Macroseismic survey of the M_L 4.4, 11 June 2023 Boksburg earthquake

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Abstract

The Council for Geoscience (CGS) performed a macroseismic investigation following the occurrence of an earthquake in the Boksburg area on 11 June 2023. The event had a magnitude of M_L 4.4 and a focal mechanism that showed the event as having strike-slip motion along a northwest-southeast oriented fault. The event resulted in aftershocks, some of which occurred away from the causative fault in the east in an area without a mapped fault. However, the cluster of past events in that area suggests that there is an active fault. Due to the size of the main earthquake, a macroseismic survey was conducted to determine its impact on the community in the region. Analysis of observed data obtained from questionnaires resulted in the creation of 153 intensity data points. Their distribution showed high intensity values close to the earthquake source area. However, the investigation highlighted a number of anomalies, such as the higher than expected intensity values observed far from the event epicentre. It could be that these anomalies are caused by site conditions, for example, amplification of ground motion due to thick soil layers.

Keywords

Boksburg, earthquake, aftershocks, questionnaire, intensity

Introduction

An earthquake of local magnitude, M_L 4.4 occurred in the Boksburg area in Gauteng Province, South Africa, in the early hours (02:38 hours local time) of 11 June 2023. Using the national network as well as the cluster network of stations that are in and around the Klerksdorp–Carletonville–Johannesburg area (Figure 1), the Council for Geoscience (CGS) recorded the event and reported its epicentre at the coordinates 26.2462°S and 28.2061°E with a depth of 1.2km. Eighteen aftershocks scattered in the area were recorded during the first day after the main event (Figure 2). Thereafter, about 50 events were located in the area within six months. The largest recorded aftershock had a magnitude of M_L 3.5. The event and its aftershocks are located in the East Rand, an area with many historical gold mines, though the mines in the area are now closed. Following the closure of the mines, seismicity has continued in the area, though with a lower activity rate. It is likely that events are triggered along prestressed faults that pass through the area.

The location of the main Boksburg event and its aftershocks are shown in Figure 2 as well as the long-term seismicity of the region (black open circles). The location indicates that the event occurred along an active northwest-southeast oriented fault located in the East Rand in an area with closed and sometimes flooding mines. The fault is a branch of the Rietfontein fault. The focal mechanism of the event indicates strike slip faulting (Figure 2). The north-south oriented nodal plane is similar (though not the same) in orientation to the northwest-southeast fault branch (Figure 2). It is not clear whether events in this area are natural or triggered. The triggering of events along the fault can be caused by an increase in pore pressure due to flooding of mines, which would result in a decrease of the clamping force. A combination of this phenomenon and the lubrication of the faults could certainly result in the triggering of earthquakes along this and other faults in the area. The long-term seismicity and location of some of the aftershocks imply that there is an unmapped north-northeast-south-southwest oriented fault east of the Boksburg event causative fault, which also appears to be active. Stress transfer from the Boksburg event probably caused aftershocks to be triggered along this possible secondary fault.

The shaking from the earthquake of 11 June 2023 was widely felt, with reports from as far afield as Klerksdorp, Pretoria, and parts of Mpumalanga. Some houses and offices in the Boksburg area were

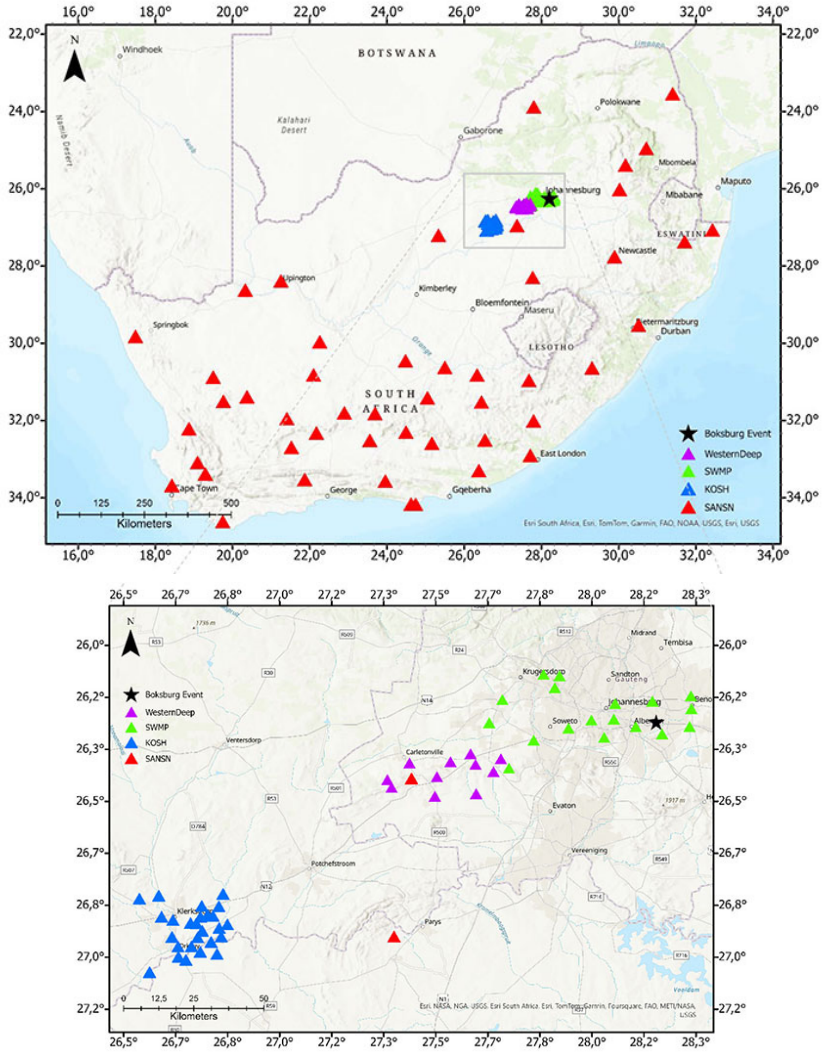


Figure 1—The South African National Seismic Station Network with the zoomed in figure at the bottom showing the cluster networks (KOSH, Western Deep and SWMP) of seismic stations that recorded the earthquake on 11 June 2023

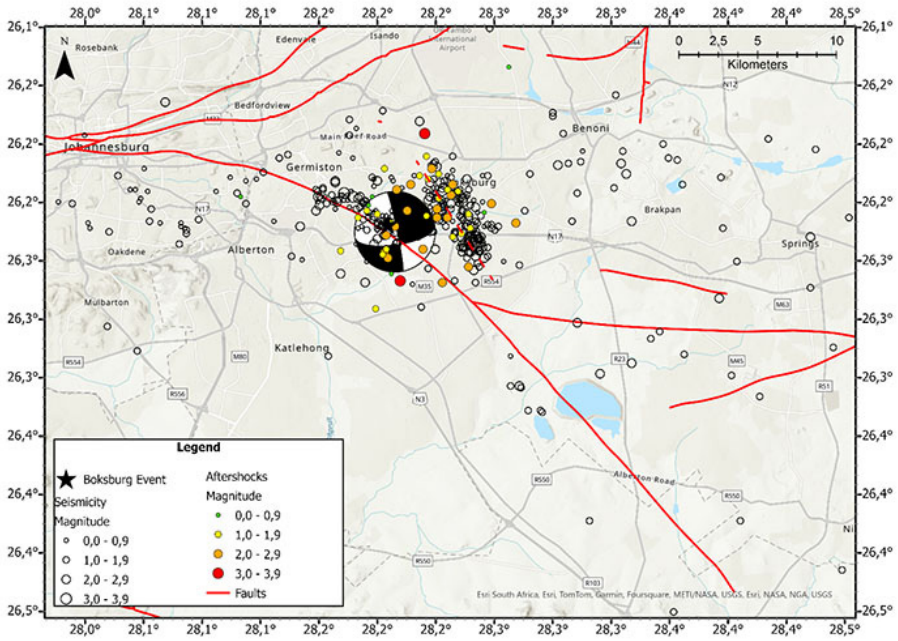


Figure 2—Location of the 11 June 2023 Boksburg event (black star) with its aftershocks (coloured circles). The empty black circles are the long-term seismicity recorded in the region (2016 to 2021). The focal mechanism of the event is represented by the beach ball shown by the circle with two black and two white quadrants. The red dashed line is the possible location of an unmapped active fault

damaged (Figure 3). The main results reported in this article are linked to the macroseismic survey that was conducted by the CGS to determine the extent of the impact of this earthquake.

Macroseismic survey and data analysis

Macroseismic intensity data play an important role in the seismological, engineering and loss modelling communities (Midzi et al., 2013). They provide the much needed, and often previously unavailable information for constraining the location and magnitude determination of historical events and for the reconstruction of shaking distributions. The data can also be useful in the selection of appropriate ground motion prediction equations, which can be done either by comparing intensity values with those of other regions of similar tectonics (e.g., Bakun and McGarr, 2002; Allen and Wald, 2009) or by direct comparisons of intensity values with ground motion predictions of peak ground acceleration and response spectral ordinates (e.g., Scherbaum et al., 2009; Delavaud et al., 2009). In South Africa, macroseismic surveys are carried out for all earthquakes of magnitude greater than or equal to 4 that occur in South Africa (e.g., Midzi et al., 2013; Midzi et al., 2015; Pule et al., 2018; Manzunzu et al., 2023) In their publication, Midzi et al. (2013) compiled an intensity database containing 57 earthquakes, using the Modified Mercalli intensity scale, MMI-56 (Richter, 1958).

Thus, following the 11 June 2023 Boksburg earthquake (M_L 4.4), the CGS conducted a macroseismic survey to investigate the effects of the event in the region. The macroseismic observations were compiled from online and in-person/face-to-face interview questionnaires.

Observations and intensity data points (IDP)

A total of 511 observations were collected from online sources (280 questionnaires) and also from the survey carried out by the CGS (231 questionnaires). Their spatial distribution is shown in Figure 4.

The methodology followed to translate the information in the collected questionnaires into intensity data points (IDP) is essentially that recommended by Musson and Cecić (2002) and implemented by Midzi et al. (2013). The first step in the analysis of the observations was to sort them according to places, where the places were defined as suburbs or districts in the region. The locations of the places were obtained using a combination of the following sources:

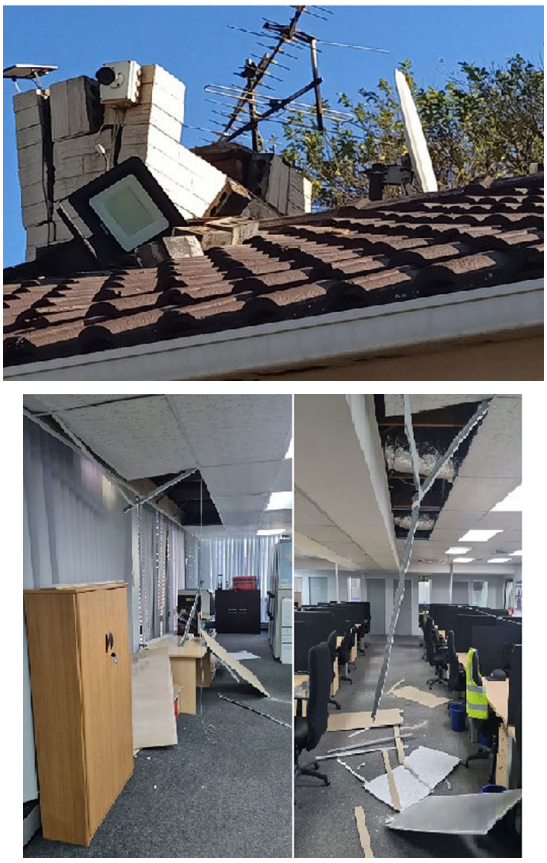


Figure 3—Examples of observed damage to houses and offices in the Boksburg area

- Google Earth
- The CGS GIS databases
- The Geonames online database of the US National Geospatial-Intelligence (GEOINT)) Agency (http://geonames.nga.mil/ggmagaz/).

All the individual intensity indicators per question in the questionnaires for each place were then summarised. Intensity values were assigned to the sorted and grouped observations by comparing the summary of the observations for each place with the descriptions given for the intensity degrees in the Modified Mercalli

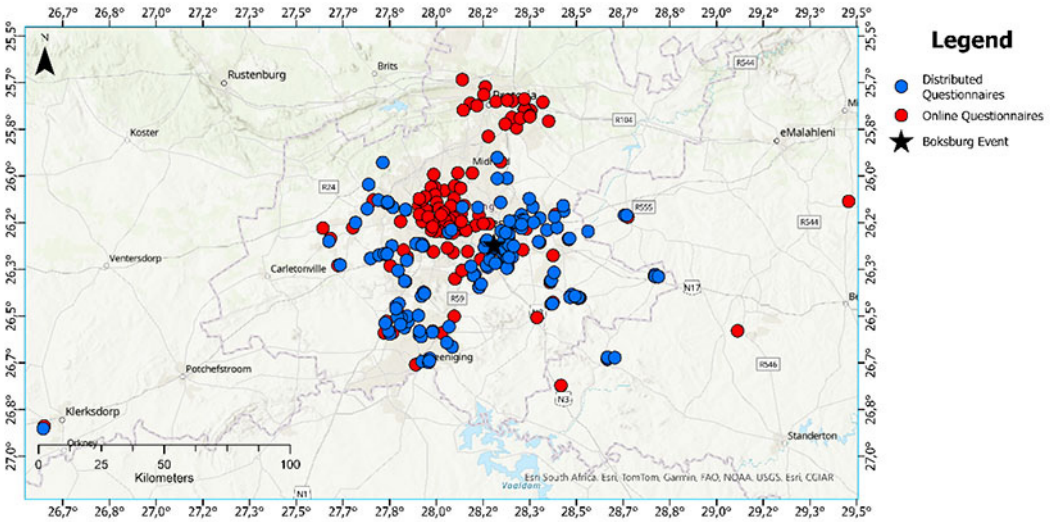


Figure 4—Spatial distribution of the observations analysed for the earthquake of 11 June 2023

intensity scale (MMI-56 scale). This was done by identifying which of the descriptions for the various intensity degrees best fit the sum of the data collected for the place under consideration. As stated by Musson and Cecić (2002), it is important in this process not to lose focus in pursuit of details of individual diagnostics. The correct assignment is the one that best expresses the generality of the observations. The process followed is described in detail by Midzi et al. (2013). A total of 153 IDP were created using information obtained from the observations (Figure 5).

On analysing the created IDP, it was observed that many (93) had been created using two or more observations (e.g., questionnaires) with 60 IDP created using only one observation each (Figure 6). Of the 93 IDP, 36 were created using at least five observations. The use of observations from several questionnaires at each place increases the reliability of the results and reduces possible bias. Thus, IDP such as that for Benoni are the most reliable, having been created using observations from 24 questionnaires (Figure 6).

The highest intensity value obtained was of level V–VI, which was experienced at five places, namely Elspark, Elsburg, Palm Ridge, Benoni, and New Redruth. All these places are located close to the epicentre. Some buildings and houses in these areas suffered damage as shown in Figure 3. The distribution of intensity levels showing the number of IDP for each intensity level is shown in Figure 7. It shows that most of the IDP obtained had an intensity level of IV.

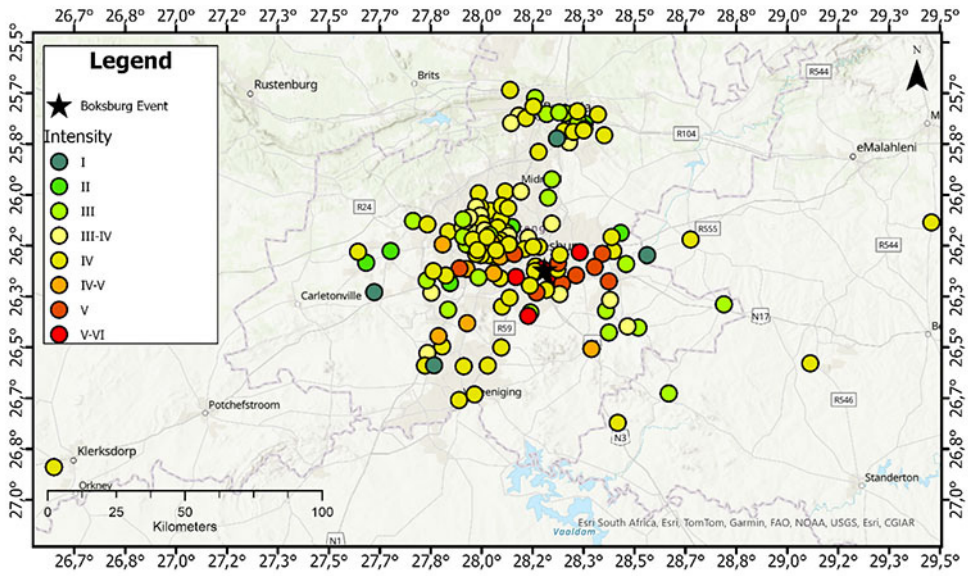


Figure 5—The spatial distribution of the IDP for the 11 June 2023 Boksburg earthquake. The black star indicates the location of the earthquake

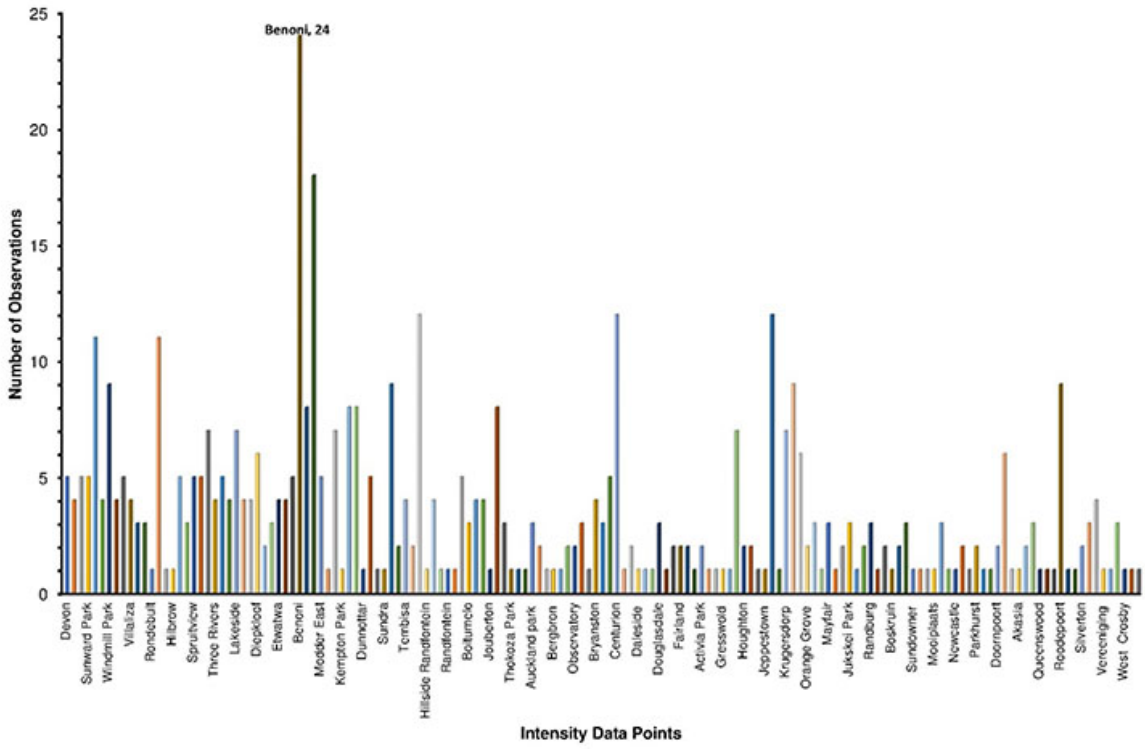


Figure 6—Number of observations used to create each IDP

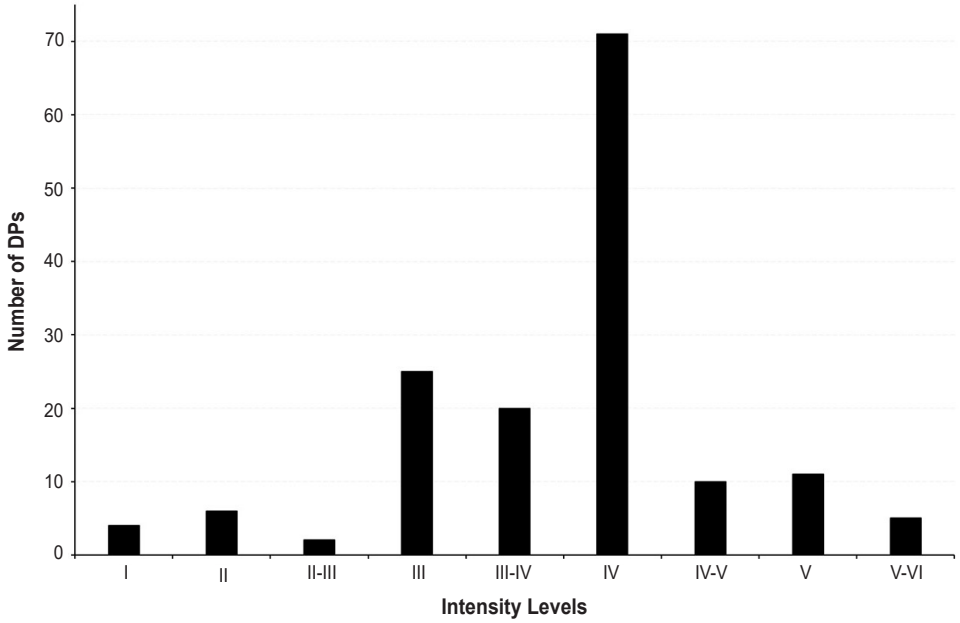


Figure 7—Number of IDP for each intensity level

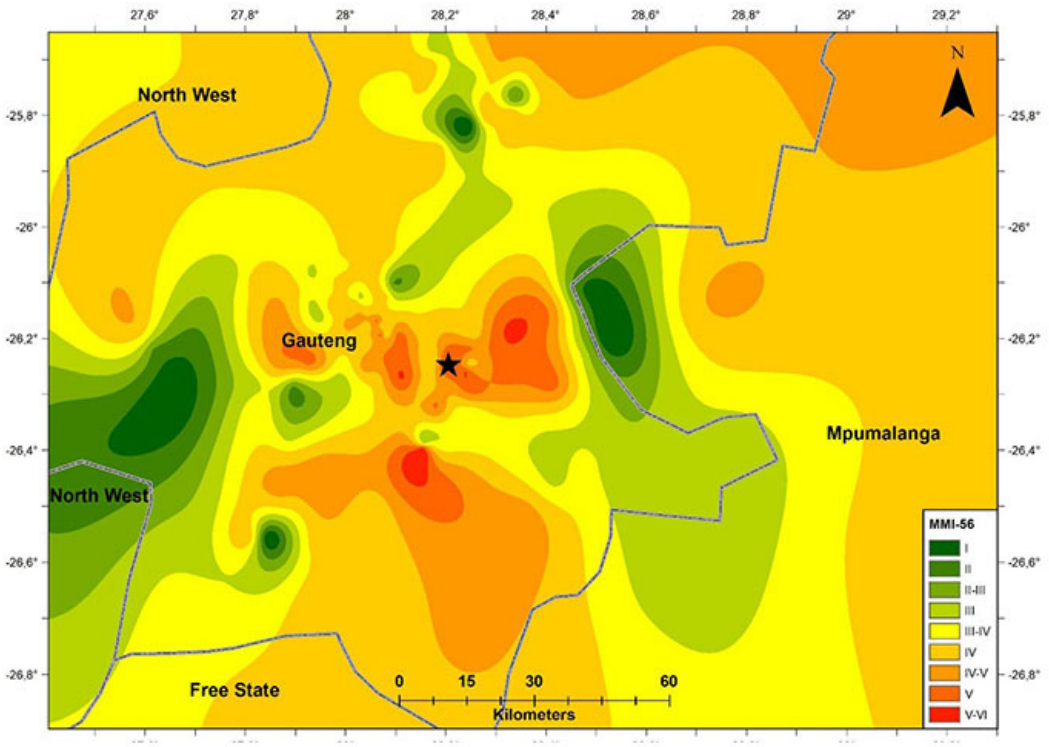


Figure 8—An isoseismal map of the earthquake of 11th June 2023, which shows bands of colours of equal intensity, gridded using the Spline with Barrier technique in ArcMap. The black star is the location of the main Boksburg event

Discussion

An isoseismal map was created using the intensity values obtained from the IDP that are shown in Figure 5. The values were gridded using the Spline with Barriers technique in ArcMap to create the map in Figure 8. The red colours indicate higher intensities up to V–VI and the lower intensities are indicated by the green colours (Figure 8). Thus, areas are shaded using the same colour to indicate that they experienced shaking of equal intensity. As expected, the epicentre is located within areas that experienced the strongest shaking. However, unexpectedly high intensity levels (Level IV) were observed in Mpumalanga at an epicentral distance of 200 km and Newcastle, approximately 250 km away. An explanation for this could be that the high intensity values at long distances are caused by the amplification of the ground motion by local geology and/or topography. Also, some observations may have been provided by observers located on the upper floors of tall buildings, which are more sensitive to earthquake shaking.

Low intensity values are also observed about 30 km from the epicentre, mixed with IDP of higher intensity that would be expected at such epicentral distance. It is difficult to explain why

there was low intensity so close to the epicentre. This could be due to site conditions, where buildings in the area are built on rock, or just subjective views of observers that, because they were sleeping at the time, might not have experienced the shaking from the earthquake. High intensity values seen near the boundaries of the area are an artifact of the gridding process. The values are influenced by the nearest IDP. Comparison between the distribution of IDP shown in Figure 5 and the isoseismal map (Figure 8) can show the influence of the IDP values on the isoseismal map.

Conclusion

Intensity values were assigned to create IDP for the 11 June 2023 Boksburg earthquake by using observation data from information provided in questionnaires submitted online to the CGS and others filled in during interviews conducted by CGS personnel. A total of 153 IDP were created, with the highest intensity level of V–VI experienced in several places located near the epicentre. There were also observations that indicate that the shaking from the earthquake was felt over 200 km from the epicentre. Higher than expected intensity values were also experienced in Johannesburg central and the northern suburbs, as well as in Pretoria to the north. Intensity has been proven to be highest at the epicentre and locations mostly nearby. Normally, the shaking from the earthquake is highest close to the epicentre and decreases with an increase in epicentral distance. However, it is clear that site geology also contributes much to the distribution of observed intensities.

Recommendations

The following actions are recommended to help in the explanation of observed outlying intensity values, which appear higher than may have been expected when considering their distances from the epicentre of the earthquake:

- Investigate the influence on the intensity distribution of observations reported by people on upper floors of multi-storey buildings.
- Investigate the influence of site geology and topography on intensity distribution.
- Investigate the link between intensity distribution, building damage and building type.
- Investigate in detail the ground motion inferred by observed variations of intensity in the epicentral region by carrying out a microzonation study of the Ekurhuleni municipality to expand the microzonation of Johannesburg results (Rathod, 2018). This should be done by carrying out a detailed seismic hazard analysis incorporating the site response analysis. The response of soil layers under earthquake excitations should be assessed to provide an indication of the variations of ground motion amplitudes/shaking level on the ground surface. This process is essential for identifying potential seismic "hotspots", which could have varying effects on structures within the same area. Such information is essential for disaster management and city planning.
- In-depth geophysical surveys to understand the fault structures which may be the causative faults of earthquakes in the region.

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