Revisiting The 2018 Kalibening Earthquake Sequence In Central Java: Call for the Revision of Earthquake Hazard

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Abstract. As a moderate devastating earthquake that impacted economic loss was about $ 1.68 million US, the 2018 Kalibening earthquake quite shocked where the faulting mechanism still unconfirmed. There was no reference indicating the existence of the faulting zone exactly on the earthquake sequence. We take a benefit from a seismic temporary network with the density ±2 km, which deployed while a macroseismic survey in purposing to evaluate the 2018 Kalibening earthquake sequence. Earthquake relocation using double difference combined with cross-correlation and determining earthquake moment tensor inversion solution using near source seismograms were applied. We suggested the deformation scheme of this earthquake with a thrust faulting with 307.5/ 28.8/ 118.5 (Strike/ Dip/ Rake) as a result from mainshock and supported by aftershock moment tensor solutions. This parameter is consistent to aftershocks relocation results which formed a lineation trending NW-SE appropriate with Strike = 307.5. The cross-section exhibits aftershocks pattern which elongated deeper and formed a slope from SW to NE approximately fit to Dip = 28.8. The results from investigating the background seismicity in Banjarnegara Region using combined catalog (ISC-USGS-BMKG) compared to BJI (single station) showed the sparse and the lacking of InaTEWS seismic network configurations. Finally impacted to losses in earthquake cataloging, leads the low area coverages around Banjarnegara region. Together with our results, we called for the revision of earthquake hazard assessment for Central Java province, especially in Banjarnegara region.

Keywords: earthquake relocation, moment tensor solution, seismic temporary network, Kalibening earthquake, earthquake hazard assessment

1. Introduction
There are seven faults lying in Central Java denoted by the red lines in Fig.1 which confirmed and summarized in Indonesian Seismic Sources and Seismic Hazard Maps 2017 [1]. One of the longest that extending from the eastern section of West Java to East Java is Baribis-Kendeng fault which passes through the northern section of Central Java. This fault is dividing into several segments and named based on the area that passes. Another study ensured there are two major strike-slip faults existing in Central Java, called the Muria-Kebumen Fault (left-lateral, trending southwest-northeast) and the Pamanukan-Cilacap Fault (right-lateral, trending northwest-southeast) denotes by orange
straight lines in Fig. 1 [2,3]. This two fault separated in the northern area but meeting in the southern area, opposite in slip and trend to each other therewith considered to have indented Central Java’s coastline and caused many geologic changes in Central Java. Both of these references are contradictions but prominently they don’t announce any faulting mechanism in Banjarnegara Region and the surrounding area.

On 18 April 2018 06:28:35 UTC, an Mw (mB) 4.4 earthquake ruptured onshore at the Kalibening District, Banjarnegara County, Central Java. BMKG reported that Kalibening earthquake epicenter at 7.21°S, 109.65°E with shallow depth as 4 km. The estimated of economic loss was about $ 1.68 million U.S (23.56 billion Rupiah) according to the National Disaster Management Authority of Indonesia (BNPB). That excessive and worst impact became a reason why this disaster is staggering. The stakeholders faced difficulty when determined the generating fault since related to the previous explanations, this moderate earthquake occurred in that unconfirmed faulting zone.

**Figure 1.** Overview map showing the seismicity, faults, and seismic stations in Central Java. The black open circles indicate combined catalog from ISC-USGS-BMKG catalog while the blue circles recorded by BJI. Blue beach-ball symbols show the earthquake mechanisms listed in GlobalCMT while the red beach-ball from GFZ catalog. Inverted triangle showing us the InaTEWS seismic network, the blue inverted triangle was used to generate mainshock’s moment tensor in this study. The yellow one notified the location of BJI sensor. Red triangle shows the volcanoes location. Red lines and orange lines denote mapped faults which confirmed from Earthquake Source and Hazard Map of Indonesia 2017 and proposed in [2,3], respectively.
In purposed to monitoring the aftershocks, BMKG had sent macroseismic survey team and in its enforcement was deployed five local temporary sensors (including three Trillium Compact Seismometer and two Taide Digital Seismograph (TDS)) which covering the damaged area in Kalibening District. Total of 24 aftershocks was recorded up to 26 June 2018 (where 18 events up to 01 May 2018 for the last day of survey). The nine of them were felted by citizens and made a disruption, both at displaced and damaged area.

There are several factors, including the network geometry, available phases, arrival time reading accuracy and knowledge of the crustal structure which controlled the accuracy of absolute hypocenter locations [4,5,6]. In further, the precision of earthquake location in terms of a better, precisely and refined distribution can be further improved by earthquake relocation [6, 7, 8]. Another hand, to investigation the earthquake source processes, the moment tensor is very well suited as a mathematical description of equivalent forces and moments in a point source. Understanding the faulting type of an earthquake to be a valuable and important task by considering the estimation of the moment tensor solution [9].

The purpose of this study is to evaluate the 2018 Kalibening earthquake sequences in lead to calling a revision of earthquake hazard in this study area. First, we relocate the aftershocks, then determine the focal mechanisms both mainshock and aftershocks. From these results, we suggest the deformation scheme in the source region that generated the Kalibening earthquake. Then we show the lacking of InaTEWS seismic network in terms of low area coverages around Banjarnegara Region and its relation with unconfirmed faulting type of the Kalibening earthquake.

2. Data
For studying Kalibening earthquake sequences, we used data from two types of seismic networks. First, to determined the mainshock moment tensor inversion, we had chosen Short Period sensor of InaTEWS seismic network which quite well in recording the signals. There are CTJI, JCII, KPJI, SMRI, UGM, and UWJI (blue inverted triangle in Fig.1) which we considered as the most suitable sensors due to data availability and to avoid the big residual between observe and synthetic waveform from other sensors (grey inverted triangle).

The second, we used a temporary network to relocated and determined the aftershocks moment tensor inversion. From the total of 24 aftershocks that occurred, we were able to process 14 events (completely shows in Tabel 3). Since the first four came before all the temporary sensors were deployed (before the survey) and another last six events after survey. We set the aftershocks that would be relocated with Event ID (1-14). As a dense temporary network with a density of around 2 km, it can be seen and became quite simple for clearly phase identified even with M 0.8 aftershock. Seismic data that we used were originated from six sites even though in total were eight as the two of them had errors in reading time (YGI1 and YGI2 were unused in this study).

Initially, there were five sites associated with five sensors but for necessity in the macroseismic survey, the three of them were forced to be moved. So that finally became eight sites sensor with different deployed times (detail in Table 1). The spread aftershock distributions at the outside in the south of initial temporary network location became a reason why some of these sensors was moved. Almost all aftershocks were not well recorded by InaTEWS seismic network as its small energy radiations and very shallow depth (for example in Fig.3). Consequently we can not use it as ancillary for relocating and determining the moment tensor inversion. Likewise with the mainshock, we found difficulties in finding the pairing events for relocating.
Table 1. Information of the temporary network during the macroseismic survey for 2018 Kalibening earthquake

| No. | Station Code | Sensor Type   | Lat. (°S) | Long. (°E) | Location   | Deploy Time (d/m h:m UTC) | Status               |
|-----|--------------|---------------|-----------|------------|------------|--------------------------|----------------------|
| 1.  | BJIX         | Taide TDL-303 S | 7.2178    | 109.6515   | Sidakangen | 19 Apr 22:00 – 26 Apr 14:00 | Used in this study   |
| 2.  | KP05         | Trillium Compact | 7.1939    | 109.6413   | Bedana     | 20 Apr 10:50 – 21 Apr 10:21 | Used in this study   |
| 3.  | KP03         | Trillium Compact | 7.2147    | 109.6332   | Sikumpul   | 20 Apr 09:57 – 22 Apr 13:05 | Used in this study   |
| 4.  | TES2         | Trillium Compact | 7.1987    | 109.6563   | Karanganyar| 20 Apr 02:12 – 23 Apr 13:11 | Used in this study   |
| 5.  | KTSI         | Trillium Compact | 7.2264    | 109.6903   | Kertosari  | 21 Apr 15:00 – 23 Apr 13:55 | Used in this study   |
| 6.  | KLBB         | Trillium Compact | 7.2547    | 109.6858   | Kaligombong| 23 Apr 00:00 – 23 Apr 14:36 | Used in this study   |
| 7.  | YGI1         | Taide TDL-303 S | 7.2183    | 109.6729   | Bakalan    | 20 Apr 18:00 – 21 Apr 08:00 | Unused in this study |
| 8.  | YGI2         | Taide TDL-303 S | 7.2114    | 109.6800   | Kasinoman  | 21 Apr 14:00 – 25 Apr 00:00 | Unused in this study |

The combined onshore earthquake catalog (depth < 50 km) from ISC-USGS-BMKG and Banjarnegara Geophysical Station (BJI) alone were used for investigating background seismicity and showing the lacks of InaTEWS seismic network around Banjarnegara Region. This area bounded by the blue rectangle in Fig.1 with the constraint area (109.55°E – 110.25°E and 7.05°S – 7.50°S). The combined catalog (denoted as black open circles) were collected between 1960 and July 2018 while the BJI catalog (blue open circles) since 2004. In avoiding the duplication, we were only selected events from the similar catalog with priority: ISC>USGS>BMKG>BJI. It means we convinced to deleted the catalog from BMKG when ISC catalog presented similar earthquake parameter. We compared that combined catalog to BJI where this catalog was mostly recorded from the single station observations. At this terms, the data used only from 2004 since the initial recording of the BJI catalog digitally. Here we also enclose the moment tensor catalog in Central Java from GlobalCMT and GFZ catalog since 1976 until now.

3. Methods

3.1. Earthquake Relocation

In this study, we used HypoDD to refined aftershocks location. HypoDD is a Fortran computer program package for relocating earthquakes with the double-difference algorithm [6]. We allow the combination use of phase delay times measured from catalog picks and from cross-correlation. Because cross-correlation methods can measure differential phase arrival times with subsample precision for events that are nearby and have similar focal mechanisms [10]. For detail in [7,11].

Solutions are found by iteratively adjusting the vector difference between nearby hypocentral pairs, with the locations and partial derivatives being updated after each iteration [6].

Since the arrival times were picked using Seismic Analysis Code (SAC) for the relocation process, the waveform data must be converted to the same form first (SAC format). The output signal of TDS sensor is in TRC format, we need to convert it to MINISEED before and then to SAC format using MSEED2SAC software. However, Trillium Compact Seismometer has output signal in MINISEED format so it can be converted directly to SAC.

First, we set the origin time as 0 time. The signal was cut 5 s before until 15 s after origin time to simplify phase identification as the raw data had one-hour continuous signals. The bandpass filtered 0.7-8 Hz was applied to all seismograms for better clearly signals. P and S-arrival were picking manually which marked by T1 and T2 as shows in Fig.2. We took the initial aftershocks parameter that generated during the macroseismic survey as part of the input to the program. Total of 160 P-phase pairs and 172 S-phase pairs were used in this processing where linked event pair as 76. We set waveform data 0.1 before – 0.5 s after P-arrival in Vertical Component and S-arrival in Horizontal
Component for cross-correlations. For velocity structure, we used as proposed in [15] from the anisotropic structure beneath Central Java study results (Table 2).

![Figure 2](image)

**Figure 2.** The example of raw waveforms from Event ID 11 recorded in temporary network vertical component (counts/m/s). The straight line with 0 denotes the origin time. T1 and T2 for P-arrival and S-arrival respectively.

![Figure 3](image)

**Figure 3.** The observed of bandpass filtered 0.7-8 Hz waveforms in vertical component from aftershock Number 2 listed in Tabel 3. This waveform recorded by the nearest SH* InaTEWS network.

### 3.2. Moment Tensor Inversion

A well-established method and software had applied to perform waveform inversion towards estimate the moment tensor solutions for small and moderate earthquakes. This code constructed by Yuji Yagi [12] where utilize an assumed that horizontal location of centroid can be approximated to the epicenter, and estimated the optimal depth of the centroid and half duration using the grid-search method. Furthermore also in under assumed that a simple source model such as the point source model, in which we assumed the seismic waveform to be radiated from one point to estimate stable moment tensor solution. This method applied the Green’s function based on Extended Reflectivity which developed by [13]. The optimum moment tensor solution is reached by best fitting between observation and synthetic waveforms through the inversion process. For more details about the method please refer to [12,14].
In determining the mainshock moment tensor, the waveform data were downloaded from Webdc3 BMKG in FULLSEED format. Then it was converted to SAC format using RDSEED software. The instrument response file for each seismometer was removed by deconvolution of the response file. We used 40 s of waveform data with start time 0.5 s before P arrival for inversion. To minimize the effects of low- and high-frequency noise on the measurement of the surface wave dispersion, we used a frequency range of 0.05 – 0.1 Hz based on trial and error. As we unable refined the mainshocks locations, the initial parameter were used forcefully.

After the waveforms were prepared as explained in earthquake relocation section, we removed the instrument response for all channels to generated aftershocks moment tensor inversion. The waveform data that used around 8 s – 12 s with start time 0.1 s before P arrival. In this study, we preferred used the aftershocks parameter resulted from relocation to obtain the optimal position of the centroid of earthquake inversions. Trial and error methods were adjusted to select the fittest bandpass filter in frequency range of 0.28 – 0.38 Hz. This configuration depends on the state that the bigger magnitude and the farther distance should provide longer durations of aftershocks and advisable adjusted with the lower frequency range. The PREM velocity model combining with Koulakov [15,16] were applied for both determining mainshock and aftershocks moment tensor as detailed in Table 2. For mapping, we used Generic Mapping Tools [17]

| No. | Vp (km/s) | Vs (km/s) | Density (g/cm³) | Thickness (km) | Qp | Qs | Vp/Vs |
|-----|-----------|-----------|-----------------|---------------|----|----|-------|
| 1.  | 4.30      | 2.46      | 1.02            | 3.0           | 150| 350| 1.75  |
| 2.  | 4.90      | 2.80      | 2.60            | 5.0           | 150| 350| 1.75  |
| 3.  | 5.70      | 3.26      | 2.60            | 8.0           | 150| 350| 1.75  |
| 4.  | 6.90      | 3.94      | 2.90            | 8.0           | 150| 350| 1.75  |
| 5.  | 7.10      | 4.06      | 2.92            | 53.0          | 150| 350| 1.75  |
| 6.  | 7.80      | 4.46      | 3.30            | 63.0          | 150| 350| 1.75  |

4. Results and Discussion

4.1. Aftershocks Relocation

We had done a double difference relocation combined with cross-correlations to Kalibening aftershocks. As P and S-wave differential times calculated from both catalog picks and cross-correlations, the final relocations have a RMS of 7 ms for catalog pick data and 17 ms for cross-correlation data. After five iterations, the inversion indicates average relative errors of ±19m (horizontally) and ± 20m (vertically). The condition number (CND) for the last iterations was 69 (to avoid over or under damping of the solution, it should between 40 – 80). We successfully refined 13 aftershocks location from the total of 14 that we proposed. Based on the output of that parameters, we assured had obtained better and constrained hypocenters in 3-D projections.

The distribution of relocated aftershocks represents in Table 3 and together mapped with Banjarnegara seismicity shows in Figure 4. In Table 3, the initial locations denote unrelotted parameters while the final locations for relocated aftershocks. Fig.4a represents the location of Kalibening earthquake sequence ruptured in the north of Banjarnegara Region, in the area of Kalibening District. The distribution of relocated aftershocks (blue-black list circles) was more concentrated in SE of Kalibening Basin where heavy damage occurred (marks by the rectangle with blue dashed line) as shown in Fig.4b. The mainshock (red star) seemingly stand a bit apart from relocated aftershocks as we didn’t relocate it. Fig.4c we clearly exhibit the relocated aftershocks more patterned in comparing to the unrelotted (yellow-black list circles).
The connecting line that linking the unrelocated to relocated aftershocks indicates the shifted patterns of aftershocks. In general, events that ruptured in the west, in the northwest and in the northeast of aftershocks centralization were moved to the east, to the southeast, and to the southwest, respectively. In average, the events were moved 0.22 km away where the farthest moved as 0.77 km.

Fig.4d and Fig.4e depict the cross-section of A-B line and C-D line respectively in Fig.4b. With range of 2 – 6 km depth, the relocated aftershocks distribution more vertically oriented as shows in Fig.4d whereas in Fig.4e seems formed a slope which elongated deeper from SW to NE. The shifted patterns of the aftershocks in the A-B and C-D cross-sections respectively represent in Fig.4f and Fig.4g. The connecting line in that two figures overall shows how the unrelocated moved to concentrate lineations of the final aftershocks location in the range of 3 – 5 km depth. Furthermore, event at the upper initial depth (1 km mostly) shifted to the downward otherwise with the event at the lower than 5 km shifted to the upward. However, the shifted vector signifies the uniformity movement in A-B cross-section (Fig.4f) while in C-D cross-section with randomly from SW and NE oriented in the upper of final location initially to the downward in the middle (event concentrated).
Figure 4. Kalibening Earthquake Seismicity Map

(a) Location of 18 April 2018 Kalibening earthquake sequence at Banjarnegera seismicity map. (b) Zoomed in map from red rectangle in figure 2.(a). Red star, yellow-black list, blue-black list, red-black list, red-blue list, blue open, black open circles denote mainshock, unrelocated aftershocks, relocated aftershocks, felt aftershocks before survey, felt aftershocks after survey, BJI catalog and combined catalog, respectively. Green beach ball, blue beach ball, and black beach ball represent mainshock, aftershocks moment tensor (the beside number marks event ID) and BMKG results, respectively. Green inverted triangle indicates temporary sensors.

(c) The shifted patterns of aftershocks where the connecting line linking unrelocated to relocated aftershocks. (d) The cross sections of A-B line. (e) The cross sections of C-D line. (f) The shifted patterns of aftershocks in the cross sections of A-B line. (g) The shifted patterns of aftershocks in the cross sections of C-D line.
4.2. Moment Tensor Inversion

Our results of mainshock moment tensor inversion show fault plane solution with a thrust faulting mechanism (green beach ball in Fig.4) with the first nodal 95.7/ 64.9/ 75.3 (Strike/ Dip/ Rake) and the second nodal 307.5/ 28.8/ 118.5. Detailed information on the resulting mechanism is listed in Fig.5 and Table 4. We assured this result was good enough as the variance about 0.38.

| Date          | O. Time | Mag | Lat. (°S) | Long. (°E) | Depth (km) | Strike (N1) | Dip (N1) | Rake (N2) | Strike (N2) | Dip (N2) | Rake (N2) | Normalized L2 norm (Variance) |
|---------------|---------|-----|-----------|------------|------------|-------------|-----------|-----------|-------------|-----------|-----------|-------------------------------|
| 18/04/2018    | 06:28:35| 4.4 | 7.210     | 109.650    | 4.0        | 95.7        | 64.9      | 75.3      | 307.5       | 28.8      | 118.5     | 0.3811                         |

We also had successfully determined a total of 11 Kalibening aftershocks moment tensor inversion (blue beach balls in Fig.4). All of aftershock moment tensor results is listing in Table 5. Even though classified as microearthquakes, we had tried to get the best fitting results as the overall variance under 0.45. At least there are 4 events that we considered as the most suitable parameter to mainshock results (event ID 4, 6, 9 and 11). The detailed information listed in Fig.6. Aftershocks moment tensor solutions in the A-B cross section visible in Fig.4d while in the C-D cross-section in Fig.4e. The fault plane solutions mainly show thrust faulting with slight oblique and observable support the mainshock moment tensor inversion result, even some the aftershocks shows strike-slip mechanisms. By the reason of the small duration which impacted to low waveform fitting quality, we were not given to warrant the aftershock moment tensor solutions and it cannot be considered as the stand-alone conclusion.

There were differences in results where BMKG reported the mainshocks focal mechanisms with strike-slip solutions (black beach ball in Fig.4). It could be happened as BMKG using the first-motion polarities of the P wave and IASP91 velocity model. In here, we keep taking a side with our results as supported by aftershocks solutions and also used local velocity structure.

From mainshock moment tensor inversion which supported by aftershock moment tensor inversion results has been explained previously, we focused to the second nodal plane which indicated a thrust faulting mechanisms with 307.5/ 28.8/ 118.5 (Strike/ Dip/ Rake). This parameter seemingly consistent to aftershocks relocations results which the formed lineation trending NW-SE appropriate with Strike = 307.5. Further as shows in Fig.4e, the C-D cross section exhibits aftershocks pattern which elongated deeper and formed a slope from SW to NE approximately fit to Dip = 28.8.

| Event ID | Date          | O. Time | Mag | Lat. (°S) | Long. (°E) | Depth (km) | Strike (N1) | Dip (N1) | Rake (N2) | Strike (N2) | Dip (N2) | Rake (N2) | Normalized L2 norm (Variance) |
|----------|---------------|---------|-----|-----------|------------|------------|-------------|-----------|-----------|-------------|-----------|-----------|-------------------------------|
| 1        | 20/04/18      | 12:24:20| 1.1 | 7.251     | 109.688    | 1.909      | 321.0       | 67.7      | 6.0       | -2.14       | 5.85      | -3.71     | -3.30                          | 0.07       | -0.48     | 0.5406E+11                   | 0.30      |
| 2        | 20/04/18      | 21:53:50| 1.3 | 7.237     | 109.682    | 4.059      | 307.2       | 89.6      | -55.5     | -0.10       | 6.14      | -6.04     | 7.54                          | -4.90      | 1.12       | 0.1089E+12                   | 0.44      |
| 3        | 21/04/18      | 00:55:15| 1.2 | 7.241     | 109.663    | 4.758      | 133.7       | 45.2      | 22.8      | 3.32        | 3.64      | -6.87     | 4.50                          | 3.91       | 2.09       | 0.8649E+11                   | 0.38      |
| 4        | 21/04/18      | 11:19:28| 3.3 | 7.238     | 109.684    | 3.532      | 300.5       | 62.8      | 116.4     | 1.00        | -1.14     | 0.15     | -0.44                          | 0.64       | 0.13       | 0.1331E+15                   | 0.32      |
| 5        | 21/04/18      | 14:31:34| 0.8 | 7.233     | 109.667    | 2.052      | 114.3       | 87.3      | 36.5      | 0.01        | 1.24      | -1.25     | 1.23                          | -0.29      | 1.10       | 0.2082E+11                   | 0.44      |
| 6        | 21/04/18      | 15:40:08| 1.8 | 7.210     | 109.689    | 4.522      | 316.5       | 47.3      | 126.7     | 4.69        | -3.96     | -0.74     | 1.67                          | 2.60       | 1.75       | 0.5490E+12                   | 0.42      |
| 7        | 21/04/18      | 17:55:28| 2.2 | 7.243     | 109.683    | 3.885      | 150.0       | 78.8      | 42.9      | 0.46        | 1.22      | -1.68     | 1.40                          | -0.99      | -0.69     | 0.2338E+13                   | 0.38      |
| 8        | 21/04/18      | 18:53:05| 1.2 | 7.245     | 109.676    | 3.376      | 321.0       | 62.5      | 85.3      | 1.73        | -0.65     | -1.08     | -0.77                          | 0.77       | 0.45       | 0.1883E+12                   | 0.34      |
| 9        | 21/04/18      | 20:58:40| 0.5 | 7.229     | 109.674    | 4.608      | 324.1       | 14.7      | 115.7     | 4.76        | -1.79     | -2.97     | 6.80                          | -2.90      | 0.59       | 0.8271E+10                   | 0.43      |
| 10       | 22/04/18      | 20:21:14| 1.5 | 7.231     | 109.675    | 3.313      | 291.4       | 69.4      | 83.0      | 0.95        | -1.73     | 0.78     | 1.77                          | 0.87       | 1.71       | 0.2653E+12                   | 0.46      |
| 11       | 23/04/18      | 12:54:05| 1.2 | 7.232     | 109.692    | 6.308      | 346.0       | 50.6      | 150.9     | 3.42        | -2.16     | -1.26     | 4.58                          | 2.84       | 5.00       | 0.7814E+11                   | 0.40      |
Figure 5. The complete output of moment tensor solution of the mainshock in this study (18 April 2018). The main information of source parameters on the top right-hand graph, the black lines and the red lines are observation waveforms and calculation ones, respectively. The numbers below the station code indicate the maximum amplitude (in unit of cm/sec).

The results from investigating the background seismicity in Banjarnegara Region with constrained area proved there were only 47 events from that combined catalog where 125 events by BJI. It showed there were almost a threefold losses in earthquake cataloging by that combined catalog compared to the closest geophysical station (BJI). Then, that seismicity patterns and the two moment tensor catalog which ruptured on 4 April 1992 (Mw 5.0) and 19 April 2013 (Mw 4.9) (Fig.4) carried us to a big question, why the faulting zone still unconfirmed in that area by Indonesian Seismic Sources and Seismic Hazard Maps 2017. As our suggested, it may be encouraged by the slight confirmed event (combined catalog) unable to leading up the comprehensive study while the BJI catalog less reliable as mostly recorded from single station observation.
Figure 6. Results of moment tensor inversion for the event ID 4 (a), the event ID 6 (b), the event ID 9 (c) and the event ID 11 (d) which the most suitable with the mainshock’s moment tensor solution. All annotation in this figure is similar within Figure 5.

The low area coverages around Banjarnegara Region were impacted by the sparse and lack of InaTEWS seismic network configurations which based on the geometry is far enough to that area. This situation was worsened since the BJI (yellow inverted triangle in Fig.4) has stopped working at the end of 2015 then the local observation only from TDS recording. The real-time earthquake monitoring in Central Java for InaTEWS not including data from BJI as yet.
The earthquake epicenter mainly ruptured in the tectonic of North Serayu Basin, in the middle between Pamanukan-Cilacap Fault and Muria-Kebumen Fault [2,3]. The systematic approach of lineament analysis to identify active fault onshore Java had been done [18]. This work was performed generally to figure out the neotectonics of Java and supposed active faults exist within North Serayu Basin but it did not even close to 2018 Kalibening earthquake concentration. A suggestion was denoted that Kalibening earthquake occurred in the Kalibening plateau as tectonically depression caused by the existence of dextral strike-slip faulting of Kalibening-Wanayasa. However, based our results we proposed the 2018 Kalibening earthquake generated by a thrust faulting mechanisms.

The previous study [15] even used information from 134 seismic stations covering a region of about 150 km x 200 km for 150 days in Central Java (MERAMEX project) seemingly did not show any significant results in this study area. As six aftershocks still recorded by BJI single station observation (TDS) after survey (Table 3), we assured that the temporary network should be installed for a longer time maybe for one month. In advising for further quantifying active deformation in North Serayu Basin, some comprehensive study like GPS observation [19], a combination of satellite and field-based geology and geomorphology mapping, paleoseismology and moment tensor analysis can be applied [18].

5. Conclusions

The relocation results showed precisely and refined Kalibening aftershocks distribution that formed a lineation trending northwest-southeast. In further, the cross section shows a slope-shaped which elongated deeper from southwest to northeast with a range of 2-6 km depth. We cannot relocate the mainshock as we found difficulties in finding the event pair for relocating.

We suggested the deformation scheme in the source region of Kalibening earthquake with thrust faulting for 307.5/ 28.8/ 118.5 (Strike/ Dip/ Rake) based on moment tensor inversion. This proposed was supported by aftershock moment tensor inversion and seemingly consistent with aftershocks relocation results. The sparse and lacking of InaTEWS seismic network configurations induced the low area coverages in Banjarnegara region with surrounding area and losses in earthquake cataloging.

As unconfirmed faulting by Indonesian Seismic Sources and Seismic Hazard Maps 2017 related to Kalibening earthquake, we suggested an advising for further quantifying active deformation in North Serayu Basin especially in this study area with a comprehensive study. The occurrence of a damaging earthquake in Kalibening called for the revision of earthquake hazard assessment for Central Java province. The research questions are related to the origin and the level of activity of earthquakes in onshore of Central Java.

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