magnitude scales from micro-events to great earthquakes through whole Egypt with high accuracy in location (Figure 9). The latest generation monitoring period, which extended from 2003 to 2019, can be named the advanced monitoring period in Egypt.

The advanced monitoring period of highly sensitive detection and high-quality location of events can trace the real seismicity map of Egypt.

New seismicity was observed from uncommon seismic sites before accomplishing the ENSN. To interpret the extended seismicity or the new active seismic sites that appeared in south Egypt and north-western desert in the last few years, we compare the lateral distribution of seismic stations and seismicity maps along the instrumental evolution periods (Figures 3–9). One of the extended seismicity sites is the Al Alameen zone, which recorded small earthquakes with moment magnitude up to 4.5. There is a strong relationship between the lateral distribution of seismic stations and detecting seismicity of small and microearthquakes. A good covering monitoring system leads to highly sensitive detection of micro and small events, good discrimination, and high accuracy location. Although the latest monitoring period is almost two decades only, it can trace the active seismic faults in Egypt.

A new delineation seismic source model of Egypt was done to overcome the discrepancy in the previous models that abruptly changed with the invention in the seismic monitoring system (Figure 10). The advanced monitoring period and the moment magnitude ≥ 4.5 instrumental catalogue from 1900 to 2019 were used together to trace and delineate the active seismic source zones in Egypt (Figure 11) to avoid the dislocation, scattering, and misidentified events. However, many authors delineated seismic source zones of Egypt but no one matching with the other and maybe different from the same author along with the progress of seismic observations as shown in figure 10. These mistakes in delineating reasonable source zones map can be attributed to the dislocation and misdetection events in the previous monitoring seismic stages before 2003. The delineated active seismic source zones were compared with the structure elements map (Figure 12) and given a good matching are found.

The results of this work concluded that because the seismicity of Egypt is characterised as a moderate and the recurrence of large earthquakes is rare, its detection is dependent and based on the lateral distribution of the seismic stations. The seismicity map of Egypt became a reality after accomplishing the full covering and well distribution of Egyptian National Seismic Network in 2010. The extended seismicity was not due to new active sites but it is attributed to the misdetection and dislocation periods before accomplishing the ENSN. The Advanced monitoring period is used successfully as a tracer to delineate the active seismic source zone map of Egypt which gives a rational matching with the structural elements map.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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