The Considerations on Local Magnitude Determination to the Lwiro Seismographical Station

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ABSTRACT

About 47 local earthquakes reported by the “Institut pour la Recherche Scientifique en Afrique Centrale (IRSAC) seismographical bulletins and the United states coast Geological survey (USCGS) bulletins in the period from 1965 to 1977 were used to compare seismic energy, 250 local earthquakes reported by the IRSAC bulletins from 1960 to 1964 were used to compare local magnitudes Eml determined by the Lwiro seismographical station and the local magnitude scale EM by Richter (1935) and 422 earthquakes recorded at Lwiro station in the period from July to December 2011 were selected to compare the Tsumura (Mtsu), Mukeng (Mmuk) and Lwiro (Mdlwi) duration magnitude. The significant differences marked to p (value) <0.05 between EM and Eml, Dcal and Dbull and Mlricand Mlbull were observed with the T test. The Tsumura (Mtsu), Mukeng (Mmuk) and the Lwiro (Mdlwi) duration Magnitudes had also presented some peculiar features as the Mmuk were lower to those of others and didn’t exceed the value of 4. For the epicentral distances superior to 140Km, the Mdlwi gave some lower values to those of Tsumura. The epicentral Distances reported by the IRSAC seismological bulletins were different from those one calculated with epicenters (coordinates) reported by other networks. The EM-Eml difference between the energies determined from the body-wave magnitudes (EM) and those determined from the magnitudes published in the IRSAC seismological bulletins (Eml) was in general lowered to zero. Most of magnitudes reported in the IRSAC seismological bulletins were overestimated, except for the great earthquakes near the stations in the IRSAC network, where magnitudes were not well calculated. This survey showed that some magnitude values published in the Lwiro bulletins should be revalued. A deeper survey could be done, especially on the velocity model to be applied in the region of concern, to allow making the choice between Lwiro magnitudes or those of other networks with a view to survey of seismic hazard assessment. The Lwiro Station should have its own definition of magnitude formulae to take account of the local conditions.

Keywords: earthquake energy, epicentral distance, local magnitude scale, body-wave magnitude, surface-wave magnitude, duration magnitude and maximum amplitude.

INTRODUCTION

In the course of historical or statistical study of earthquakes in any given region it is frequently desirable to have a scale for rating these shocks in terms of their original energy, independently of the effects which may be produced at any particular point of observation (Richter, 1935). The magnitude is a number that characterizes the relative size of an earthquake and allows comparing the released energies by two different earthquakes. It allows to the quantification of the source energy of an earthquake with the help of its analogical or digital recording. It is urgent that magnitudes determined from seismograms at single stations should not be published unaccompanied by the amplitude and period readings on which they are based (Gutenberg and Richter, 1956b).

The first approach to the concept of magnitude was the local magnitude Ml designed by Richter (1935) for the classification of local shocks in Southern California, and defined as:

\[ ML = \log_{10} A - 2.48 + 2.76 \log_{10} \Delta \]  

(1)

Where A (in mm) is the maximum trace amplitude recorded by the Standard Wood-Anderson torsion seismometer (\( T_0=0.8s, h=0.8, V_0=2800 \)), \( \Delta \) the epicentral distance in Km for 25<\( \Delta \)<600Km (Richter, 1935) and supplemented for 0<\( \Delta \)<25 (Gutenberg and Richter, 1942). The content of the amplitude tables is included in a nomogram (Figure 1) in which the original format has been modified by Eiby and Muir (1961).
Figure 1. The Nomogram for determining local earthquake magnitude (Richter, 1958; modified by Eiby and Muir, 1961). The same used by the Lwiro station.

The Richter magnitude scale reflects the quantity of seismic energy released by an earthquake. The scale has been said «saturated» above of M\(_L\) 6.5. It is used for local earthquakes. It is defined from the maximum amplitude of body-wave. If a two-component Wood-Anderson system is available, the arithmetic mean of the two values of maximum trace amplitude should be used, irrespective of the arrival times (Willmore, 1979). It is always weighted on several stations by allowing for the local corrections. These corrections take account of the seismograph type used, the distance between the earthquake and the station of recording, the earthquake focal depth, the nature of the basement where the recording station is. The corrections permit to calculate everywhere in the world the same magnitude for the same earthquake.

It was found that local magnitude scale of earthquake determined by the Lwiro Station are usually greater than those given by other institutions, e.g. USCGS, ISC, NEIS... (Wafula and Zana, Centre de Recherche en Sciences Naturelles de Lwiro, personal communication, 1987).

Using 86 selected earthquakes of magnitude \( \geq 4 \) for the period from 1965 to 1977 recorded by the short-period Benioff seismograph at Lwiro seismological station and those provided by the United States Geological Survey (USGS), a regression relationship was determined between Lwiro magnitude \( M(LWI) \) and USGS’s \( M_b \) magnitude using the least square method as:

\[
M_b(USGS) = 3.315 + 0.282M(LWI) \quad R^2 = 0.521
\]  

It is noticeable that, statistically, the regression coefficient \( R^2 \) obtained by equation (2) is poor due to limited data available used for this regression analysis (Mavonga, 2010). The Uvira earthquake main shock of September 22, 1960 took place at 09h05m36.8 GMT (Lat.=3.0°S. Long.=29.0°E. Depth=28Km) with the magnitude of 6.3-6.5 at Lwiro (LWI) or 6.5 at Pasadena(PAS). It was preceded by two foreshocks with the LWI magnitude 5.5 and 4.9 (Zana and Hamaguchi, 1978). An earthquake (M=5.1) occurred on April 25,1965 at the south of the Lake Kivu (Zana and Tanaka, 1981), an earthquake of magnitude M\(_I\)4.5 on April 25, 1965 with its epicenter 10 km south of Bukavu City (Wohlenberg, 1968). The Ruwenzori earthquake of March 20, 1966 occurred at 01h42m48.9s GMT (Lat.=0.72°N. Long.=29.95°E. Depth= 34Km) with Lwiro magnitude 7.0 (Zana and Hamaguchi, 1978; Lahr and Pomeroy, 1970).
Owing to the narrow dynamic range recorded by a single seismometer, it is often impossible to measure the maximum amplitude of strong seismic movements, and the magnitude determination by duration is a useful and simple way of overcoming this problem. Thus, the method has been adopted at many seismological stations with their own definition of duration time and empirical magnitude formulae. The method is especially convenient for local shocks (Willmore, 1979).

Soloviev (1965) and Tsumura (1967) derived empirical relationships between the total signal duration of local earthquakes and magnitude for the areas of Sakhalin, USSR, and Kii Peninsula, Japan, respectively. The Tsumura empirical formula was:

\[ M = 2.85 \times \log_{10}(F - P) + 0.0014 \times \Delta - 2.53 \]  

(3)

Where \( M \) is the magnitude (mainly in the range of 3–5), \( F-P \) is the total duration of oscillation in seconds, \( \Delta \) is the epicentral distance in kilometers. With small epicentral distances (\( \Delta \leq 200 \text{Km} \)) the term containing \( \Delta \) may be omitted in all of the formulae.

Mukeng (1989) derived formulae between local Richter magnitude and \( F-P \) duration for estimation of magnitude of local earthquake at Lwiro:

\[ M_{F-P} = 0.28 + 0.42 \times \log^2(F - P) + 0.103 \times 10^{-2} \times \Delta \]  

(4)

Where \( F-P \) the time interval between the onset of \( P \)-wave and the end \( F \) of the coda-wave and \( \Delta \) the epicentral distance in Km.

**Relation between energy release and magnitude**

The linear relation between \( E \) (Energy) and the magnitude (Gutenberg and Richter, 1956b) is defined as:

\[ \log_{10} E = 1.5M + 11.8 \]  

(5)

\[ \log_{10} E = 2.4m + 5.8 \]  

(6)

Where \( E \) is the energy expressed in Erg, \( M \) is the surface-wave magnitude and \( m \) is the body-wave magnitude.

**Data presentation and analysis method**

The main sources of seismic data used in this are from the IRSAC Network and the USCGS network. The IRSAC seismographical network has been in operation since May 1953 when the Lwiro station was set up. This network operated initially with three stations: Lwiro (LWI), Butare (BTR) and Uvira (UVI) (Sutton and Berg, 1958). It was extended later by setting up the Rumangabo (RMG) and Butembo (BTC) stations in the North Kivu Province. All seismic data were centralized and analyzed at Lwiro station for publication.
About 47 local earthquakes reported by the Lwiro seismological bulletin in the period from 1965 to 1977 and those published by the USCGS in the same period were selected in this study. Those earthquakes occurred at the epicentral distance less than 600Km from the Lwiro station.

The magnitudes published by Lwiro (LWI) station were determined by a procedure similar to that proposed by Richter [1935] using the records of standard torsion seismometer by Anderson and Wood (1925). The Nordquist (1945) nomogram, adapted for the short period Benioff seismometer (To=1 sec, Tg=0.25 sec, Mag=100K, (De Bremaecker, 1955), was used to determine magnitudes at LWI.

The notes after analyzing seismograms from earthquakes recorded during the period from July to December 2011 to the Lwiro station have also been used in this work. The recordings were made from the Kinematics seismometer SS-1 short period of vertical component (To=1s) connected to analogical recorder PS-2 and a Broadband Seismometer Guralp CMG-40T with three components connected to a registrar digital DATAMARK LS7000 in the same period.

Earthquakes of magnitude >3 of the Lwiro station and those USCGS have been compared. The local magnitudes of Lwiro have been converted in terms of energy by the relation (5). Those of the USCGS were converted by the relation (6). The difference between EM (seismic Energy valued from body-wave magnitudes as reported USCGS) and Eml (Energy valued from the local magnitudes of Lwiro as reported by the seismographical bulletins of the IRSAC) was calculated and presented (Table 1). The diagram in the Figure 3 was drawn to see the EM-Eml curve with regard to the calculated distance Dcal. The calculated distance (Dcal) was established between the station of Lwiro (Coordinates: 2,28° S and 28,80° E) and epicenters reported by the USCGS bulletins. The difference between Dcal and Dbull (Epicentral distance as reported by IRSAC bulletins) was established. The curve of the Dcal-Dbull difference is given in the Figure 4.

We had used the relation (1) to calculate the local magnitudes of Richter (Mlric) by using maximum amplitudes and epicentral distances of 250 earthquakes reported by the Lwiro bulletins in the period from 1960 to 1964. The Difference was done between these magnitudes and those reported by the Lwiro bulletins (Mlbull) .
The figure 5 show the histogram of this difference (Mlric-Mlbull) with respect to the epicentral distance reported in the Lwiro bulletins.

About 422 earthquakes recorded to the Lwiro station during the period from July to December 2011 have been read and analyzed. The time interval between the onset of S-wave and the onset of P-wave (S-P time) was determined to calculate epicentral distances of these earthquakes. Total duration F-P was determined for all earthquakes.

The following relations have been used to determine magnitudes based on duration:

- The relation (3): Tsumura duration magnitude (Mtsu)
- The relation (4): Mukeng duration magnitude (Mmuk)
- The relation: \( M_d(lwi) = -2.35 + 2.85 \log_{10}(F - P) \): the relation currently used at Lwiro station for calculating the local magnitude. This relation derivates from Tsumura duration Magnitude by replacing the value of \( \Delta =128 \text{Km} \) in (3).

The t test was applied to compare EM and Emls, Dcals and Dbulls, Mlrics and Mlbulls, Mtsus, Mmuks and Mdlwis values.

The software STATISCA 6.0 was used for the test of comparison, Quakeview - Earthquake Data Viewer and Quakeview-LT Graph Generating Tool were used for the seismogram analysis.

RESULTS AND DISCUSSION

Table 1. List of earthquakes reported by Lwiro séismographical and USCGS bulletins for the period from 1965 to 1977, classified according to the ascending order with respect to the calculated Distance.

<table>
<thead>
<tr>
<th>DATE</th>
<th>ORIGIN TIME</th>
<th>LAT.</th>
<th>LONG.</th>
<th>DEPTH (km)</th>
<th>Dbull. (Km)</th>
<th>Dcal. (Km)</th>
<th>M (LWI)</th>
<th>Mb (USGS)</th>
<th>Eml (10^20Erg)</th>
<th>EM (10^20 Erg)</th>
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<td>25/04/1965</td>
<td>10-01-07.0</td>
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<td>1,5848893192</td>
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Columns 6 and 7 of this table have been compared. The t test was used to see the difference between these two columns. The result of the t test gave $P=0.032$, what shows a meaningful difference between the calculated Distances and those given by Lwiro Bulletins. However the same test applied to columns 10 and 11 gave $P=0.293$. Statistically, there is not a remarkable difference between the calculated energy from body-wave magnitudes given by USCGS and the calculated energy from the local magnitudes given by Lwiro bulletins.
We have then calculated the difference between these values of energies EM and Eml. We put the calculated distance (in Km) in the horizontal component and the difference EM-Eml (in 10^20Ergs) in the vertical component. The EM-Eml difference is negative in nearly all cases, except only one case. It is in fact the earthquake of April 25, 1965 that was reported with the local magnitude Ml = 4.5 by the Lwiro station (WohlenBerg, 1968), whereas the USCGS reported it with the body-wave magnitude Mb = 6.0. We wanted to know the reason of this difference, and we have found that, this earthquake took place 35.2 Km near the Lwiro Station. The bulletin of Lwiro gives the Distance of 34 Km and the maximum amplitude of 122.5mm. We had taken the Nomogram to measure the magnitude, the value of magnitude found was 4.4. However the value of the maximum magnitude that one can find to this distance with the Nomogram used to the Lwiro Station are 4.6. It is due to the narrow dynamic interval recorded by the Lwiro Station seismomètre, that Lwiro station could not record the entirely maximum amplitude. Clearly, we saw that this magnitude could not be well determined at Lwiro Station, that is the reason why it has been underestimated. Therefore, if we must consider that the magnitude could not be well determined at Lwiro, then the magnitude given by the USGS would be considered. Henceforth, we count three earthquakes with Magnitude Mb ≥ 6 that took place within the Lake Kivu since 1960.

In the other cases, these differences are EM-Eml<0 that is to say EM<Eml. Therefore, magnitudes given by Lwiro bulletins are higher than those given by the others international agencies. This fact was also reported by Mavonga (2010) and Wafula and Zana (CRSN-Lwiro, short communication)
Reference to that, we had also analyzed parameters that intervene for the determination of the magnitude viz epicentral distance $\Delta$ and the maximum trace amplitude $A$ of the signal as recorded by the seismometer. With regard to the épicentral distance, we had noticed a meaningful difference between those one reported by Lwiro Bulletins and those one calculated from epicenters given by USCGS. In the Figure 4, we saw the Dcal-Dbulls differences that run until 100Km. What must normally be a problem on the calculation of the local magnitude and the precise localization of earthquakes. Reasons of these differences are to look for elsewhere. Either it is the problem of reading at the Lwiro station that uses little or less stations or either the velocity model on which the velocity structure is based. We had considered differences of the magnitudes $M_{lirc} - M_{lbulls}$ (Figure 5), they were remarkable. Differences of magnitudes were in certain cases more than an unit. However, magnitudes of Lwiro were determined by using the same method as described by Nordquist (1945). The March 20, 1966 at 01h42m48.9s GMT (Lat. =0.72°N, Long. =29.95°E, H=34Km), an earthquake took place in the region of Ruwenzori with a magnitude local $M_{bull} =7.0$ (Zana and Hamaguchi, 1978). For this event, the Lwiro bulletin gives a maximum trace amplitude higher than 200mm (A>200 at 373Km of epicentral distance. Clearly, we cannot know the true value of $A$, so we cannot determine the local magnitude precisely. Therefore the value of $M_l = 7.0$ ma doubtful a bit. Whereas one knows that this magnitude scale is saturated to $M_l 6.5$.

![Face 4. The histogram of the Dcal-Dbull difference with respect to the Dcal](image-url)
September 22, 1960 at 09h05m36.8s GMT (Lat. =3.0°S, Long. =29.0°E, H=28Km), an earthquake took place in the region of Uvira with the magnitude of 6.3-6.5 at Lwiro. Lwiro Bulletins don't give any detail on the parameters (Zana Hamaguchi and, 1978) that it based to determine this magnitude as meant by Gutenberg and Richter (1956b). It is as the same case for the aftershock of the same earthquake at 09h14m51s GMTS which Lwiro gives the magnitude “ Ml>5.2 ” whereas USCGS gives the magnitude of 6.25-6.5

![Figure 5. The histogram of the Mlric-Mlbull difference with respect to Dbull](image)

We noticed that some magnitude values of local earthquakes such as reported by the Lwiro Station bulletins was not always the local magnitudes, especially for the great earthquakes. Because of determining local magnitudes of great earthquake, Sometimes the values of magnitude reported by USCGS were published like local ones by the Lwiro bulletins without mentioning their origin.

A linear relation established with the local magnitudes reported by the Lwiro station and body-wave or surface-wave magnitudes reported by others agencies would give weak regression coefficient value. To make the unification of magnitudes, it would be necessary to think about reviewing some values given by Lwiro bulletins.

The Lwiro Station operated during a long moment with a short period Kinematics vertical component SS-1 ranger seismometer one connected to a PS-2 seismic recorder. The determination of the maximum trace amplitude in the seismogram had become difficult because of the saturation of amplitudes. The duration magnitude was then used.

![Figure 6. Duration magnitudes of Tsumura (1967) triangle of green color, of Mukeng (1989) square of red color and Lwiro lozenge of blue color with the epicentral distances lower to 140Km.](image)

The duration magnitudes calculated here doesn't reflect the reality indeed, but an example of earthquakes which total duration F-P were read to the Lwiro Station. For epicentral distances lower to 140Km, magnitudes of Lwiro (Mdlwi) were nearly the same with those of Tsumura (Mtsu) in accordance with what said Tsumura (1967) for
earthquakes of epicentral distances lower to 200Km. However, the magnitude of Mukeng (Mmuk), for the same values of F-P Mmuk did not exceed the value of 4. The formula of duration magnitude Mdlwi is a derivative of the Mtsu magnitude for epicentral distances running between 0 to 130Km. The Magnitude Mmuk is applicable for earthquakes of magnitude inferior to 4.

For epicentral distances superior, the Mtsu magnitudes are bigger than those of Mdlwi. In the Mdlwi relation, the parameter of distance doesn't appear. Therefore the influence of this parameter is remarkable for the big epicentral distances (Figure 7.). The Mmuk magnitudes always remain lower to 4.

The Figure 8 is an illustration of difficulty that one can meet when calculating the duration magnitude. The determination of the total duration of the signal as recorded in the analogical paper seismogram is not always easy operation in certain cases.
In this seismogram, one can clearly distinguish two events that seem overlap, the first that comes before and the second that follows.

![Seismogram Image]

By observing the figure 8 and the figure 9, we noticed that in the figure 8. One cannot see the onset of P-wave’s second event such as seen in the figure 9. An attempt to read the F-P in the first seismogram would follow from a bad estimation of the duration magnitude.

For Stations that have only analogical recorders, the case of misinterpretation of the total duration can arrive. Thus, considering the figure 8, the event 2 and event 3 were read as one earthquake. The value of F-P was then overestimated.

CONCLUSION

The IRSAC network had made up of many Stations but the magnitude values reported were only for one station instead of the average value given by all station. The Lwiro station used the Nordquist (1945) nomogram but there were lot of discrepancy between magnitudes reported by Lwiro and others agencies. The local magnitudes of great earthquakes were not well calculated at Lwiro. Sometimes others magnitude scales were used for local earthquake without mentioning the scale type.
We found a remarkable difference between epicenters determined by the IRSAC network and those reported by others networks. Sometimes difference between epicentral distance of local earthquake reported by the IRSAC and USCGS ones was more than 100Km, what was abnormal. With the same maximum trace amplitude, we found two magnitude value of local earthquake by using both the nordquist nomogram and the local magnitude scale of Richter. In some case the difference was more than one unity of the magnitude, which is enormous.

An effort must be done so that Lwiro station develops and establishes its owns formula and method to determine local magnitude scale. A survey might be foreseeing for revaluation some seismic parameter such as magnitude, epicentral distance and maximum trace amplitude.

This work would be a reference for survey of seismic hazard assessment in the region of concern, On account of the importance of the Lwiro station.

COMPETING INTEREST

The seismic hazard assessment in the Lake Kivu Basin in the Eastern of the Republic Democratic of Congo

AUTHORS’ CONTRIBUTION

We are all in the same institution that is CRSN-Lwiro in the Geophysique Department. In this present, we used data from different period thus: the 1965 to 1977period was carry out by Tambala, the 1960 to 1964 by Jeje and the July to December 2011 by Bagalwa with the use of the Quake View Software. The analysis and the results were carried out by Tambal and Maki. Dr. Wafula is the promoter and helped us to have conclusion.

REFERENCES
