A 51 cm tsunami amplitude was observed in Tehoru, Seram Island (Indonesia), following an $M_w$ 5.9 earthquake. Such a relatively large tsunami is highly unexpected from this size earthquake. Our analyses showed that the tsunami was 15 times larger in Tehoru tide gauge station than that recorded on two other stations located nearby. These observations imply that the tsunami was most likely generated by a secondary source such as a submarine landslide that potentially occurred near Tehoru. Local people reported landslide activities around Tehoru following the earthquake. We conducted numerical modeling of the tsunami by considering the tectonic source and found that the resulting tsunami was only a few centimeters in Tehoru. Therefore, it is very likely that the earthquake was not responsible for the tsunami observed in Tehoru. By assuming that a submarine landslide was responsible for the tsunami, we applied spectral analysis and tsunami backward raytracing to gain information about the potential size and location of the landslide. Backward raytracing was also applied to identify the earthquake source of the tsunami. Numerical modeling of eight candidate landslide scenarios showed that a landslide with a length and a thickness of approximately 4 km and 50 m, respectively, was potentially responsible for the tsunami. We note that our results serve only as the first and preliminary estimates. Bathymetric surveys and high-resolution bathymetry data are essential to provide more detailed information about the landslide.

**KEY POINTS**

- The 51 cm tsunami in Tehoru in June 2021 cannot be reproduced by a model of an $M_w$ 5.9 earthquake source.
- Spectral analyses of tsunami and backward tsunami raytracing informed about size and location of the landslide.
- Tsunami in Tehoru was likely generated by a submarine landslide with a length of 4 km and thickness of 50 m.

**INTRODUCTION**

A mysterious tsunami was observed at the southern coast of the Seram Island in Eastern Indonesia on 16 June 2021 following an $M_w$ 5.9 earthquake (Fig. 1). According to the U.S. Geological Survey (USGS), the earthquake occurred at 04:43:07 UTC, its epicenter was at 129.524° E and 3.558° S, and the earthquake depth was 7.0 km. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) reported the magnitude as M 6.0, the origin time at 04:43:08.335 UTC, the epicenter at 129.52° E and 3.558° S, and a depth of 11 km. According to Global Centroid Moment Tensor (Global CMT) catalog, the earthquake parameters are $M_w$ 5.9, origin time 04:43:10.0 UTC, epicenter 129.55° E and 3.39° S, and depth 14.3 km (Fig. 1c). Table 1 provides a summary of the earthquake's epicentral data from different agencies. The epicenter locations reported by different agencies are up to approximately 20 km distant from one another (Fig. 1c; Table 1). The earthquake was the result of a normal faulting with USGS focal mechanism of 27° (strike angle), 34° (dip angle), and −98° (rake angle) (Table 1). Some buildings sustained damage because of the earthquake, but no deaths and injuries were reported. A 51 cm tsunami amplitude was reported following the earthquake in Tehoru, located approximately 20 km from the USGS epicenter.
epicenter and less than 5 km from the BMKG and Global CMT epicenters (Fig. 1c). In general, such a relatively large tsunami is highly unexpected from an $M_w$ 5.9 normal-faulting earthquake; experience from past events indicates that the potential tsunami from an $M_w$ 5.9 event would be either unnoticeable or would achieve a few centimeters in amplitude at maximum.

The 16 June 2021 $M_w$ 5.9 earthquake occurred within the rather complex tectonic setting of Eastern Indonesia (Fig. 1; Pairault et al., 2003; Gusman et al., 2009; Spakman and Hall, 2010; Fisher and Harris, 2016; Patria and Hall, 2017; Watkinson and Hall, 2017; Heidarzadeh et al., 2021; Patria et al., 2021; Pranantyo et al., 2021). Major tectonic features around the epicenter are the Seram trough to the north and Banda Arc (inner and outer) and Weber Deep to the south of the epicenter (Fig. 1). These tectonic features show complex behavior, and controversies have surrounded their origins and seismic behavior (Hall et al., 2017; Patria and Hall, 2017). In terms of seismic activities, the region experienced devastating earthquakes and tsunamis, among which are the major events in 1629, 1674, 1852, and 1899 (Wichmann, 1918; Berninghausen, 1966; Latief et al., 2000; Brune et al., 2010; Liu and Harris, 2014; Fisher and Harris, 2016; Cummins et al., 2020; Pranantyo and Cummins, 2020). The source regions and detailed impacts of many historical events in this region are not known due to the lack of instrumental data and paucity of historical records. This highlights the importance of instrumental records of tsunamis in the Banda region and is a motivation to conduct this study.

The purpose of this research is to explain the generation mechanism of the 16 June 2021 tsunami following an $M_w$ 5.9 earthquake. Because it is highly unlikely that the earthquake alone was the source of the 51 cm tsunami observed in Tehoru, here we examine potential submarine landslide

**Figure 1.** (a) The map of Eastern Indonesia showing the epicenter of the $M_w$ 5.9 earthquake (pink star) on 16 June 2021, tide gauge stations analyzed in this study (green squares), and tsunami travel time (TTT) contours in minutes (dashed lines) with 15 min intervals. For the TTT analysis in this figure, it is assumed that the earthquake was the source of the tsunami. (b) The map of southeast Asia showing the location of the epicenter relative to the region. (c) The TTT contours for areas around the epicenter with 1 min intervals by assuming that the U.S. Geological Survey (USGS) earthquake was the source of the tsunami. The data of epicenter are based on the earthquake catalogs of the USGS, the Global Centroid Moment Tensor (Global CMT), and the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). The focal mechanism is based on the USGS. The color version of this figure is available only in the electronic edition.
sources of the event and confirm them through numerical simulations and validation with actual tsunami records. Fourier and wavelet analyses are performed to characterize the tsunami waves and approximate the dimension of the tsunami source area. Backward tsunami raytracing is applied to gain information about the potential location of the landslide.

**DATA AND METHODS**

Thirteen tide gauge records were examined in this study to trace the effects of the June 2021 tsunami across the Banda Sea region (Fig. 1, squares). All tide gauge records have a sampling interval of 1 min and are maintained by the Indonesian Geospatial Information Agency. The data underwent a quality control procedure. The tidal waves were estimated by the polynomial fitting of the original records and then were removed from the records. We observed clear tsunami signals only in three tide gauge stations of Tehoru, Amahai, and Banda with respective maximum tsunami zero-to-crest amplitudes of 51 cm, 2 cm, and 3.4 cm, respectively (Fig. 2). The tsunami travel times (TTTs) to these stations are 2 min (Tehoru), 14 min (Amahai), and 18 min (Banda) (Fig. 2). Analyses of the other 10 tide gauge records revealed that no clear tsunami signal was identified in them (Fig. S1, available in the supplemental material to this article).

Fourier analysis is conducted using an updated version of the Welch algorithm, which is based on computation of a modified periodogram for segments of waveforms followed by averaging these estimates to produce the power spectral density (Welch, 1967; Heidarzadeh and Satake, 2015a; Mathworks, 2021). Approximately 4–5 hr of background and tsunami time series (equivalent to 240–300 data points) from before and after tsunami arrival at each station were used for Fourier analysis considering Hanning windows and 50% of overlaps of time windows. Wavelet analysis is applied in this research to study the temporal variations of tsunami dominant periods. We used the wavelet package developed by Torrence and Compo (1998) considering Morlet wavelet function. Wavelet and Fourier analyses were conducted using the detided waveforms. TTT analysis was performed using the TTT code provided by Geoware (2011).

The Cornell Multi-grid Coupled Tsunami model numerical package is applied for tsunami simulations (Liu et al., 1998; Wang and Liu, 2006), which solves linear and nonlinear shallow water equations in cartesian and spherical domains. Bathymetry data are based on the 2020 version of the General Bathymetric Chart of the Oceans (GEBCO) digital atlas (Weatherall et al., 2015), which has a spatial resolution of 15 arcsec. Here, we resampled the original GEBCO grids into a single uniform grid with the spatial resolution of 3 arcsec for our tsunami simulations. A timestep of 0.25 s is used for simulations to satisfy the stability condition of finite elements simulations based on the Courant number criterion, also known as the Courant–Friedrichs–Lewy condition (Courant et al., 1928).

For modeling the tsunami generated by the earthquake source, we calculated the coseismic seafloor deformation employing the elastic dislocation model of Okada (1985) and using the fault parameters reported by the USGS for this earthquake (Table 2). The calculated coseismic seafloor deformation is considered as the initial condition for modeling tsunami propagation and coastal amplification. Four single fault models based on nodal planes (NPs) calculated by the USGS were considered to simulate the tectonic tsunami. Two of these models have a depth of 10.0 km (models NP1, eastward dipping; and model NP2, westward dipping), whereas the other two models (models NP1S and NP2S) have similar fault parameters as NP1 and NP2 except for their focal depth, which is shallower (depth of 4.0 km) (Table 2). The rationale for considering the two shallow models was to study the sensitivity of our results to earthquake depth and examine whether a shallower focal depth could reproduce the observed tsunami. To estimate the length and width of the fault, we used the scaling relations of Blaser et al. (2010), which correlate fault length ($L$) and width ($W$) with the moment magnitude of the earthquake ($M_w$) using the following equations:

$$\log L = -1.91 + 0.52M_w,$$  \hspace{1cm} (1)

$$\log W = -1.20 + 0.36M_w.$$  \hspace{1cm} (2)
in which $L$ and $W$ must be inputted in kilometers. Figure 3a shows the crustal deformation resulting from the aforementioned four fault models (i.e., NP1, NP2, NP1S, and NP2S).

For modeling landslide tsunamis, we applied a trial-and-error approach by considering eight submarine landslide scenarios (Table 3). Our scenarios are designed based on estimating the dimensions of the landslide source from the dominant period of the tsunami by following the approach developed by Heidarzadeh and Satake (2015b). This method is further discussed in the next section. We consequently applied the semi-empirical equations of Watts et al. (2005) to estimate the initial sea surface displacement due to landslides, which is considered as the initial condition for tsunami modeling. For all scenarios, some landslide parameters are fixed such as travel distance $2000$ m and density $2000$ kg/m$^3$. The equations of Watts et al. (2005) were successfully used by several authors for modeling landslide tsunamis in the past (e.g., Synolakis et al., 2002; Satake and Tanioka, 2003; Tappin et al., 2008; Heidarzadeh and Satake, 2015a, 2017).

The misfit between tsunami observations and calculations are calculated using the following equation:

$$
\epsilon = \frac{\sum_{i=1}^{N}(\text{Obs}_i - \text{Sim}_i)^2}{N},
$$

in which $N$ is the total number of waveform points, $i$ is a counter of the waveform points ($i = 1,2,3,\ldots, N$), Obs$_i$ is an observation point, and Sim$_i$ is the corresponding simulation point. For the case of a perfect match, in which simulations coincide with observations, $\epsilon$ takes a value of zero; otherwise it increases by an increase in deviations between observations and simulations. The better the match between observation and simulations, the smaller the value of $\epsilon$ will be. We used a few first waves after tsunami arrival for misfit calculations. To optimize misfit calculations, limited adjustments (1–2 min) for timing of the simulations are made to match the first arrivals of the observations.

**NUMERICAL SIMULATIONS OF TSUNAMI FROM THE EARTHQUAKE SOURCE**

Figure 3 presents the results of crustal deformation calculations (Fig. 3a) and tsunami simulations (Fig. 3b) from the four earthquake sources listed in Table 2. The simulated tsunami waveforms from the eastward-dipping (NP1) and westward-dipping (NP2) models are significantly smaller than those of observations at the Tehoru tide gauge station. However, the simulated tsunami amplitudes from both models are closer to

![Figure 2. Tsunami waveforms at three tide gauge stations that clearly recorded the 16 June 2021 Seram Island tsunami. (a) Original tide gauge records, and (b) detided tsunami waveforms. The red vertical dashed lines represent the time of the earthquake. See Figure 1 for the locations of the tide gauges. The color version of this figure is available only in the electronic edition.](http://pubs.geoscienceworld.org/ssa/bssa/article-pdf/doi/10.1785/0120210274/5672774/bssa-2021274.1.pdf)
the observations at Amahai and Banda tide gauge stations. There is no major improvement of waveform match at Tehoru station from the two additional shallow models (NP1S and NP2S; Fig. 3b).

The simulation results imply that an additional tsunami source (also known as a secondary tsunami source) was likely involved in the generation of the large tsunami in Tehoru. A likely candidate secondary source could be a submarine landslide, triggered by the earthquake, that potentially occurred near the Tehoru station. As the amplitude of the observed tsunami in Tehoru tide gauge is at least 15 times larger than those in Amahai and Banda stations, it is most likely that the submarine landslide occurred close to the Tehoru station. This theory is also supported by the short TTT of 2 min for the Tehoru station, which is recorded by the actual tsunami observation at this tide gauge station (Fig. 2). According to the TTT analysis in Figure 1c based on the USGS epicenter, if the earthquake was the main source of the tsunami in Tehoru, the TTT to the Tehoru station must have been 5 min. The hypothesis of the occurrence of a submarine landslide is further explored and modeled in the following sections.

**SPECTRAL ANALYSES AND ESTIMATING TSUNAMI SOURCE DIMENSION**

Results of spectral analyses (Fourier and wavelet) are shown in Figure 4. Background spectrum refers to the spectrum for part of the waveform before the arrival of the tsunami in a tide
This may indicate that the earthquake source of the tsunami is closer to the Banda tide gauge station compared to the landslide source of the tsunami.

By considering that the tsunami signal generated by the submarine landslide had a dominant period of 3.1–4.8 min, we can estimate the dimension of the initial sea surface displacement ($L$) generated by the submarine landslide through applying the following equation (Heidarzadeh and Satake, 2015b; Heidarzadeh et al., 2020):

$$L = \frac{T}{2} \sqrt{gd}, \quad (4)$$

in which $T$ is the dominant tsunami period for the LS ($T = 3.1–4.8$ min), $g$ is the gravitational acceleration ($g = 9.81 \text{ m/s}^2$), and $d$ is the water depth around the landslide ($d = 400–500$ m). By inputting the aforementioned values into equation (4), the dimension of the initial sea surface displacement ($L$) becomes $L = 5.8–10.1$ km. It is noted that $L$ in equation (4) is not the length of the submarine landslide (as listed in Table 2), but it is the possible length of the initial sea surface displacement generated by the landslide.

**BACKWARD TSUNAMI RAYTRACING**

Backward raytracing has been successfully used in the past to locate submarine landslides or to determine the extension of

---

**TABLE 2**

Earthquake Fault Parameters for Four Fault Scenarios Considered for Modeling the 16 June 2021 Seram Island Tsunami Based on the USGS Focal Mechanism Solution

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Length (km)</th>
<th>Width (km)</th>
<th>Strike (°)</th>
<th>Dip (°)</th>
<th>Rake (°)</th>
<th>Depth (Center, km)</th>
<th>Slip (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP1</td>
<td>14.0</td>
<td>8.0</td>
<td>27</td>
<td>34</td>
<td>−98</td>
<td>10.0</td>
<td>22</td>
</tr>
<tr>
<td>NP2</td>
<td>14.0</td>
<td>8.0</td>
<td>217</td>
<td>57</td>
<td>−85</td>
<td>10.0</td>
<td>22</td>
</tr>
<tr>
<td>NP1S</td>
<td>14.0</td>
<td>8.0</td>
<td>27</td>
<td>34</td>
<td>−98</td>
<td>4.0</td>
<td>22</td>
</tr>
<tr>
<td>NP2S</td>
<td>14.0</td>
<td>8.0</td>
<td>217</td>
<td>57</td>
<td>−85</td>
<td>4.0</td>
<td>22</td>
</tr>
</tbody>
</table>

The fault models are NP1, eastward dipping; NP2, westward dipping; NP1S, shallow eastward dipping; NP2S, shallow westward dipping.

---

**TABLE 3**

Parameters of Landslide Scenarios for Modeling the Landslide Source of the 16 June 2021 Seram Island Tsunami

<table>
<thead>
<tr>
<th>Name</th>
<th>Long. (°)</th>
<th>Lat. (°)</th>
<th>Water Depth (m)</th>
<th>Slope (°)</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Thick. (m)</th>
<th>Max. Initial Depr. (m)</th>
<th>Max. Initial Elev. (m)</th>
<th>Misfit*</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS1</td>
<td>129.70</td>
<td>−3.35</td>
<td>500</td>
<td>10</td>
<td>5000</td>
<td>5000</td>
<td>50</td>
<td>−0.5</td>
<td>0.4</td>
<td>0.130</td>
</tr>
<tr>
<td>LS2</td>
<td>129.70</td>
<td>−3.33</td>
<td>500</td>
<td>20</td>
<td>3000</td>
<td>5000</td>
<td>70</td>
<td>−2.1</td>
<td>1.7</td>
<td>0.225</td>
</tr>
<tr>
<td>LS3</td>
<td>129.70</td>
<td>−3.33</td>
<td>500</td>
<td>20</td>
<td>4000</td>
<td>4000</td>
<td>70</td>
<td>−1.3</td>
<td>1.1</td>
<td>0.178</td>
</tr>
<tr>
<td>LS4</td>
<td>129.65</td>
<td>−3.33</td>
<td>400</td>
<td>20</td>
<td>3000</td>
<td>5000</td>
<td>70</td>
<td>−3.4</td>
<td>2.4</td>
<td>0.496</td>
</tr>
<tr>
<td>LS5</td>
<td>129.68</td>
<td>−3.33</td>
<td>400</td>
<td>20</td>
<td>3000</td>
<td>5000</td>
<td>50</td>
<td>−1.6</td>
<td>1.2</td>
<td>0.233</td>
</tr>
<tr>
<td>LS6</td>
<td>129.70</td>
<td>−3.33</td>
<td>500</td>
<td>20</td>
<td>4000</td>
<td>4000</td>
<td>50</td>
<td>−0.6</td>
<td>0.5</td>
<td>0.106</td>
</tr>
<tr>
<td>LS7</td>
<td>129.70</td>
<td>−3.33</td>
<td>500</td>
<td>20</td>
<td>3500</td>
<td>4500</td>
<td>51</td>
<td>−0.9</td>
<td>0.7</td>
<td>0.124</td>
</tr>
<tr>
<td>LS8</td>
<td>129.70</td>
<td>−3.33</td>
<td>500</td>
<td>20</td>
<td>3500</td>
<td>5000</td>
<td>48</td>
<td>−0.8</td>
<td>0.6</td>
<td>0.121</td>
</tr>
</tbody>
</table>

Lat., latitude; long., longitude; max. initial depr., maximum initial sea surface depression; max. initial elev., maximum initial sea surface elevation; thick., thickness of the landslide.

*The misfit values are calculated using equation (3).
source regions for tectonic tsunamis (Hayashi et al., 2011; Heidarzadeh and Satake, 2014). This method is based on assuming point tsunami sources at the location of each observation point (e.g., a tide gauge station) and allowing the tsunami to propagate for the duration of actual TTT for that station. The area where the backward travel-time curves meet each other is considered as the tsunami source region. The TTTs for three tide gauge stations of Tehoru, Amahai, and Banda are shown in Figure 2. As the tsunami wavefield is mixed with waves generated by both earthquake and landslide, we apply the TTT of landslide-generated waves (i.e., period = 3.1–4.8 min) using the wavelet plots (Fig. 4) which are: 2 min (Tehoru), 14 min (Amahai), and 20 min (Banda). The result of the backward analysis is shown in Figure 5a, which reveals the approximate location of the submarine landslide. It is noted that this analysis significantly relies on the accuracy of the bathymetry data. Because the accuracy of GEBCO bathymetry data is generally low around the coastlines, Figure 5a gives only an approximation of the landslide location rather than an exact location.

The same approach also can be used to approximate the location of the earthquake epicenter. Considering that the tsunami signal generated by the coseismic crustal deformation has a period of 11.9 min (Fig. 4), the wavelet plots show that the arrival times of this 11.9 min signal (due to the tectonic source) at different tide gauges are approximately 5 min in Tehoru, 10 min in Amahai, and 15 min in Banda (Fig. 4). The result of backward raytracing for these TTTs reveals the approximate location of the earthquake epicenter (i.e., the location of the coseismic crustal deformation zone), which is roughly around the epicenter reported by the USGS (Fig. 5b).
NUMERICAL SIMULATIONS OF SUBMARINE LANDSLIDE SCENARIOS

Based on the estimates of potential landslide locations and their dimensions (the previous sections), we considered eight scenarios for the potential submarine landslide and modeled the resulting tsunamis. Figure 6a shows the initial sea surface displacements generated by these eight scenarios, which reveals that their lengths are in the range of 6–10 km as estimated previously (i.e., $L = 5.8$–$10.1$ km). The simulated waveforms from landslide scenarios are compared with the observed ones (Fig. 6b). The best match is achieved by LS6 (Fig. 6, Table 3). This implies that the potential submarine landslide responsible for the large waves in Tehoru had a length of approximately 4000 m with a thickness of approximately 50 m (Table 3). It is possible that other combinations of landslide parameters (length, width, thickness, and travel distance) and locations could reproduce the observed tsunami waves. Therefore, our estimates of the landslide size and location should not be considered as definite values, rather they are estimates of possible landslide sources. We note that it is not possible to provide detailed and precise information about the location and dimension of the landslide source without bathymetric surveys of the region and acquiring high-resolution bathymetry (e.g., resolution of 10–20 m). Therefore, our results only indicate that a submarine landslide was most likely involved in the tsunami generation process and provide first estimates on its location and dimension. We recommend marine geological surveys to be conducted for this area to provide more detailed information about the size and location of the landslide.

GEOLOGICAL EVIDENCE FOR SUBMARINE LANDSLIDES IN THE BANDA SEA REGION

According to media reports, local residents reported two coastal landslide incidents at Tanjung Muhu and Saunulu (Fig. 7), around the Tehoru tide gauge station, following the 16 June 2021 Seram Island earthquake, which were later surveyed by the BMKG (Indonesia Agency for Meteorology, Climatology, and Geophysics) Ambon station (TEMPO, 2021). According to these news reports, the coastal collapse at Tanjung Muhu reached 350 m in length and 50 m in width, and the beach subsided 10 m toward the sea, whereas the landslide at Saunulu extends for 220 m along the coast (Fig. 7). Although these reported onshore landslides are not from the location of our best submarine landslide scenario (LS6, Fig. 6, Table 2), and their sizes may not be large enough to generate a noticeable tsunami, they confirm that the region has a large potential for coseismic landslides.

In the Banda Sea region, the Weber Deep is a prominent 7.2-km-deep basin derived from the extensional tectonics of the active Banda detachment fault (Pownall et al., 2016). Submarine landslides on the eastern wall of the Weber deep might be triggered by earthquakes and cause tsunamis (Fig. 7a; Hall et al., 2017; Cummins et al., 2020). The offshore south Seram is characterized by steep bathymetric slopes, up to 23°, with a maximum depth of about 4 km (Fig. 7b). Similar steep bathymetric slopes are also observed along the coast of Buru and the eastern margin of the Weber Deep. Many fan deltas are also developed along the coast near the steep bathymetric slopes. The steep slope and sedimentation might lead to failure and generate submarine landslide tsunamis following earthquakes (Prior et al., 1982; Perissoratis and Papadopoulos, 1999; Tappin et al., 2008; Leynaud et al., 2009; Frederik et al., 2019). A landslide tsunami was suspected to have occurred in the Seram area following the 1899 M 7.8 earthquake according to a previous report (Brune et al., 2010). The 1899 earthquake was considered to have
ruptured the Kawa and Bobot fault (Fig. 7a; Watkinson and Hall, 2017) and caused coastal landslides around Tehoru with a 12-m-high tsunami (Verbeek, 1900).

CONCLUSIONS
We studied the 16 June 2021 tsunami in Seram Island (Indonesia) following an $M_w$ 5.9 earthquake through the analysis of tide gauge records, spectral analyses, and numerical modeling. The tsunami recorded at the Tehoru tide gauge station (distance to epicenter $\sim 20$ km) had a zero-to-crest amplitude of 51 cm whereas the two stations of Amahai (distance to epicenter $\sim 70$ km) and Banda (distance to epicenter $\sim 114$ km) measured amplitudes of 2 cm and 3.4 cm, respectively. The generation of a 51 cm tsunami from an $M_w$ 5.9 earthquake...
Figure 7. (a) Bathymetry map of the source region in the Banda Sea region showing locations susceptible to sliding. Bathymetric contour and slope are generated from the Indonesian Bathymetry Data BATNAS (see Data and Resources). (b) A 3D model (view to the north) of topography and bathymetry around Tehoru, south Seram. The numbers on the depth contours show water depth. The color version of this figure is available only in the electronic edition.
is normally highly unlikely, and thus we speculate that a submarine landslide was potentially involved. There is strong evidence that supports the contribution of a submarine landslide. The tsunami amplitude in Tehoro is at least 15 times larger than that at the other two stations whereas all tide stations are relatively close to the epicenter. In addition, landslide activities were reported in the areas around the Tehoro station by local people following the earthquake. Numerical modeling of the tsunami from the earthquake source showed that the resulting tsunami is only a few centimeters in amplitude and cannot reproduce the 51 cm tsunami in Tohero. Spectral analysis and tsunami backward raytracing informed about the potential size and location of the landslide. We considered eight landslide scenarios and performed numerical modeling, which revealed that a landslide with the length and thickness of approximately 4 km and 50 m, respectively, was potentially responsible for the tsunami.

DATA AND RESOURCES
All data used in this study are given in the body of the article. For earthquake data, we used the earthquake catalogs of the U.S. Geological Survey (USGS; https://earthquake.usgs.gov/), the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG; http://repo.geophy.bmkg.go.id/repo_new/), and the Global Centroid Moment Tensor (Global CMT) catalog (https://www.globalcmt.org/CMT-search.html). Tide gauge data are provided by the Indonesian Geospatial Information Agency (https://www.big.go.id/). This article includes supplemental material that consists of a figure (Fig. S1) showing the tide gauge records of the 16 June 2021 Seram Island Tsunami. The information about BATNAS is available at https://tanahair.indonesia.go.id/demnas. All websites were last accessed in August 2021.

DECLARATION OF COMPETING INTERESTS
The authors declare that they have no competing interests regarding the work presented in this article.

ACKNOWLEDGMENTS
A number of figures were drafted using the Generic Mapping Tools (GMT) software (Wessel and Smith, 1998). The authors are sincerely grateful to Jonathan Griffin and Mark Williamson Stirling (Deputy Chief Editor) for their constructive review comments on an early version of this article. This research is funded by the Royal Society (the United Kingdom) Grant Number CHL/R1/180173. The authors also acknowledge funding from the Lloyd’s Tercentenary Research Foundation, the Lighthill Risk Network, and the Lloyd’s Register Foundation-Data Centric Engineering Programme of the Alan Turing Institute.

REFERENCES
Courant, R., K. Friedrichs, and H. Lewy (1928). Über die partiellen Differenzengleichungen der mathematischen Physik, Mathematische Annalen 100, no. 1, 32–74 (in German).