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Zona Aktif Gempabumi di Sulawesi Tenggara, Berdasarkan Relokasi Hiposenter Menggunakan Metode Double Difference

Earthquake Active Zones in Southeast Sulawesi, Based on Hypocenter Relocation Using Double-Difference Method

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Abstrak. Zona aktif gempabumi dapat diidentifikasi berdasarkan distribusi hiposentrumnya. Terkadang, informasi mengenai kejadian gempabumi harus diberikan sesegera mungkin, sehingga hiposenter gempabumi tidak tepat. Sebuah katalog gempabumi yang telah direlokasi dengan menyertakan gempabumi lokal yang terekam oleh penambahan yang signifikan pada jaringan sensor seismik sangat diperlukan. Relokasi hiposenter gempabumi di Sulawesi Tenggara dilakukan dengan menggunakan metode double difference pada data event gempabumi periode Januari-Desember 2024, untuk menentukan zona aktif gempabumi. Data event gempa pada koordinat 02°45' - 06°15' Lintang Selatan dan 120°45' - 124°30' Bujur Timur. Proses relokasi hiposenter dengan menggunakan program hypoDD dan model kecepatan 1D ak-135, menghasilkan total 277 event gempabumi yang direlokasi menggunakan 21 lokasi sensor pencatat. Hasil relokasi hiposenter gempabumi terlihat jelas pada kejadian gempabumi yang berkumpul (berdekatan). Kedalaman gempabumi setelah relokasi adalah kedalaman dangkal ($h < 60$ km), dengan nilai yang bervariasi, tidak hanya kedalaman 10 km atau lainnya. Pada tahun 2024 terdapat enam zona aktif gempa bumi, yaitu Kabupaten Kolaka, Kabupaten Kolaka Timur, Kabupaten Konawe Selatan, Kabupaten Konawe bagian Selatan, Kota Kendari, Pulau Kabaena, dan satu zona di perairan timur Sulawesi Tenggara (sebelah utara Pulau Wawonii, Kabupaten Konawe Kepulauan).

Abstract. *Earthquake active zones can be identified based on the distribution of their hypocenters. Sometimes, information on earthquake occurrences must be provided as soon as possible, so earthquake* *hypocenters are not precise. A catalog of earthquakes that have been relocated by including local earthquakes recorded by significant additions to the seismic sensor network is needed. Earthquake hypocenter relocation in Southeast Sulawesi was performed using the hypocenter double difference method on earthquake event data from January to December 2024, to determine the earthquake active zones. Earthquake event data at coordinates 02°45' - 06°15' South Latitude and 120°45' - 124°30' East Longitude. The hypocenter relocation process using the hypoDD program and the 1D ak-135 velocity model, produces a total of 277 relocated earthquake events using 21 recording sensor locations. The results of the earthquake hypocenter relocation are clearly visible in the clustered (close together) earthquake events. The depth of the earthquake after relocation is a shallow depth earthquake (h < 60 km), with varying values of depth, not only through fixed depth of 10 km or other. In 2024 there there are six earthquake active zones, including Kolaka Regency, East Kolaka Regency, South Konawe Regency, southern Konawe Regency, Kendari City, Kabaena Island, and one zone in the eastern waters of Southeast Sulawesi (north of Wawonii Island, Konawe Islands Regency).*

1. *INTRODUCTION*

One of the most seismically active regions of Indonesia is Southeast Sulawesi. The high level of seismicity in this area is caused by the presence of faults. According to the findings of the National Earthquake Study Center team, the Southeast Sulawesi region is subject to earthquakes due to seven active faults. Each of these faults can generate earthquakes up to a certain maximum magnitude. The seven faults are the Tolo Rise Fault, the Buton A Fault, the Buton B Fault, the Kendari North Fault, the Kendari Central Fault, the Kendari South Fault, and the Lawanopo Fault. There are also other active faults known as the Lainea and Kolaka faults (Pusgen, 2017).

When there is a major earthquake, people want to know about it because they are fascinated. News of an earthquake is usually announced by the USGS or BMKG on their respective websites or social media accounts shortly after the event. The location, magnitude, and origin time of the earthquake are among the many details that need to be communicated. Because of these requirements, the public must be informed of these criteria as soon as possible. However, the epicenter of an earthquake is often not precisely known. Relocation is necessary because the results of the earthquake catalog hypocenter model sometimes do not match the tectonic conditions, such as an earthquake that is at a fixed depth of 10 km. This depth occurs as a result of the inversion results being trapped in a local minimum caused by a number of factors. The primary wave velocity model used for hypocenter determination in the BMKG catalogue is one of the causes (Jatnika et al., 2015; Naamin et al., 2018; Putra et al., 2019). Several variables, such as network geometry, available phases, accuracy of arrival time measurements and knowledge of crustal structure, affect the accuracy of absolute hypocenter positions (Pavlis, 1986; Gomberg et al., 1990).

The earthquake information released by BMKG, which consists of magnitude and hypocenter parameters, is very good as an earthquake information product and tsunami early warning, because it is in accordance with the 2009 Meteorology, Climatology, and Geophysics Law (MKG), which requires BMKG to release earthquake parameters and tsunami early warnings in under 5 minutes. The information released is very useful for emergency response for relevant stakeholders dealing with natural disasters. The information obtained will assist these agencies in carrying out emergency response operations quickly and accurately.

Accurate earthquake locations are important for understanding earthquake processes (Chang et al 2021). The global catalog of relocated earthquakes (Engdahl et al., 2007) has been used for seismic tomography, b-value, a-value, magnitude completeness, seismic hazard assessment, slab models, and several other advanced tectonic studies in Indonesia (Hayes et al., 2012). The hypocenter model parameters updated in this study are useful for further tectonic and seismicity studies. Seismicity studies have a correlation to positioning of earthquake sources (Jatnika et al., 2015; Sabtaji et al., 2015). Relative relocation techniques like the Double-Difference (DD) method, which use plenty of precise arrival time difference data from waveform correlation analysis, are necessary for a fine picture of seismicity (Matsumoto et al., 2024). The relocated earthquake catalog is also very useful for updating this study with higher spatial resolution, as it includes local earthquakes recorded by significant additions to the seismic sensor network.

A hypocenter relocation study of earthquakes occurring in Sulawesi has been conducted for earthquake event data from 2009 to 2020 (Bidang Informasi Gempabumi dan Peringatan Dini Tsunami-BMKG, 2021). The relocation results show that the Southeast Sulawesi region is one of the low-frequency earthquake clusters, so there has been no further analysis of the activeness of faults in the Southeast Sulawesi region. However, as time goes by, earthquake occurrences in Southeast Sulawesi show an increase in the number of events each year. For example, the number of earthquake events in Southeast Sulawesi in 2024 increased by 5% from the previous year (source: earthquake data catalog of Kendari Geophysical Station-BMKG). Earthquakes are well recorded by seismometer sensors placed by BMKG (Agency for Meteorology, Climatology, and Geophysics) at several locations in Southeast Sulawesi. Geophysical Station Class IV Kendari, as one of BMKG's technical implementation units in Southeast Sulawesi, collects earthquake event data in an earthquake data catalogue. In this study, the relocation of earthquake hypocentres in Southeast Sulawesi was carried out using the hypocenter double difference (hypoDD) method on earthquake event data for the period January to December 2024, to update the catalogue of earthquake hypocenter parameters, so that it can be used to determine the earthquake active zones.

2. *LITERATURE REVIEW*

One of the most commonly used methods for earthquake relocation is the Double-Difference (DD) method (Waldhauser & Ellsworth, 2000), and previous studies in the region (Yoshida et al., 2023a and b; Kato et al., 2024) and other regions around the world (Naoi et al., 2015; Ruhl et al., 2016; Ross et al.,2017; Yoshida & Hasegawa, 2018; De Barros et al., 2019; Hatch et al., 2020) have employed this method. The double difference technique exploits the fact that the raypaths between the source region and a common station are similar along almost the entire raypath when the hypocentral separation between two earthquakes is small relative to the event-station distance and the scale length of velocity heterogeneity (Got et al., 1994). In this case, the spatial offset between the events can be used accurately to explain the difference in transit times for two events observed at a single station. The double-difference algorithm minimizes errors due to unmodeled velocity structure without the use of station corrections (Waldhauser and Ellsworth., 2000).

The hypoDD program used to relocate the hypocenter of the Southeast Sulawesi earthquake is the hypoDD version 1.0, by Waldhauser F, 2001. HypoDD determines travel time durations for the present hypocenters at the station where the phase was recorded using a layered velocity model, in which velocity alone relies on depth. Using either the conjugate gradients approach LSQR (Paige and Saunders, 1982) or the singular value decomposition (SVD) method, weighted least squares minimizes the double-difference residuals for earthquake pairings at each station. The locations and partial derivatives are changed after each iteration, which iteratively modifies the vector difference between neighboring hypocentral pairs to find solutions. Provide specifics on the algorithm (Waldhauser and Ellsworth, 2000).

Double-Difference (DD) was created based on the observation that the wave ray trajectory patterns of two recorded earthquakes will be identical if the hypocenter distribution distance between two earthquakes is significantly smaller than the distance between the observing stations and the two earthquake hypocenters (Hijriani et al., 2017; Supendi et al., 2019). As a result, the distance between the two hypocenters can be used to calculate the difference in travel time between the two earthquakes recorded at the same station. Relocating the location of the earthquake source is required to acquire more precise and accurate earthquake information characteristics, like the hypocenter and epicenter, to comprehend and research the tectonic conditions in a given area (Syafriani et al., 2023).

The Geiger principle, which underlies the inversion approach used to determine earthquake sites, is the foundation of the Double-Difference methodology (Geiger L, 1912). The travel time data of earthquake waves from the epicenter to the station is calculated to estimate the location of the earthquake using inversion modeling. Once the residual value - the difference between the observation value and the modeling value - is determined, the outcomes of this computation of the travel time data are compared and iterated. To "linearize" the nonlinearity by using the first term of the Taylor series, the Geiger principle was developed.

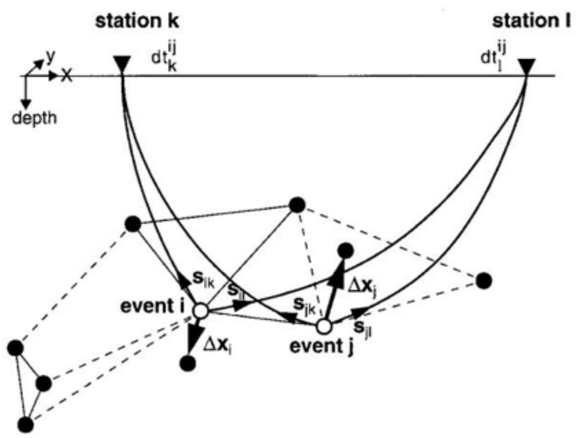


Figure 1: Illustration of the Double-Difference method (Waldhauser and Ellsworth, 2000).

For the double-difference method of linking earthquake events, the residual equation cannot be used directly. The equation must be modified to obtain the relative hypocenter parameter between two earthquake events (Waldhauser and Ellsworth, 2000). The Double-Difference method has several advantages over other approaches for earthquake relocation, including the fact that it does not require station correction parameters, unlike the JHD method, and that it is especially helpful in regions with a high seismicity level where hypocenters are close to one another. Before relocation with Double-Difference, the epicenter is still scattered and unfocused, making it difficult to delineate the fault zones. However, after relocation with Double-Difference, the epicenter tends to be focused and centered to form a linear-zones that is easier to identify as a fault system.

Selecting more waveform phases, like the depth phases, could improve the constraint of event depths and the absolute hypocenter positions (Weston et al., 2018), although the implementation of more complex algorithms, such as the double-difference method, could enhance the relative hypocenter placements between earthquakes. The double-difference approach enables the use of any combination of high-precision differential journey durations from phase correlation of P- and/or S-waves (cross-correlation data) and/or regular phase picks from earthquake catalogs (referred to as catalog data below).

3. *METHODS*

Earthquake hypocenter relocation uses earthquake event data that occurred in the Southeast Sulawesi region at coordinates 02°45' - 06°15' South latitude and 120°45' - 124°30' East longitude, recorded in the earthquake data catalogue of BMKG - Geophysical Station Class IV Kendari, from January to December 2024. The earthquake data catalog used consists of parameters such as origin time, magnitude, epicenter location (latitude and longitude), depth, arrival time of earthquake waves recorded at each recording sensor site, and distance between the recording sensor site and the earthquake epicenter. Earthquakes that occur in the Southeast Sulawesi region are recorded by seismic sensors located in Southeast Sulawesi and South Sulawesi.

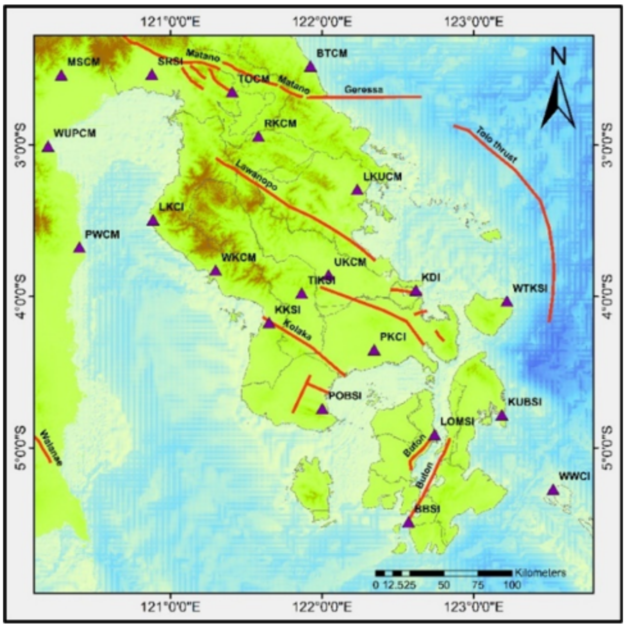


Figure 2: The box in the image is the location of the earthquake that will be relocated. The purple triangle is a seismic sensor that records earthquakes in Southeast Sulawesi. (source: Geophysical Station Class IV Kendari - Agency for Meteorology, Climatology, and Geophysics Indonesia).

Table 1. Sensor site codes that record earthquake events in the Southeast Sulawesi Region.

No	Site Code	Location Remarks
1	KDI	Kendari City
2	KKSI	Kolaka, Kolaka
3	LKCI	Lasusua, North Kolaka
4	LKUCM	Langgikima, North Konawe
5	PKCI	Palangga, South Konawe
6	POBSI	Poleang, Bombana
7	TIKSI	Tinondo, East Kolaka
8	WWCI	Wang-Wang, Wakatobi
9	BBSI	Baubau City
10	LOMSI	Lohia, Muna
11	KUBSI	Kulisusu, North Buton
12	UKCM	Unaaha, Konawe
13	WKCM	Wolo, Kolaka
14	WTKSI	Wawonii Timur Laut, Konawe Island
15	PWCM	Pitumpanua, South Sulawesi
16	MSCM	Masamba, North Luwu
17	RKCM	Routa, Konawe
18	SRSI	Soroako, East Luwu
19	TOCM	Towuti, East Luwu
20	WUPCM	North Wara, South Sulawesi
21	BTCM	Central Bungku, Morowali

There are two steps involved in earthquake relocation with hypoDD. The first step is to determine the variations in travel times for earthquake pairings by analyzing the phase and/or waveform data (ph2dt program). To reduce repetition in the data collection and maximize the connection between the events, the data must be screened. The second step involves locating double-difference hypocenters using the differential travel time data from step one. After ensuring that there are no weak points in the network of vectors connecting each earthquake to its neighbours that could cause numerical instabilities, the procedure performed by hypoDD solves for hypocentral separation. As with any least squares process, the hypoDD-derived solution must be evaluated closely, and the findings must not be accepted without question. The double-difference approach is implemented in the computer program hypoDD, which has been thoroughly evaluated using data from aftershock arrays and permanent networks worldwide. In each case examined, the algorithm has shown that it can improve the seismicity image.

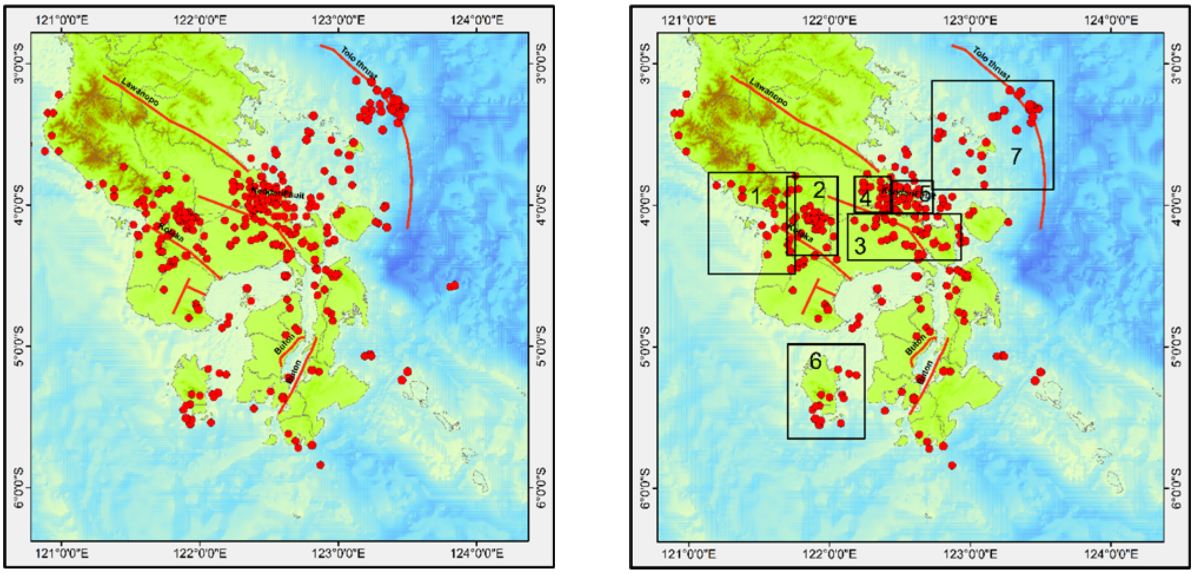
The hypoDD approach was used to hypocenter the relocation of seismic occurrences in Southeast Sulawesi based on the data catalog of Geophysical Station Class IV Kendari for one years, from January to December 2024. Travel time differences for earthquake pairs at common stations are the basic data used in hypoDD. These data can be retrieved from waveform cross correlation (Poupinet et al., 1984) or earthquake catalogs, which are supplied by nearly all seismic networks. To maximize connectivity between events and guarantee the stability of the least squares solution, travel time differences for pairs of events are necessary in both situations. To maximize the quality of the phase pairs and the connectivity between the events, ph2dt looks for event pairs containing travel time information at common stations in the catalog's P-phase and S-phase data and subsamples these data.

Some of th value conditions used in the ph2dt program to analyze the Southeast Sulawesi earthquake data. The output from ph2dt will be used as input to the hypoDD program. The seismic wave velocity model used the 1D ak-135 velocity model (Kennett et al., 1995; Arimuko et al., 2020), with a number of layers (NLAY) of 5 layers, and the vp/vs velocity ratio is 1.75 (Bormann et al., 2012). Using these parameter values and a set of 3 iterations, there are 44 clusters of relocation processes.

4. *RESULTS AND DISCUSSION*

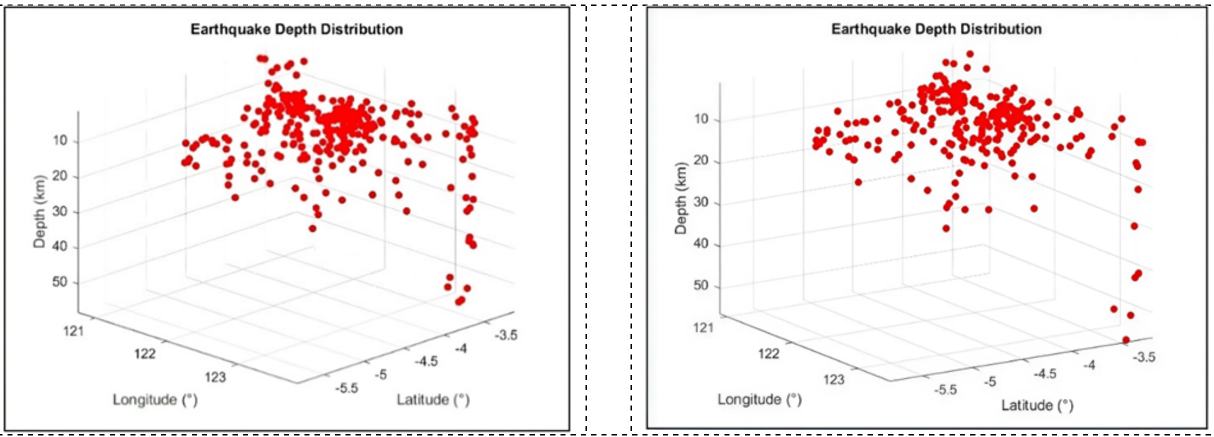
The hypocenter relocation process using the hypoDD program produces a total of 277 relocated earthquake events with 21 recording sensor locations. **Figure 3** is a map of the distribution of earthquake epicenters (colored circles) in the Southeast Sulawesi region before relocation (a) and after relocation (b). In mapping the epicenter of an earthquake, the depth of the earthquake is indicated by different colored circle. Red circles indicate shallow depth earthquakes ($h < 60$ km), yellow are medium depth earthquakes (60 km $\leq h <$ 300 km), and green are deep depth earthquakes ($h \geq 300$ km). The red lines on the map represent active fault that are scattered in several areas in the Southeast Sulawesi region.

Earthquakes occur in almost all districts/cities, with low to high frequencies. Areas that were previously unmapped for earthquake occurrence have now begun to be recorded and mapped, indicating that there are quite several locally active faults. The earthquake occurrence map after relocation (**Figure 3(b)),** or commonly referred to as the seismicity map, shows that there are six earthquake active zones, including Kolaka Regency (box number 1), East Kolaka Regency (box number 2), South Konawe Regency (box number 3), southern Konawe Regency (box number 4), Kendari City (box number 5), Kabaena Island (box number 6), and one zone in the eastern waters of Southeast Sulawesi (north of Wawonii Island, Konawe Islands Regency), which is in box number 7. This earthquake active zones is an area of earthquake occurrence where the epicenters of earthquakes are close to each other and occur in large numbers. The large number of earthquakes that occur in a zones/region is something to be grateful for, meaning that the stored energy has been released gradually.



(a) (b)

Figure 3: Map of earthquake epicenter distribution in Southeast Sulawesi (a) before relocation (b) after relocation. The black line box is the zone of the region identified as an active earthquake zone.



(a) (b)

Figure 4: 3D view of earthquake depth variations in Southeast Sulawesi (a) before relocation (b) after relocation.

The precise hypocenter relocation results revealed that seismicity moved from deep to shallow via multiple planar structures (Yoshida et al., 2023a and b; Kato et al., 2024). The hypocenter relocation results show that the earthquake that occurred in the Southeast Sulawesi region was a shallow earthquake (**Figure 4**). This is consistent with the results of Hutchings and Mooney's research, 2021, location and depth have significant impact on seismic activity. The most important findings of seismicity rates in relation to depth can be summed up as according to worldwide seismicity rate-depth distributions derived by Frohlich (2006), seismicity is most common at depths ≤ 40 km. Seismicity maxima in 0-10 km and 30-40 km, however, might represent poorly resolved places with default depths of 10 and 33 km. Despite this, it is generally known that majority as seismicity worldwide resides within the brittle crust (Zhan, 2020), which in Indonesia can be up to 42 km thick (Ali and Suardi, 2018), is where most seismicity occurs globally.

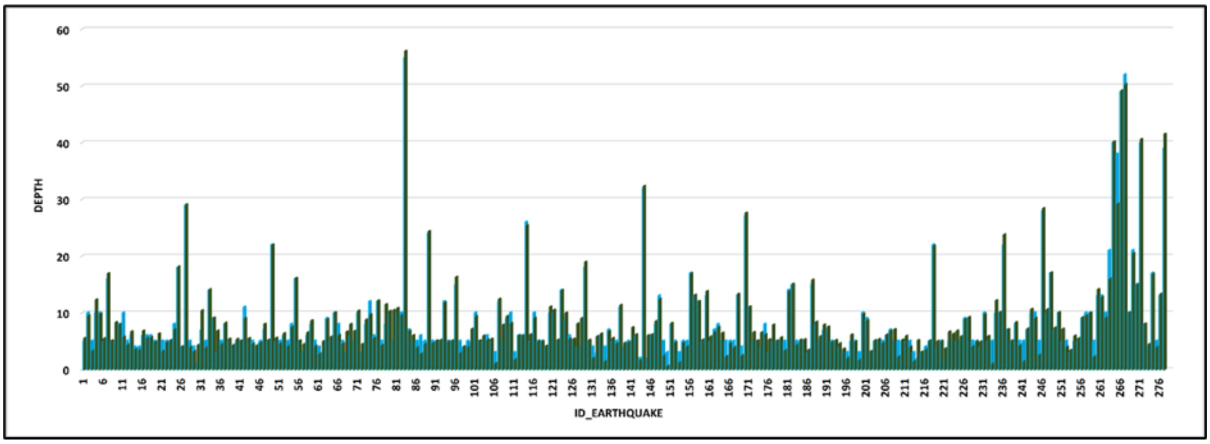


Figure 5: Graph of the difference in earthquake depth values before relocation (blue) and after relocation (green).

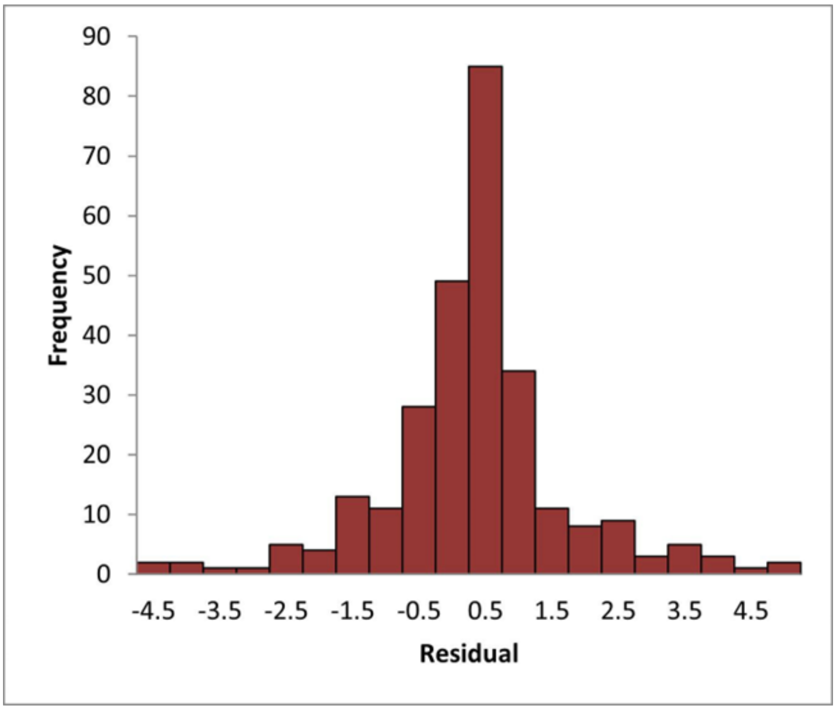


Figure 6: Histogram of the residual earthquake depth values between before and after relocation.

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SeiscomP4 serves as a data acquisition system for obtaining earthquake event parameters. The resulting earthquake depth parameters often use a fixed depth of 10 km, so hypocenter relocation is necessary to obtain varying earthquake depths. **Figure 5** shows the difference in earthquake depth values between the results of the Seiscomp4 analysis and the results of hypocenter relocation using the hypoDD method. The relocation of earthquake hypocenters in the hypoDD programme is done by a trial-and-error process, so that the residual earthquake depth is minimised (close to zero). **Figure 6** shows a histogram of the residual earthquake depth values between before and after relocation. The resulting residual values are close to zero, indicating that the earthquake depth values after relocation are precise.

According to later field research, Sulawesi's geology is the result of several tectonic processes, including collision, rifting and accretion, oceanic basin opening and closing, subduction, and extension (Zhang et al., 2020). The Southeast Arm Sulawesi is underlain by Mesozoic sedimentary, Paleogene ultrabasic, basic, metamorphic rocks and Paleogene carbonates (Nugraha et al., 2022). Kolaka Regency is one of the earthquake active zones due to the Kolaka Fault that crosses the region. Earthquakes in the South Konawe region are caused by the Lainea Fault, Kendari Central Fault, and Kendari South Fault. Earthquakes that occur in the southern part of Konawe Regency and Kendari City are due to the activity of the Kendari North Fault. Earthquakes in the Eastern Waters of Southeast Sulawesi are dominantly located on the Tolo Thrust Fault, as well as the suspicion of locally active faults in East Kolaka Regency and Kabaena Island, which causes the high frequency of earthquakes in these two areas. Other districts, despite the low frequency of earthquake occurrence, also need to be considered, because it is interpreted that almost all areas of Southeast Sulawesi have local active faults, such as North Buton Regency, West Muna Regency, and South Buton Regency.

During 2024, a cluster of earthquakes on the Tolo Thrust Fault occurs starting in early April 2024. An earthquake consists of several earthquakes of similar magnitude, one after the other, in succession at one time, without a clear main shock. Earthquakes that occur in groups and continuously without a main earthquake are said to be swarm earthquakes (such swarm activity usually starts without a clear seismic signal, lasts for days, months, and even years, and is often seen in volcanic and geothermal areas and around anthropogenic fluid injection wells). If we look at the phenomenon of earthquake occurrence in the North Banda Sea region, it cannot be said to be a swarm earthquake because there is no volcanic activity in the region. The cause of a group of non-volcanic earthquakes in this region must be understood in terms of the geological structure, geophysical anomalies, and the tectonic order that develops in the North Banda Sea waters (Pertiwi et al., 2024).

The geological structure of the North Banda Sea waters consists of granitic crust and basalt crust. At the meeting between granitic and basal crusts, the granitic crust thins and splits/stretches, forming a contact in the form of a stepping fault against the North Banda Sea crust. This thrust fault is known as the Tolo Thrust, which is in the North Banda Sea. The basement crust that underlies the North Banda Sea area is curved, thinned, and forms a compartmentalized structure due to the sinking of the remaining crust of the Molucca Sea. The curving of the North Banda Sea crust causes the development of stresses and strains in the crustal body, creating opportunities for incisions and fractures that trigger the flow of liquid or semi-molten material from the top of the envelope to the surface of the seafloor. High gravity anomalies in the North Banda Sea waters indicate the distribution of micro-faults in the region (Surono et al., 2013).

Many earthquakes also occur in Kendari City and South Konawe. The earthquakes that occur are not near each other but are in the Lawanopo Fault and Kendari Fault. The Kendari Fault is divided into three segments, namely the northern, central, and southern segments. The three fault segments are active faults. Earthquakes in South Konawe Regency are caused by the Lainea Fault, whereas those in Kolaka Regency are caused by the Kolaka Fault. The mechanism of movement of these faults is strike-slip. The Buton Segment B Fault and Segment A Fault also contribute to earthquakes in Buton Island and Muna Island (Pusgen, 2017).

High seismicity leads to high hazards in areas far from known faults (Cipta et al., 2016), such as Bombana Regency, Kabaena Island, and East Kolaka Regency, which also experienced high-intensity earthquake events between January and December 2024. Malolite or metamorphic rocks dominate the Bombana to Kabaena Island region's geological structure. Mafic rocks are those that were created by extreme heat or pressure. Metamorphic rocks are another name for Malihan rocks. These rocks go through a metamorphosis process that creates a new rock with a different structure. Igneous or sedimentary rocks that were subjected to high temperatures and pressures were the precursors of malleable rocks. The location, minerals that develop, temperature and pressure, and earthly events all influence the creation of malachite rocks. When two huge boulders collide and rub against one another, heat is generated between the two rocks, forming the structure of calcic malachite rocks. This friction may arise because of a fold or defect. The primary structures created by tectonic forces are folds and faults.

The fact that Bombana and Kabaena Island are composed of malachite/metamorphic rocks suggests that the region is subject to strong tectonic forces, such as high temperatures and pressures, which have led to the formation of numerous faults and microfolds. The major earthquakes felt by the population are caused by the development of faults and micro-faults in this area (Pertiwi et al., 2023). The Bombana Regency area contains smaller geologic features or local geologic structures. There are three minor local faults in Bombana Regency, which is situated at the southern end of the Southeast Sulawesi Arm: the Mateupe, Lameroto, and Lemo faults (Surono et al., 2013). These three faults are believed to be horizontal thrust faults since they strike northwest-southeast and are comparatively parallel to the major fault in this arm.

Geological conditions in the Buton Island Waters based on the results of shallow reflected seismic recordings show that in the southern part of Buton Island with the direction of the southwest - northeast, northwest-southeast track has a depth of 600 meters, and the morphology of the seabed is undulating and there are rather prominent elevations. In this situation it can be observed that the tectonic process is active and strong enough to affect the formation of geological structures in the form of faults, folding, uplift, and instrusion (Arifin et al., 2015). In the east-west traverse direction, there is a basin containing thick sediments in the eastern part. To the southwest of the basin, there is also an elevation that is thought to be the continuation of many small islands around southern Buton Island. This trajectory is also thought to still be influenced by active tectonic phenomena. It is important to know the active zones of earthquakes, as a reference for preparedness and awareness of mitigation measures and self-evacuation.

5. *CONCLUSION*

The relocation of earthquake hypocenters in the Southeast Sulawesi region results in a change in depth parameters. The depth of the earthquake after relocation is a shallow depth earthquake ($h < 60$ km), with varying values of depth, not only through fixed depth of 10 km or other, which is done based on observation results in SeiscomP4. The residual depth value between before and after of the relocation results is close to zero, so that the earthquake depth parameter becomes more precise. After relocation, the distribution of earthquake epicenters is spread almost throughout Southeast Sulawesi. The earthquake that occurred in the Southeast Sulawesi region was a shallow earthquake. During 2024, there are six earthquake active zones, including Kolaka Regency, East Kolaka Regency, South Konawe Regency, southern Konawe Regency, Kendari City, Kabaena Island, and one zone in the eastern waters of Southeast Sulawesi (north of Wawonii Island, Konawe Islands Regency).

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