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Probability of Magnitude Detection for the Greater Cairo Seismological Network, Egypt

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KEY WORDS

The Greater Cairo Seismological Network, the Probability of Magnitude Detection, Magnitude Detection Probability Maps, Magnitude Completeness Map, Egypt, ENSN

ABSTRACT

The target of this work is to evaluate the performance of the Greater Cairo seismological network through the probability of magnitude detection in this region, adopting the probability-based magnitude of completeness method. This method was already applied to the largest seismic network in the Middle East which is the Saudi National Seismic Network (SNSN) and also to the Oman Seismic network, but this is the first study of the earthquake detection capability in Egypt. To implement this method of work: the use of the spatial configurations of seismological network, the phases of recording data and the magnitude equation are constructing the all needs. The historical data and current configurations of each station in this region are saved with document. The scrutiny is done on the magnitude of an earthquake database for all events in the period of January 2018 to December 2020. The method is applied to calculate the probability of the detection capability on each seismic station, which is then combined into maps resulting from these calculations for events with certain magnitudes. These maps clarify that the Greater Cairo Seismic Network of station is already able to record successfully small earthquakes and nearest regions for this detection. The probability of the magnitude of completeness plot indicates that most earthquakes generated with a strength magnitude equal to or greater than ML 2.5 are completely recorded. Nonetheless, the results displayed clearly that adding some observatory stations will enhance the detectability of humankind and naturalist small earthquakes at certain regions around the Greater Cairo Region.

Introduction

The speed of seismic network development is increasing around the world and to continue work toward this development; The Egyptian National Seismological Network (ENSN) was established and continues to achieve this by monitoring seismic activity in and around Egypt.

History of ENSN, stages of development

Today, the ENSN consist of about 70 active seismic stations covering all of Egypt **(Fig. 1)** monitored by a data center located in Helwan and a backup at Aswan. This type of redundancy provides the ability to be sure the network is always up and running with no gaps in data from the central base side.

Remote stations transmit recording data to the Center via different communication protocols; radio waves or VSAT satellite communication **(Soliman *et al*., 2019)**.

Geographically, the ENSN can be divided into four main seismic zones.

These zones are: The Northern Coast Seismic Zone, Greater Cairo Seismic Zone, Red Sea, Sinai Seismic Zone and Aswan Seismic Zone.

Our study focus will be on the Greater Cairo Seismic Zone due to it is importance for the planned extension of one of the most sensitive governmental projects. The New Administrative Capital (NAC) is a large-scale project to build a new capital city in Egypt which is planned to accommodate many governmental buildings and a significant population. The city is planned to consist of 21 residential districts for employees and external resources and 25 dedicated districts. The current work aims to assess the earthquake detection capability of the Greater Cairo Seismic Zone.

This study also will be a good guide with historical data to use in deep learning model such as Earthquake (EQ) mitigation relying on satellite system, Internet of Things (IoT) **(Abdalzaher *et al*., 2021).**

The station types are mainly short-period sensors and broad band sensors **(Table 1)**. Recent developments to enhance the detection capability are a must, but the need to calculate the current detection capability or the regional station detectability is a major aim.

It is important to know the current situation and the regional capabilities of detection so that we can enhance them by adding more stations or moving the current stations if necessary.

The network –region – earthquake detection capability always refers to the minimum magnitude that can be detected by the network –region – seismic stations and can be recorded in a complete manner. It should provide important information about earthquake strength along with distance that would be observed by this network -region – seismic stations.

Such observatories are controlled by the geographic location of the stations, their location characteristics, record quality, and communication systems. Simply put, seismic detectability can be used as an alternative to observability.

Three main approaches have been taken into consideration to evaluate the observation capability of a seismic network. These methods are categorized into the three approaches. The premier approach is based on information from the seismic catalog itself. This approach provides only information about the integrity of the seismic catalog and does not consider the seismic network configuration or the distance to the recording station **(Schorlemmer and Woessner, 2004; Woessner, 2005).** The second approach relies on seismic station parameters summarized in Modeling the signal-to-noise ratio at the station **(Amorese, 2007; Enescu *et al.*, 2009)**, depending on the characteristics of the seismic wave, such as velocity model and propagation. The fine-tuning of this approach depends on the completeness of these assumptions and the presence of waveform data **(Enescu *et al.*, 2007; Gomberg, 1991; Kværna *et al.*, 2002; Enescu *et al.*, 2009)**. The third approach is a network-based method, known as a probability-based integrity measurement (PMC) probabilistic magnitude of completeness method. It uses seismic network configurations, recorded phases, and magnitude equations.

This method was already applied to the largest seismic network in the Middle East which is the Saudi National Seismic Network (SNSN) and also to the Oman Seismic network **(Soliman *et al.*, 2019)**

Also with ability to calculate the b-value and a-value such a method applied in Indonesia to determine the magnitude of completeness **(Chasanah and Handoyo, 2021)**

PMC results in a realistic assessment of the detectability of the seismic network and has been applied by many authors. More details about this method are provided in section II.

Materials and Method

The PMC method depends on two main phases, as described in the literature **(Schorlemmer and Woessner, 2004; Woessner, 2005; Nanjo *et al.*, 2010).** The first stage involves calculating the probability of detection as a function of earthquake strength and the distance of the seismic station from that earthquake **(Schorlemmer and Woessner, 2004; Schorlemmer *et al.*, 2018)** In the second stage, an integration is performed to map the Detectability of observing an event of earthquake force M at a location x away from the recorded station for the given time period t and yields the magnitude of the completion as well **(Sereno and Bratt, 1989; Fischer and Bachura, 2014 ; Schorlemmer *et al*., 2018)**.

In the first phase, a non-interrupted internal of observed events and a list of all observation stations are defined for Greater Cairo Seismic Zone (see section III). All observations that occurred during this non interrupted interval are chosen carefully. For each observation, the P-wave phases are selected. After wards, for every observation station in the region, all selected phases are collected and a set of data triplets are constructed in terms of strength (M) and distance-away (L) and whether the phase is hitted at this station or missed. The probability of detection (P_D) is instituted on a observation station's data triplets according to the following equation:

$$\mathrm{P_D}(M, L) = \frac{N_+}{N_+ - N_-} \tag{1}$$

(Schorlemmer and Woessner, 2004)

Where, (N+) represents the number of triplets near which hit the recorded and enough to the giving pair (M, L) and (N-) is the one missed in the recording. These triplets are taken into consideration by defining a metric that measures the distance-away between each data triplet and the giving pair. The identity of this measurement is defined by the exchange distance to magnitude using the magnitude equation that was applied for magnitude determination in the observation station network. In our study, we set the metric value (LM) to be able to select all triplets that achieve this criterion:

$$LM \leq 0.1 \tag{2}$$

(Schorlemmer and Woessner, 2004)

The computation of 0.1 is fixed to compensate for the expected magnitude error in recording and is also used as the sampling coefficient in the current statement. The number of recorded events in each bit of recording data affects the rigidness of the analysis procedure. So, [4]; offered an assumption that in a matter of a scrawny number of events (≤ 10), they should be added to the set selected first. However, **(Gentili *et al*., 2011)** proved that this criterion led to some causes overspeculation in the results, predominantly,

If scattered data exist, edit the original method by setting the probabilities equal to zero for samples with less than 10 earthquakes. Then, the Detectability of observing a certain amount M at a distance L for each seismic station (i),$\mathrm{P_{D,i}}(\mathrm{M}, \mathrm{L})$, is calculated according to "(1)"and under two real constraints as follows: (A) the probabilities of detection cannot decrease either for larger volumes at the same distance from the station or (B) even with an equally smaller distance at same strength.

Subsequently of this method, the probability of observing an event with strength M at a distance (x), during the non-interrupted interval of recording (t), $\mathrm{P_E(M, x, t\ )}$, is showed as the joint probability that four or more observatory stations have detected this event. There's no doubt that majority of seismic networks have more than four stations, the PMC computes this Detectability of observing as:

$$P_E\ (M, x, t) = \ 1 - P_0 - P_1 - P_2 - P_3 \qquad (3)$$

(Schorlemmer and Woessner, 2004)

P_0 = probability that no observation for the event

P_1 = probability that one station observes the event

P_2 = probability that two stations observe and the rest do not observe;

$\mathrm{P_3}$ = probability that three stations observe and the rest do not observe.

More details about the calculations of each probability can be found in [4].

The eventuality for magnitude of completeness $M_P\ (x,\ t)$ is given by finding the tenuousness strength value at which events are observed without interruption and completely. This is almost happening when the $\mathrm{P_E\ (M, x, t)} \geq 1 - Q$, where Q showed the probability of non-detecting the event at all (Schorlemmer *et al.*, 2018). In the current inspections, we consider Q as equal to 0.1 and the coming equation is used to determine the probability of completeness magnitude:

$$Mp(x, t) = \min_{M \in m} M|(M, x, t) = 0.9 \quad (4)$$

(Schorlemmer and Woessner, 2004)

m = m is the interval of possible magnitudes;

Data

A lot of different data types being used in this work and preparation; not only the observed and saved events for catalog along with the magnitude but also the observatory network settings themselves.

The six seismic stations of the Greater Cairo Seismic Zone (mentioned in Section I and mapped in Fig. 2.) have been used in our detailed rummage work. All observation stations are transmitting data around the clock. These six observation stations transmitted non-stop observed seismic data via a satellite communication link to the ENSN location where software called Atlas II responsible to perform an automatic beginning stage of event parameters determination (i.e., geo placement, born time and magnitude). Then this automatic geo placement information is checked out and stored in the convenient database format at the system. Table (1) shows each station name, type of each station’s sensor and the sampling rate. We evaluated the Greater

Cairo region to illustrate the no interruption interval of recording.

The significant offline times of the observation stations in the ENSN network, with the exception of upgrading periods, were almost all short and attributable to common reasons, which equally affected all the seismic stations or part of its operation. The authors have verified that the best non-interrupting data recording interval starts from January 1, 2018 to December 31, 2020. Therefore, the event database catalog is created for these internal observations without an assigned magnitude are excluded from the consideration. There were 22199 collected triplets from 7934 observations.

The magnitude of these observations is reported using the local magnitude (ML) and the body wave magnitude (mb). To standardize the magnitude scale, all the events shown in ML and mb were decomposed and used in the transformation formula using orthogonal regression (Fig. 3). The derived conversion formula is:

$$\mathrm{ML} = 1.007\,mb - 0.441 \quad (\mathrm{R2}=0.70) \tag{5}$$

(Schorlemmer and Woessner, 2004)

EMR has the mission of computing the local magnitude **(Woessner, 2005)** as introduced **(Hutton and Boore, 1987)** according to the formula:

$$\mathrm{ML}=\log A + 1.11\log(L/100) + 0.00189\,(L-100) + 3 \tag{6}$$

(Schorlemmer and Woessner, 2004)

A = maximum trace amplitude in millimeters
L = hypocentral distance

This sizing equation is used to convert all observed triplets into observation probabilities, as described by the PMC method.

Results

The rummage of the observations stream was carried out by using a programming and numeric computing platform with Matlab R2022 code which written based on the Probability-based Magnitude of Completeness (PMC) method. The rummage is begun by drawing three characteristics of data which are detecting or not detecting, distance from the station and the Magnitude of the event itself at the observation station, called (triplets), these calculations are done for each observation station to visualize the observed and non-observed events **(Figs. 4, 5)**.

The probability of detection (PD) for each observation station (Fig. 6-7) is stated based on the observed and non-observed events at a measured distance far away from the observation station as mentioned in Section II. The estimate of PD is median of each observation station and used in the adjacent observability rating of the six observation stations of the Greater Cairo Seismic Zone.

In the second phase of the method, two types of symptoms appear. One of them is a certain amount of detection probability figure for specific magnitudes. The entire Greater Cairo Seismic Zone is divided into a 0.1° × 0.1° grid. This division is suitable for splitting the map into small cells and focus in calculations in each cell. Then the Detectability of observing an observation with strength M at middle point of each cell (x) is stated and interpolated to produce the probability of detection for this observation figure for strength equal M. Figures (8-10) show examples of these figure maps. Magnitude detection probabilities are usually formed by the spatial composition of six seismic stations in the Greater Cairo Seismic Zone. Therefore, the ability of the ENSN to observe low magnitude (ML=3) earthquake events in a reliable way (PD <0.5), is certainly measurable in the middle part of The Greater Cairo sector due to the stations and the zone characteristics (Fig. 2). Moreover, the Probability of detection of earthquake magnitude ≥ 3.5 ML is distinctly extended to a greater distance in all directions around the six stations, where less earthquake data is available.

The other manifestation type is for the probability of completeness magnitude. It is stated for each cell in the grid pertaining to the tenuousness magnitude that has an observation probability ≥ 0.3 “(4)”. As shown in **Fig. 11**, the magnitude detection completeness starts from 3.5 ML.

Conclusion

The capability of observing earthquakes by the working six seismic stations in the ENSN Greater Cairo Seismic Zone is evaluation according to PMC method calculations by use the setting of the observations of each station on the seismic network, the good saved noted phases, and the applied magnitude equation. The history of the six stations in the ENSN Greater Cairo Seismic Zone is discussed and the latest settings of the observation stations is presented. We construct a homogenous database that includes all non-interrupting events from January 2018 to December 2020 and the magnitudes were stated based on factual retraction equations. For each observation station the capability of detection is stated and is used for an adjacent comparison between the six Great Cairo Seismic Zone stations.

The results of this work, Great Cairo Seismic Zone charts for the probability of detection at known magnitudes. These charts clarify that events with a low magnitude (ML=3.5) are certainly registered in any proximity geolocation to the observation stations (i.e., the middle part of Egypt). These seismic stations have a better competence in increasing the probability of detection of a volume of 3.5 ML. An event with magnitude greater than or equal to 4.0 ML is efficaciously saved across all entire Greater Cairo Seismic Zone sector.

The probability of the completeness magnitude map is displayed. It is the ultimate goal of any seismic network detectability study. The map clarified that the small magnitude (1.2 ≤ ML≤ 2) is not completed and cannot be detected with acceptable probability if and only if we consider these stations only and their discussed locations. The completeness map indicates that most of the earthquakes generated in the Great Cairo Seismic Zone with magnitude 2.5 ≤ ML ≤3 have been recorded since 2018 by the ENSN. Still to fully cover artificial earthquakes and small earthquakes in specific areas in the Greater Cairo Seismic Zone, additional observation stations should be taken into consideration to be installed.

Finally, we certainly sure that this study will help with planned expansions / upgrades of the ENSN especially Great Cairo Seismic Zone and make the case for constructing new stations or changing the current station locations or components.

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Table(1): Station information of the Egyptian National Seismic Network (ENSN) and the six stations of the Greater Cairo Seismic Network Zone

station code	station name	instrument model	sensor name	sample per second
KOT	Kotamaya seismic station	Trident305	STS-2	100
NAT	Natrun seismic station	Trident305	T-120C	100
BNS	BeniSwef seismic station	Trident305	TRILLIUM_40	100
SQR	Sqara seismic station	HRD	SS1	100
RYAN	RAYAN seismic station	Trident305	TRILLIUM-120	100
ZAF	ZAFARANA seismic station	Trident	TRILLIUM-120	100

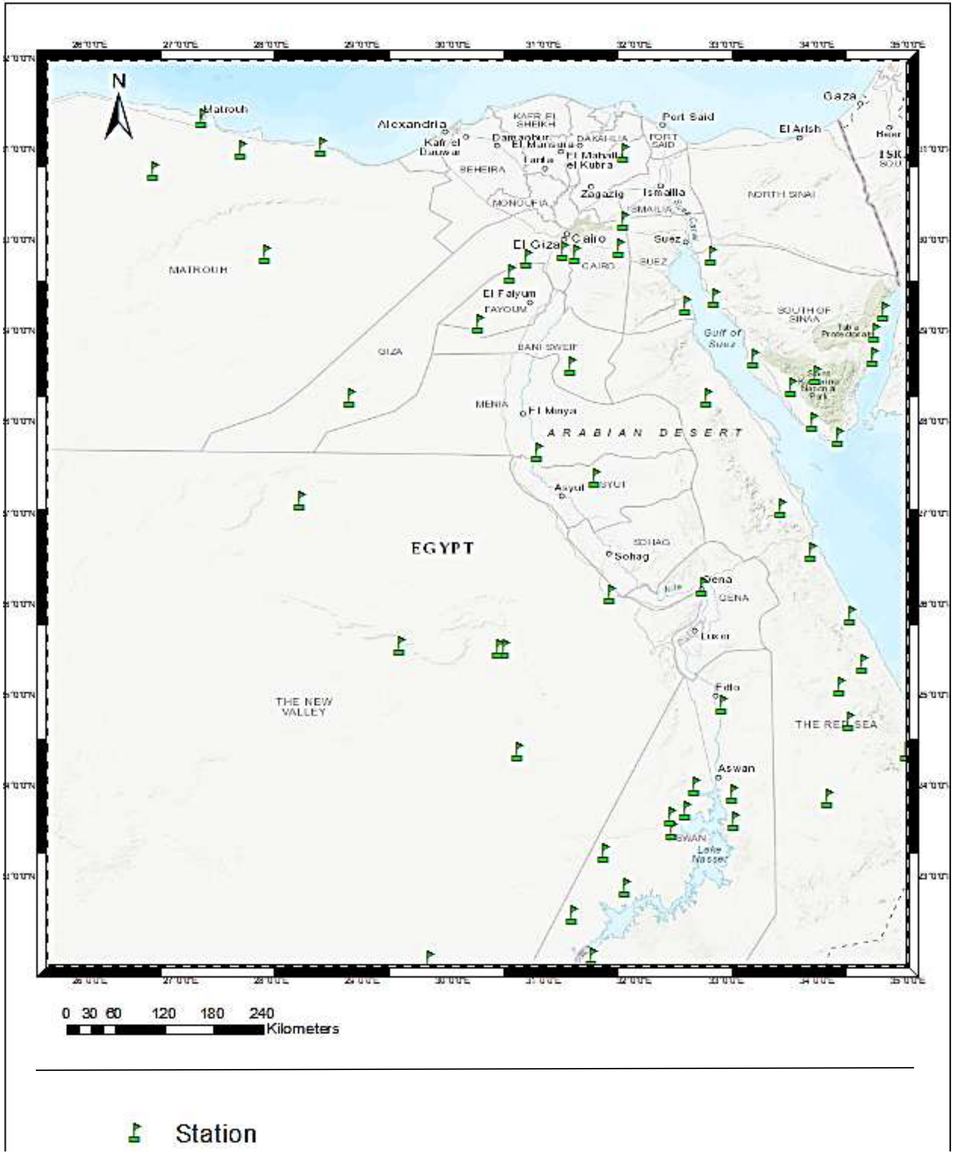

Fig. (1): The locations of all ENSN seismic stations

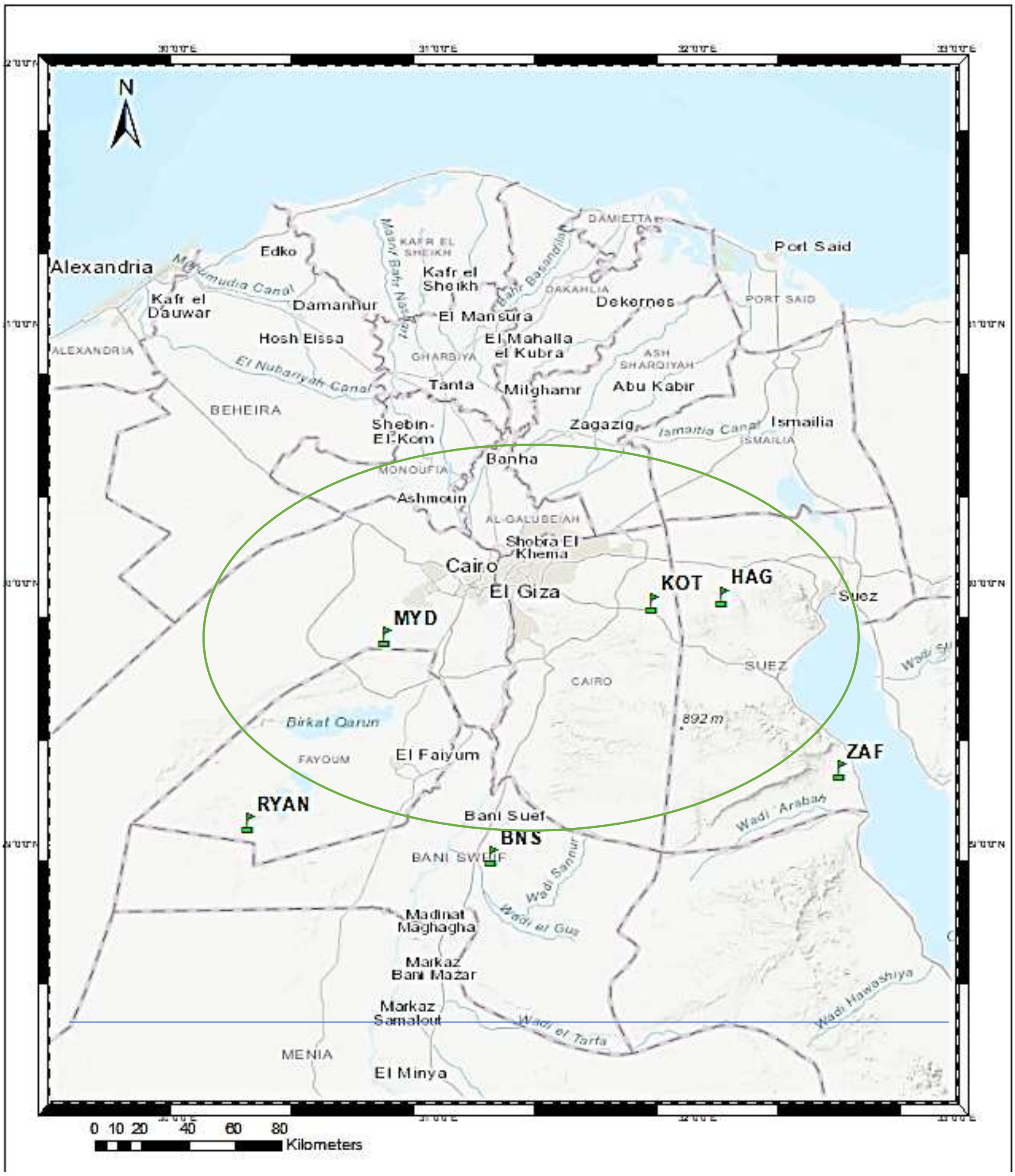

Fig. (2): Location of the seismic stations of the Greater Cairo Seismological Network labeled by the station code.

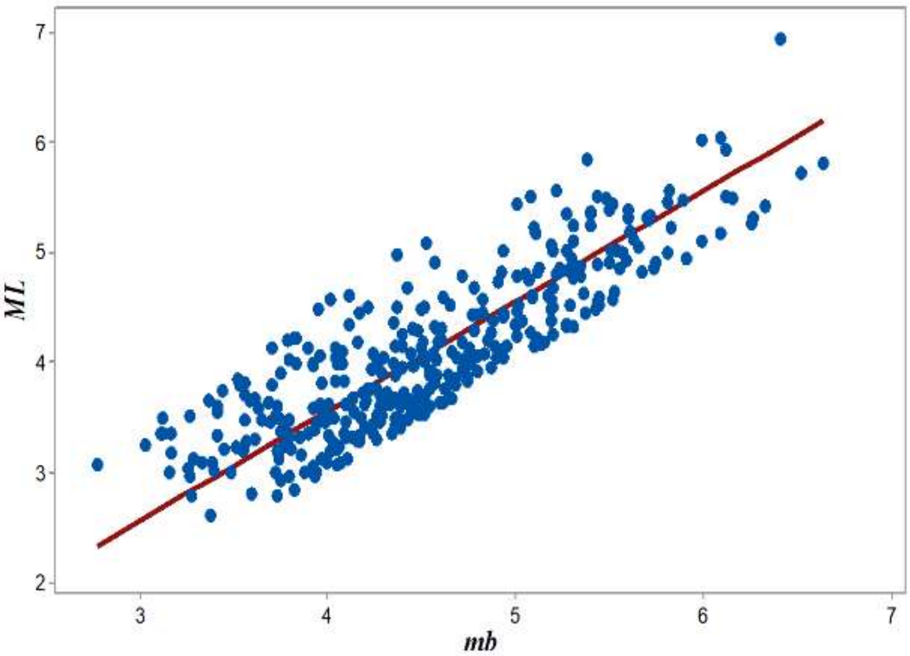

Fig. (3): Orthogonal regression graph for M_L-*mb* recorded by ENSN

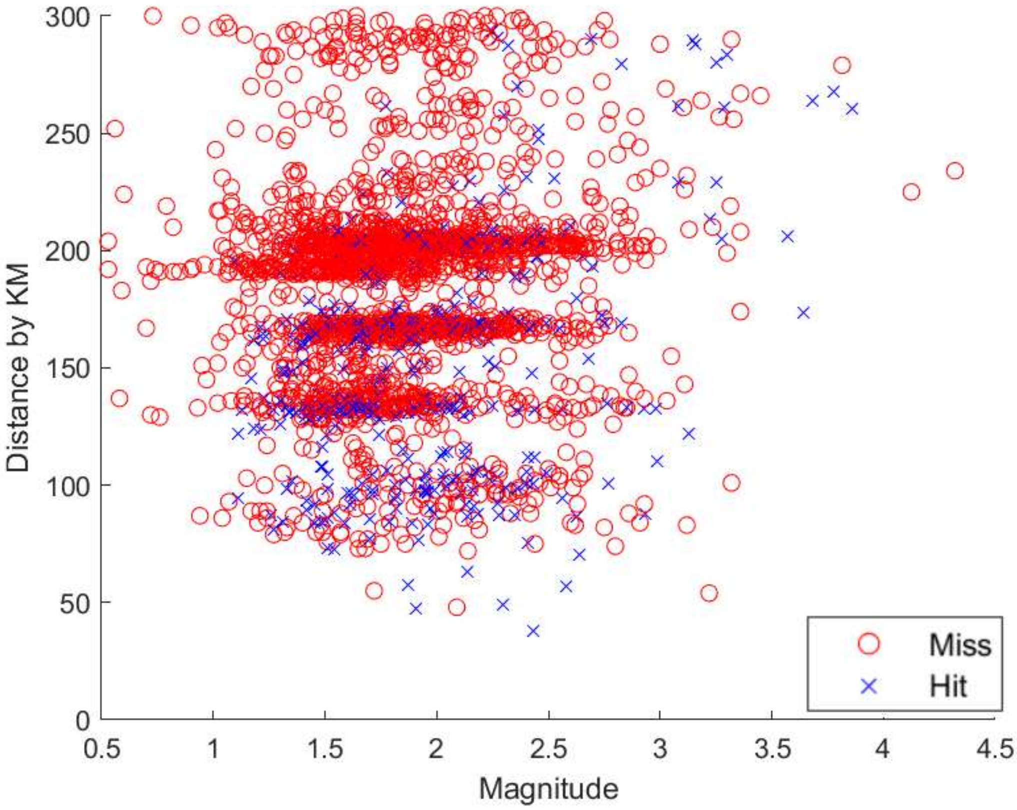

Fig. (4): Chart for data triplicates for RYAN seismic station

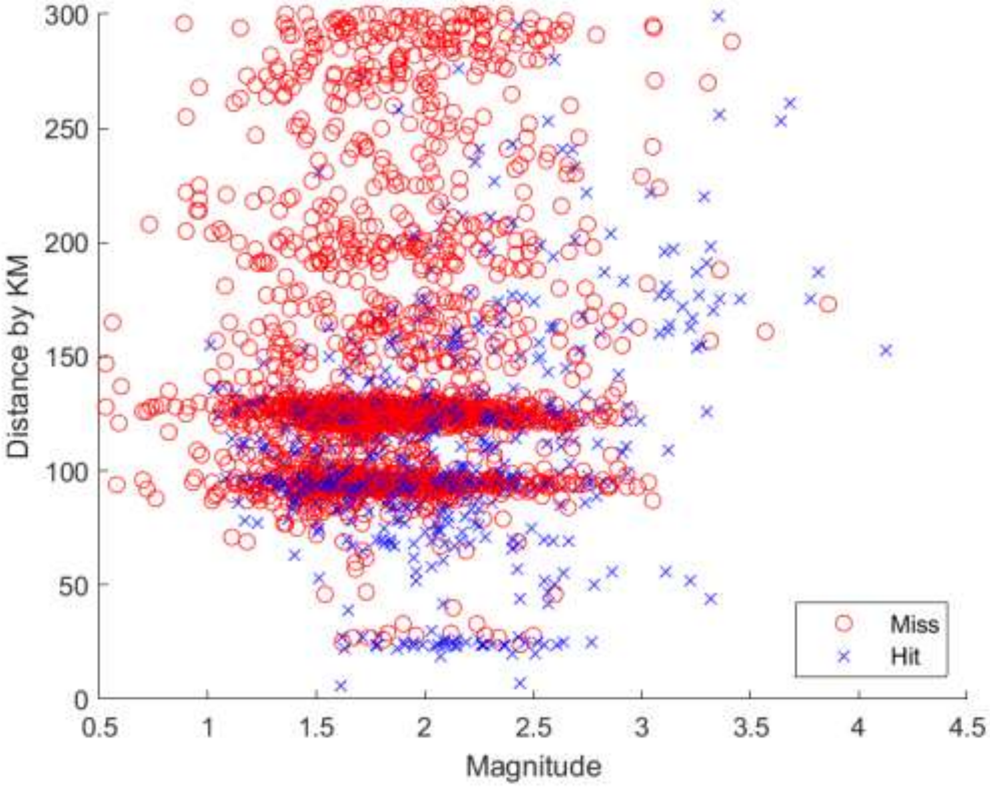

Fig. (5): Chart for data triplicates for BNS seismic station.

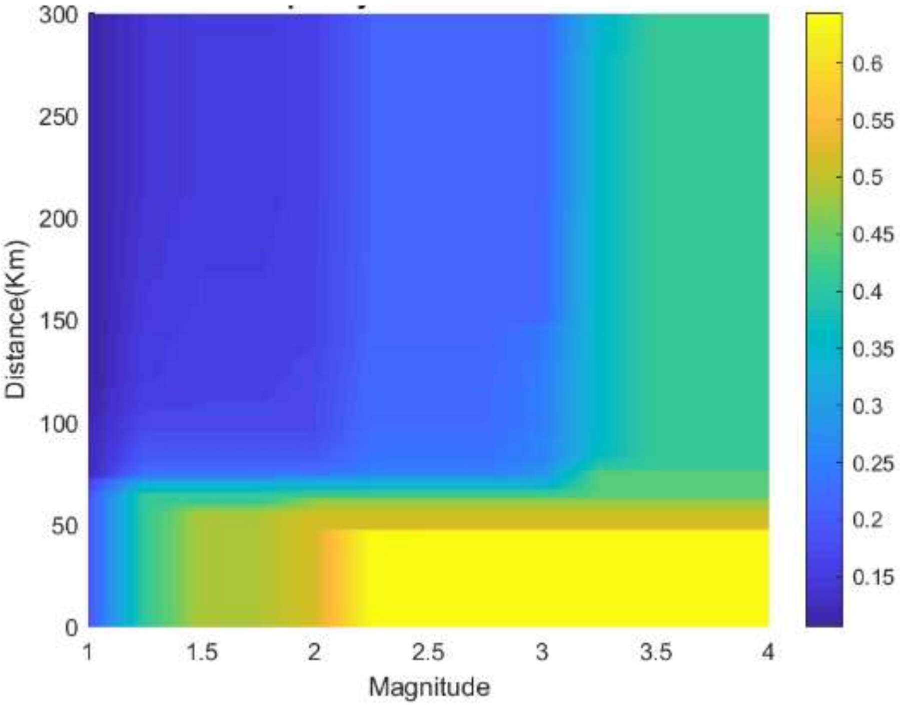

Fig. (6): An Example for detection Detectability for RYAN observation station. The right column states the ratio of observation probabilities.

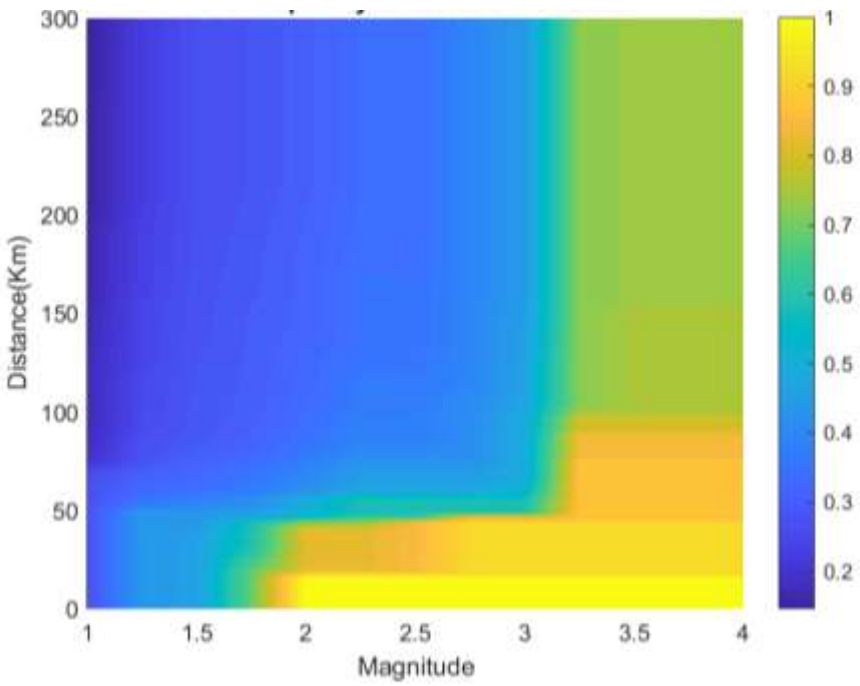

Fig. (7): An Example for detection Detectability for BNS observation station. The right column states the ratio of observation probabilities.

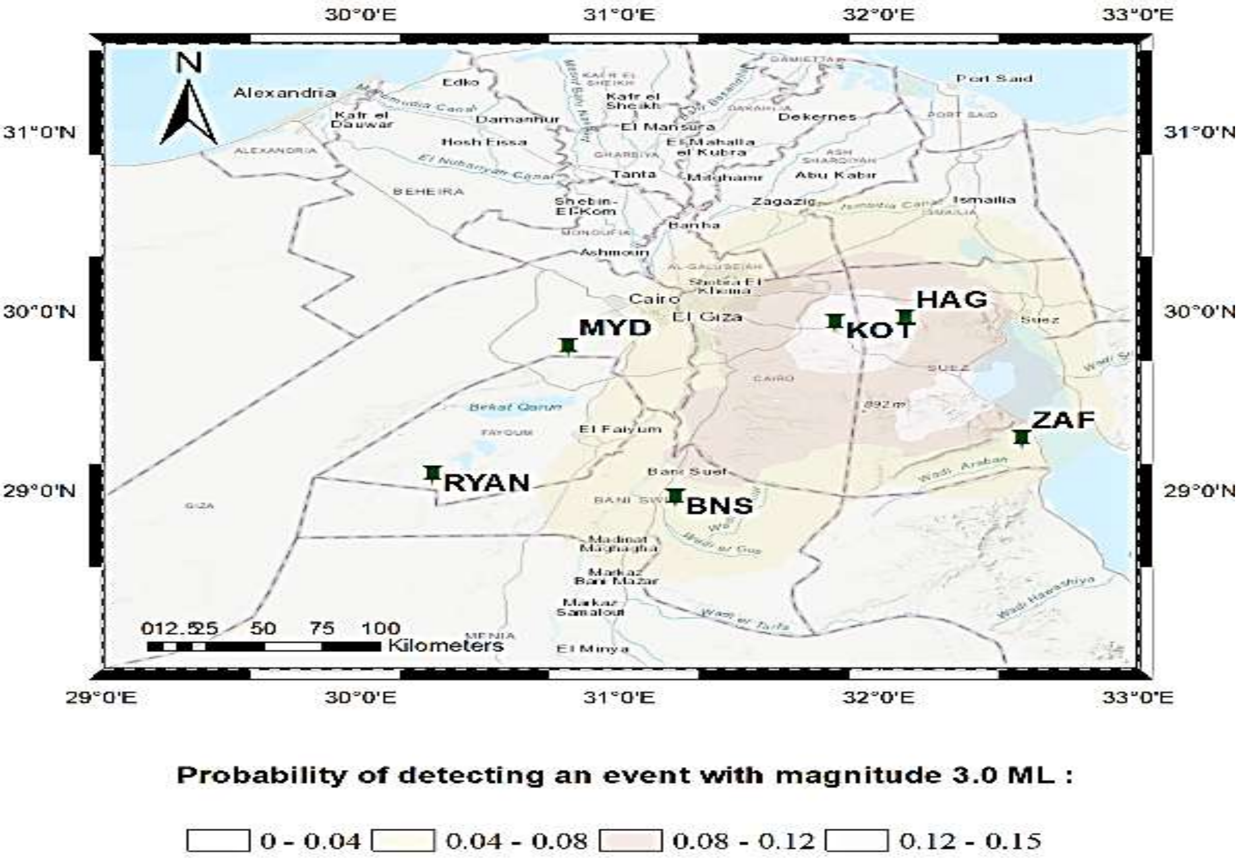

Fig. (8): Detectability of observing an event with magnitude 3.0 M_L by the Greater Cairo Seismic Network.

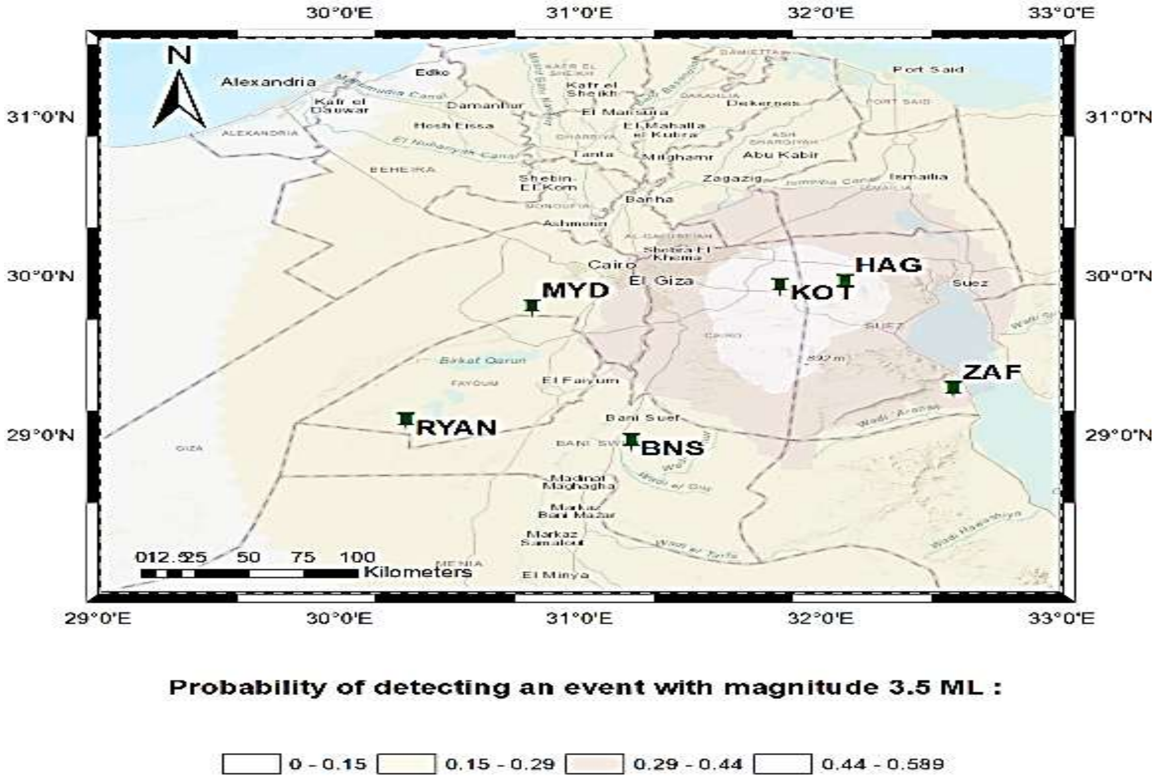

Fig. (9): Detectability of observing an event with magnitude 3.5 M_L by the Greater Cairo Seismic Network.

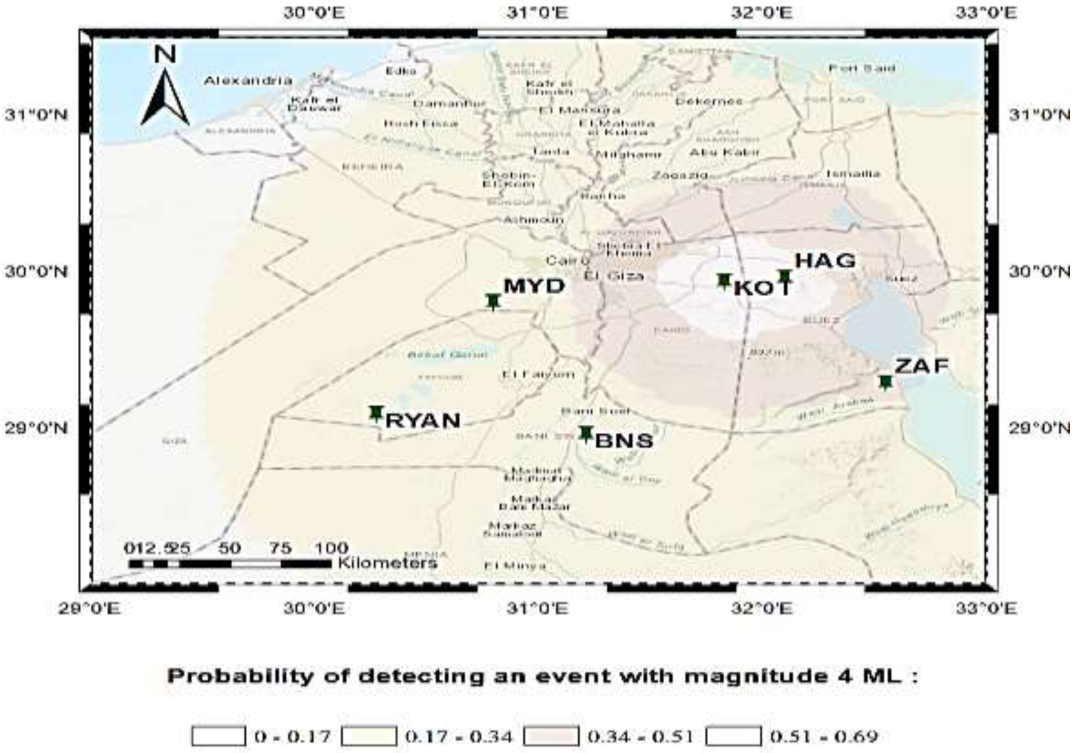

Fig. (10): Detectability of observing an event with magnitude 4.0 M_L by the Greater Cairo Seismic Network.

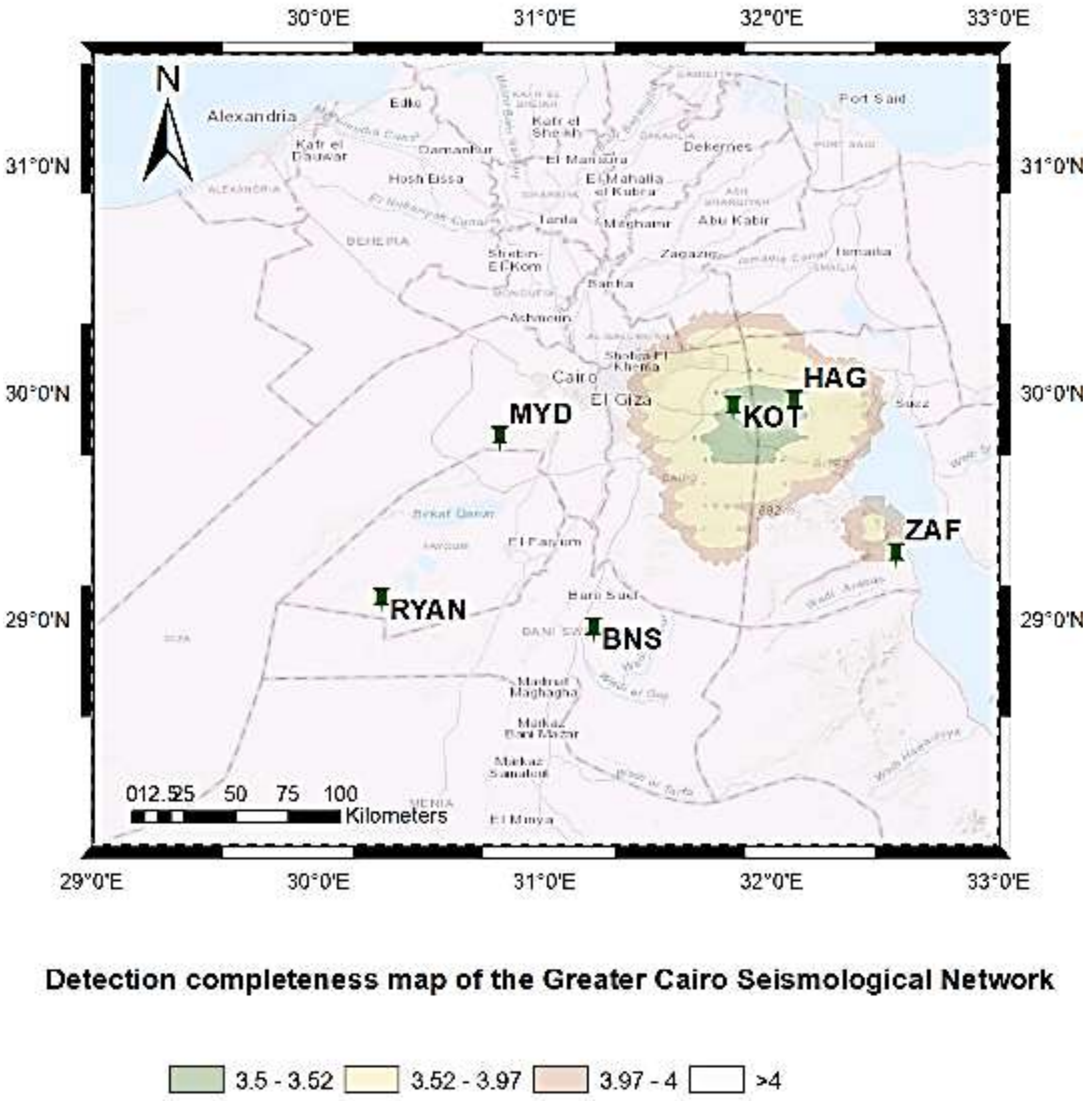

Fig. (11): Detection completeness map of the Greater Cairo Seismic Network.

احتمالية الكمالية لقوى الزلازل لمحطات القاهرة الكبرى للزلازل ، مصر

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تقرير كفاءه محطات الزلزل وقدرتها علي التسجيل اصبح من الموضوعات الهامة هذه الايام نظرا للتطبيقات المتعدده في مجال المخاطر وتحديد مشاكل التشغيل للمحطات ،هناك طريق عديده تستخدم هذه الايام لتحديد كفاءه الشبكات منها من يعتمد على دراسة كتالوج المحطات ومنها من يتمد علي تحليل الموجات المسجله ومنها من يعتمد علي معلومات المحلله من الزلازل خلال هذه الدراسه سيتم تطبيق طريقه حديثه هي مرجعه احتماليه الكماليه لقوى الزلازل المسجله وتطبيق مع البيانات المسجله بوسطه مجموعة من محطات الشبكه القوميه لرصد الزلازل والتى تغطى القاهرة الكبرى لمرجعه كفاءه للحظات الشبكه بعد ٢٠ عاما من التشغيل

<u>تعتمد طريقة الدراسة على</u>

- تحليل موجات الزلازل المسجلة
- رسم خريطة لاحتمالية التسجيل اعتمادا على المسافة والقوى

وستعتمد تنفيذ هذة الطريقة على

- البيانات المسجلة ومواقعها والقوى المحسوبة
- حساب كفاءة التسجيل لكل محطة
- مزج القيم المحسوبة لكل المحطات
- رسم خريطة معبره عن كفاءة التسجيل للمحطات المحددة

نتائج الدراسة ستكون هامة جدا لتحديد كفاءة هذا القطاع من محطات شبكة الزلازل ومشاكل التشغيل للمحطات وكيفية علاجها مما سيزيد ويحسن من جودة تسجيل المحطات.