論文 / 著書情報
Article / Book Information

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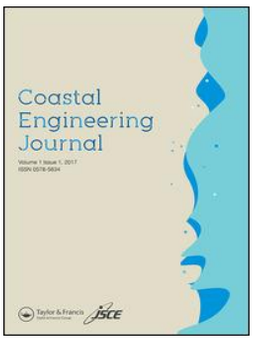
Citation	Coastal Engineering Journal, ,
Pub. date	2023, 1
Creative Commons	Information is in the article.



Coastal Engineering Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcej20

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To cite this article: Kanako Iuchi, Hiroshi Takagi, Yasuhito Jibiki, Tamiyo Kondo, Ayako Kusunoki, Nuraini Rahma Hanifa, Dicky Pelupessy, Rahmadiyah Tria Gayathri & Robert Olshansky (2023): Questioning the hazard map-based rebuilding process: learning from the 2018 Sulawesi earthquake in Indonesia, Coastal Engineering Journal, DOI: 10.1080/21664250.2023.2165430

To link to this article: https://doi.org/10.1080/21664250.2023.2165430

Published online: 24 Jan 2023.

COASTAL ENGINEERING JOURNAL
https://doi.org/10.1080/21664250.2023.2165430

ARTICLE

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Questioning the hazard map-based rebuilding process: learning from the 2018 Sulawesi earthquake in Indonesia

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ABSTRACT

To reduce hazards in post-disaster rebuilding, governments often first revise existing hazard maps to update land use plans and regulations. This sequence assumes that the disaster event immediately improves knowledge of the hazard. To learn from an actual case, we document PASIGALA's rebuilding process following the 2018 Central Sulawesi earthquake. We reviewed public documents in-depth, assessed coastal hazards with new information, and reflected on our field observations. We documented the 3.5-year situation in detail and developed recovery narratives. We also found that the actual post-disaster development does not fully incorporate the planned goals of hazard risk reduction. Reasons include: i) the need to create a hazard map before knowing the hazard's mechanism; ii) the scale of hazard mapping does not correspond to that of individual building parcels; iii) residents, out of necessity, restart their lives in the prohibited areas, and iv) relocation plans do not attract affected residents when rebuilding their lives. Governments may create simplified hazard maps to facilitate timely rebuilding, but this overlooks nuanced problems residents face, further complicating their situation. Although the hazard maps show the region's potential hazards, the next disaster could be different. We conclude the current practice of hazard map-based rebuilding needs more deliberation.

ARTICLE HISTORY
Received 25 August 2022
Accepted 3 January 2023
Published online

KEYWORDS
Hazard maps; recovery and reconstruction plans; 2018 Central Sulawesi earthquake; disasters in Indonesia; coastal hazards

1. Introduction

Hazard reduction has become an important goal when rebuilding after devastating disasters. In the past decade alone, multiple rebuilding efforts have considered hazard reduction through land use zoning. These include the 2010 and 2011 Christchurch earthquakes in New Zealand (Johnson and Olshansky 2016), 2010 Mount Merapi eruption in Indonesia (Muir et al. 2020), the 2011 Tohoku Earthquake and Tsunami (Ubaura 2018), the 2013 Typhoon Haiyan in the Philippines (Iuchi, Jibiki, and Tamayose 2020), and the 2015 Gorkha earthquake of Nepal (JICA 2018). Similarly, in the US, small island communities are relocating to reduce future threats from hazards, as they face land loss from sea level rise. Well-known ongoing relocation examples include Isle de Jean Charles, Louisiana and Newtok, Alaska (Maldonado et al. 2013).

The process of hazard reduction following a disaster begins by incorporating the new damage information into existing hazard maps and conducting damage simulations with this new knowledge. A notable example of this process was the new tsunami hazard zoning created after the 2011 Tohoku Earthquake and Tsunami, in which the tsunami exceeded recent historical experience (Iuchi, Johnson, and Olshansky 2013). Governments then develop land use plans based on these revised hazard maps and adopt regulations for reconstruction. While this model of rebuilding sequence seems rational, planners and engineers overlook the need to have some time to update scientific knowledge, especially after complex disasters like the earthquake that shook the Central Sulawesi region in 2018.

The 2018 Central Sulawesi earthquake on September 28 generated unusual geophysical effects, including tsunamis and flowslides, causing 4,340 fatalities, including 667 missing people (Mason et al. 2019). While the distribution of fatalities due to specific causes is unknown, coastal communities were devastated mainly by tsunamis and by flowslides in densely populated residential and farming areas (Mason et al. 2019). In total, 173,000 people were permanently displaced (International Federation of Red Cross and Red Crescent Societies 2022), and the direct loss was calculated to cost IDR 18.48 trillion (roughly USD 1.3 billion) (Central Sulawesi Provincial Government 2018;

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Purnamasari et al. 2021). Rebuilding safely was an important mission for the region, due to a history of recurrent tsunamis generated by earthquakes, including those in 1927, 1968, and 1996, generated by the Palu-Koro fault rupture (Ho et al. 2021; Fuady, Munadi, and Fuady 2021). In addition, the west coast of Donggala was affected by a 2 m tsunami in 1930 and a tsunami up to 10 m in 1938 devastating all the villages on the west coast (Nane et al. 2018; Central Sulawesi Provincial Government 2018). While complete scientific explanations of this complex phenomenon are still evolving after three and half years, governments had initiated recovery efforts immediately after the disaster to rebuild with reduced risk. As of mid-2022, rebuilding is still ongoing, with some large-scale relocation sites completed, while other sites are in limbo because unexpected issues emerged along the way. Along the tsunami-hit coast, a new coastal seawall is now complete, and a few residences have been built back.

This paper draws insights on hazard map-based rebuilding from the coastal recovery of Palu City and its vicinity three and half years after the earthquake (See Figure 1). Objectives are three-fold. First, we document rebuilding decisions and processes in Palu City, Sigi Regency, and Donggala Regency (locally called the PASIGALA region) between October 2018 and March 2022, using officially published literature, publicly available information, and on-site interviews. Our purpose is to document rebuilding rationales and efforts before details get lost in time. Second, we explore emerging discrepancies and challenges between the plan for hazard map-based rebuilding and the actual rebuilding process. To highlight the differences, we explore both spatial-related laws, regulations, and acts guiding PASIGALA's hazard-map based recovery, and the actual damage, spatial management procedure, and current on-site rebuilding status. Third, we identify opportunities and complications of the hazard-map-based rebuilding process, and propose further research to better incorporate hazard risk reduction efforts into spatial (re)development.

Following this section, we explain the methods used for developing this paper. With authors having multi-disciplinary background training (e.g. planning, architecture, coastal engineering, geosciences, sociology, political science, and community development), this research took a non-traditional, mixed approach to consider a better way of reducing coastal hazard risks while also sustaining vibrant living in the affected regions. Section 3 shares five key findings on the PASIGALA region's hazard map-based rebuilding following the 2018 Sulawesi earthquake. It includes: i) basic recovery structure, ii) recovery timeline key events, iii) PASIGALA's hazard map, iv) tsunami mechanisms, impacts, and preventive measures, and v) hazard-based zoning and its enforcement. We then discuss complications emerging from pursuing the goal of reducing hazard risks, followed by conclusions. While inland areas of Sigi and Donggala Regencies were also significantly affected by earthquake-generated flowslides, our focus for this paper is on the tsunami impacts and countermeasures to reduce the potential damage from future events along the Palu Bay coast. That said, most of our observations and findings regarding rebuilding in tsunami hazard areas would also apply to the areas affected by flowslides, which have also been the subject of ongoing scientific investigation while simultaneously implementing map-based reconstruction regulations.

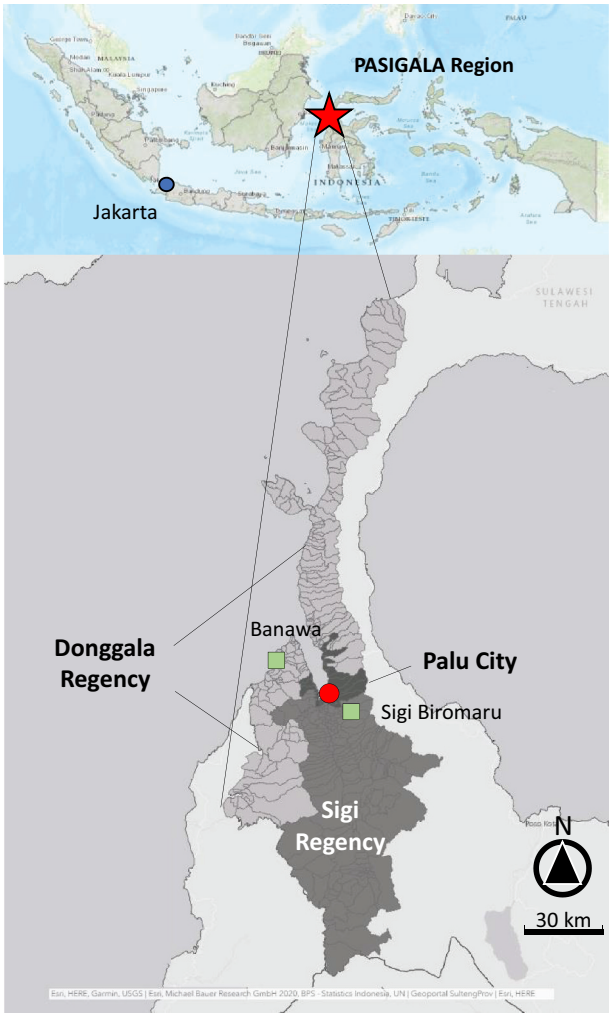


Figure 1. Location of the PASIGALA region. Source: Created by authors using ArcGIS online open data Kawasan Hutan (KLHK) Feature Layer

2. Methods

To understand the development of post-earthquake reconstruction and to unpack opportunities and constraints of hazard-map based rebuilding, we adopt varied methods to develop a hazard map-based rebuilding narrative from the 2018 Central Sulawesi earthquake. The first approach was the in-depth document review on published governmental information,

academic literature, and newspaper articles. We reviewed a total of 75 documents on national-level laws and regulations, recovery plans, reports, papers and loan agreements by the international agencies and NGOs to document the governmental approach to PASIGALA rebuilding (See Table 1). We also examined academic literature published between 2018 and 2022 referencing PASIGALA's rebuilding governance and policies, land use and hazards, and post-disaster housing. Furthermore, we gathered international and local newspaper articles to develop recovery timelines and identify key events that influence hazard-based spatial (re)construction.

The second approach focuses on assessing coastal hazards by examining the tsunami heights generated by the 2018 earthquake, coastal infrastructure designed and constructed post-earthquake, and designated zones prohibited for new construction. For this assessment, we used published survey results on tsunami heights, publicized information by international donors supporting region's hazard risk reduction efforts, and the revised hazard map shared with the public.

Third, we referenced our knowledge, interview results, and experiences gained through field investigations to supplement document-based analysis and explorations. Authors have engaged in various field investigations surveying geo-physical phenomenon of tsunami (Takagi) and flowslides and ground rupture (Hanifa). Others have followed developments of recovery planning and policy decisions (Iuchi, Jibiki, Olshansky) as well as issues related to displacements and housing provision (Pelupessy). One of our authors is a social researcher, artist and local resident who survived this disaster (Gayathri). Members' first field investigation took place less than a month to capture the impact of the natural phenomena, and the most recent field work took place in March and April 2022 to investigate the current reconstruction status of coastal infrastructure, housing, and residents. Our activities for three and half years have resulted in various outcomes – including journal articles, reports and book publications, seminar presentations, film, and memorial activities (See Table 2).

There are research limitations. The COVID-19 outbreak since early 2020 has complicated the field investigations and direct communications with those involved in rebuilding. Thus, the information in this paper heavily relies on the publicly available published documents and the past and current field information that is within our reach.

Table 1. A breakdown of selected literatures reviewed by document type.

Document type	Number
National-level laws and regulations	11
Recovery plans	6
Reports	16
Loan agreements by donors	5
Scholarly literature	22
International and local newspaper articles	15

Note: Selected literatures are exclusively about the 2018 Central Sulawesi earthquake.

3. Results

Based on our cross-disciplinary review and assessment, we found that all levels of governments intended to reduce hazard risk from the beginning of rebuilding, but faced difficulties as the plans moved forward. We depict five key aspects relating to the effort of PASIGALA's hazard risk reduction in rebuilding and its development. We also share the up-to-date field situations to better understand the affected areas' reconstruction status.

3.1. Basic recovery structure of the 2018 Central Sulawesi earthquake

A recovery structure was formed to rebuild the earthquake affected region. Sulawesi's recovery and reconstruction master plan played a foundational role as a road map to the region's recovery and development. The national government established the legal and institutional structures to initiate rebuilding efforts, and the Central Sulawesi provincial government adopted a recovery and reconstruction master plan. Palu City, Sigi Regency, and Donggala Regency governments then aimed to reflect these ideas in their rehabilitation and reconstruction plans and to translate into spatial reconstruction plans.

3.1.1. Rebuilding in-situ (on-site) and ex-situ (new-area): Central Sulawesi's recovery and reconstruction master plan

The 2018 recovery and reconstruction master plan, adopted by the Central Sulawesi government on December 31, serves as a basis for the region's rebuilding. The slogan of this master plan was to build the region back better, safer and sustainably (Central Sulawesi Provincial Government 2018). This message reveals the key intentions of using reconstruction to reduce future hazard risk. One of the distinctive features of this master plan are the two recovery paths equally emphasized, the *in-situ* (on-site) and the *ex-situ* (new area) development (Erlinna, Santoso, and Dowon 2020). Compared to plans following disasters elsewhere (e.g. the 2010 Mount Merapi Eruption, the 2011 Tohoku Earthquake and Tsunami in Japan and the 2013 typhoon Haiyan in the Philippines), it was unusual that the first round of reconstruction master plans underscored *ex-situ* development with detailed plans for relocation destinations (see, for example BNPB and BAPPENAS 2012; NEDA 2014; Reconstruction Design Council, 2011).

Table 2. List of activities authors participated.

Activities (Funders)	Purpose	Methodologies/Approaches	Involved author(s) and related outcomes
2018.11 - ongoing Field investigation and geo-physical analysis	Capturing geo-physical phenomenon of flowslides and ground rupture	Fieldwork including ground surveys, interviews with residents, and analysis using unmanned aerial vehicles (UAVs)	Hanifa • Mason et al., 2021 [Article]
2018.11 - ongoing Field investigations and interviews	Identifying the better ways of governing cascading risks in Indonesia	Systematic literature review and reviews on natural, socio-cultural governance systems	Hanifa • Triyanti et al., 2022 [Article]
2018.11.2–11.3 Field investigation (JICA)	Recording local residents' memory on tsunami height	Interviews and field reconnaissance	Jibiki • Jibiki et al., 2020 [Article]
2018.11.6–11.11 Field investigation (Tokyo Institute of Technology, CONICYT (Chile), Waseda University)	Capturing geo-physical phenomenon of tsunami	Topographical/bathymetric survey and interview survey	Takagi • Takagi et al., 2019 [Article]
2018.12–2019.12 Developing a collage book "Yang Kitorang Rasa Waktu Gempa (what we felt during the earthquake)" (Forum Sudut Pandang)	Documenting children's experiences	Obtaining and documenting stories and photos of more than 400 children (3–12 years) in eight evacuation sites (Mamboro, Komodo, Loru, Sidera, Tipo, Tavaili, Rogo and Loli)	Gayathri • "Cerebrating Memorama 2019" event [Activity] • A collage book "Yang Kitorang Rasa Waktu Gempa (what we felt during the earthquake)" [Book] • 'Yellow Memories' art space in Talise beach [Activity] (Information available in: Pandang 2022; Palu 2022)
2019.11.14–11.23 EERI Reconnaissance trip to Palu, LfE program (EERI)	Understanding the initial status of rebuilding policies, decisions, and actions	Interviews, document collection and field reconnaissance	Olshansky, Iuchi, Hanifa • Olshansky et al, May 2020a [PowerPoint presentation] in EERI Seminar 2020 [Seminar] • Olshansky et al, October 2020b [PowerPoint presentation] in Bandung Institute of Technology and BAPPENAS seminar 2020 [Seminar] • Tada 2020 [Article]
2019.12.17 JICA on-site seminar (JICA)	Sharing practical world-wide experiences on post-disaster relocation as a reference for post-Palu relocation and land use decisions	Knowledge sharing/Presentations	Iuchi, Pelupessy • Iuchi 2019 [PowerPoint presentation] • Tada 2020 [Article]
2020.1–2020.11 Filming on earthquake and education (The Charles Engelhard Foundation - UNESCO)	Documenting stories by survivors from earthquakes and tsunamis of Central Sulawesi in 1927, 1938, 1968, and 2018	Interviewing and documenting survivors' experiences	Gayathri • Living Witness History of Earthquake, Tsunami & Liquefaction in Central Celebes 2020 (UNESCO 2022) [Film]
2020.1–2020.12 SKP-HAM: Relocation housing program (World Bank)	Monitoring compliance of PUPR resettlement housing project by the World Bank emphasizing on reducing Child Sexual Exploitation Abuse (CSEA) and Gender Based Violence (GBV)	Workshops, focus groups and interviews	Pelupessy • SKP-HAM 2020 [Report]
2022.3–2022.4 Field investigations on relocation status and coastal infrastructure (Tohoku University)	Recording recovery and reconstruction progress	Obtaining images (photos) of the affected areas, and synthesizing residents' reflections.	Gayathri (together with co-authors) • Current paper
2022.9 – ongoing Developing a model of people centered disaster preparedness (CBM-Global Disability Inclusion Vereniging)	Developing an inclusive model of disaster preparedness for the disabled population	Workshops, data-collection trainings and plan development with organizations of persons with disabilities (OPD)	Pelupessy • Desk study of PCIHA (CBM and University forum for disaster risk reduction, unpublished) [Report]

Articles, reports and presentations

- All referenced in the references section

Seminars

- EERI seminar: Learning from Earthquakes. "Preliminary observations and findings from the EERI Palu, Indonesia Earthquake and Tsunami Resilience Reconnaissance Team." EERI. May 20 2020. Online.
- EQ Talk #5: Unique Challenges on Build Back Better for Community Resilience after the Palu earthquake. October 16 2020. Bandung Institute of Technology and BAPPENAS.
- JICA Seminar: Seminar on Spatial Planning and relocation for Build Back Better (BBB) in Post-Disaster Contexts. December 17 2019, Jakarta, Indonesia.

Additionally, having the region's revised hazard map (*Peta Zona Rawan Bencana Kota Palu dan Wilayah Sekitarnya*: Disaster-Prone Zone Map for Palu City and Surrounding areas) with four hazard levels included in the master plan is unique. By law, regional governments are mandated to incorporate the hazard map information into their local spatial plans (RTRW: *Rencana Tata Ruang Wilayah*), and the 2007 Spatial Planning Act (UU 26/2007) instructs them to revise these plans after every major disaster (President of Indonesia 2007a). The intent of including this revised hazard map in the master plan was for the regional governments to revise their spatial plans as a basis for recovery actions. The master plan included four relocation sites in Palu City and Sigi Regency for the *ex-situ* (new area) (re)development, where the affected residents in the high-risk areas are planned to be relocated.

3.1.2. Legal and institutional setup

Since September 28 2018, instructions, decrees, and regulations have been established to legally support rebuilding. One of the foundational instructions by the President became effective on November 28 2018, to accelerate the rehabilitation and reconstruction following the earthquake and tsunami in Central Sulawesi Province and other affected areas (President of Indonesia 2018a). This instruction mainly designated the responsibilities of the 29 related ministers and six heads from the National Army, Police, Attorney and three national agencies, as well as governors and mayors from Central Sulawesi Province and the affected cities and regencies regarding collaborative work on reconstruction until December 31 2020 (President of Indonesia 2018b). A presidential task force (Disaster Management Task Force (*Satgas Penanggulangan Bencana*)) was then established on November 28 2018, aiming to manage Central Sulawesi's rebuilding (President of Indonesia 2018b). This task force was chaired by the vice president with two vice chairs (coordinating ministers for political, legal, and security affairs and human development culture), and a chief executive officer (minister of BNPB) (President of Indonesia 2018b) (See Figure 2). In this structure, heads of each institution had complementary responsibilities to support rebuilding (See Table 3 for the examples on the responsibilities on spatial management in recovery; see Appendix 1 for a list of abbreviations with full Indonesian and English translation).

Besides the presidential task force, some other task forces were established to guide rehabilitation and reconstruction (See Table 4 for all task forces established). One was the KAPP, a coordination and assistance team for Central Sulawesi's recovery and development, which was tasked to develop a recovery and reconstruction master plan for the affected regions (Central Sulawesi Provincial Government 2019). This included seven ministries and government agencies of BAPPENAS, PUPR, ATR, BNPB, ESDM, BMKG, and BIG (Geospatial Information). Second, an *adhoc* rehabilitation and reconstruction team, TAA-RR, was also formed with BAPPENAS and BNPB to technically support Central Sulawesi Province, requiring cross-

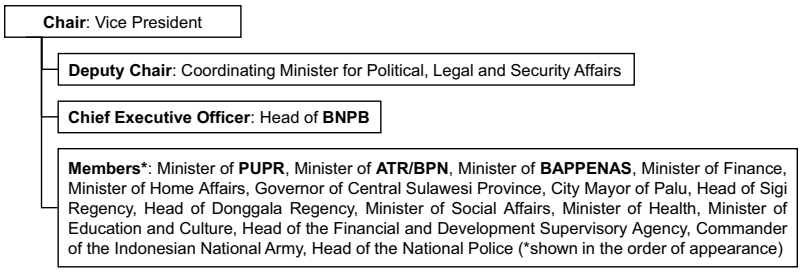


Figure 2. Structure of the disaster management task force for Central Sulawesi Province and surrounding areas. Source: Developed by authors based on KEPPRES 28/2018 (President of Indonesia 2018b)

Table 3. Examples of responsibilities by ministries and agencies on spatial management.

Lead agency	Roles and responsibilities
BAPPENAS (National Development Planning Authority)	Craft recovery plans and oversee implementation of identified projects with such ministers as PUPR (Ministry of Public Works and Housing), ATR (Land and Spatial Planning) and BNPB (Disaster Management)
ATR (Ministry of Land and Spatial Planning)	Provide recommendations and facilitate the governments of the affected regions to revise the spatial plans; Decide relocation sites and facilitate project implementations for the affected regions to reduce future risks with the ministers and heads of ESDM (Energy and Mineral Resources), PUPR, BMKG (Meteorology, Climatology and Geophysics), and BAPPENAS
BNPB (National Disaster Management Agency)	Coordinate the designated national ministries and governments of the affected regions throughout the rebuilding period, for instance to decide and allocate funding with rebuilding projects; Report the reconstruction progress to the President on a monthly basis
PUPR (Public Works and Public Housing)	Carry out rehabilitation and reconstruction of damaged infrastructure, including critical infrastructure and public facilities (education, health, religion, and economic development); provide technical support to ministries responsible for reconstructing infrastructure and facilities; coordinate with ministers and heads of related agencies

Table 4. Task forces established for the recovery from the 2018 Central Sulawesi earthquake.

Name	Legal base	Year
Disaster Management Task Force (*Satgas Penanggulangan Bencana*)	Presidential Decree (KEPPRES) on Disaster Management Task Force in West Nusa Tenggara Province, Central Sulawesi Province, and Other Affected Areas: KEPPRES 10/2018 (President of Indonesia (2018b))	2018
Central Sulawesi Disaster Management Task Force (*Satgas Penanggulangan Bencana Sulawesi Tengah*)	Decree of the Minister of Public Works and Public Housing Number 565/KPTS/M/2019 (PUPR 2019a) Decree of Minister of Public Works and Housing No 17/KPTS/M/2022 (PUPR 2022)	2019 (Original) 2022* (Updated)
Coordination and Assistance Team for Recovery and Development: KAPP (*Tim Koordinasi dan Asistensi Pemulihan dan Pembangunan*)	Central Sulawesi Governor Regulation on Master plan for recovery and reconstruction from the Central Sulawesi disasters: Pergub 10/2019 (Central Sulawesi Provincial Government 2019)	2019
Adhoc Rehabilitation and Reconstruction Team: TAA-RR (*Tim Adhoc Rehabilitasi dan Rekonstruksi*)		

* In 2022, the Central Sulawesi Disaster Management Task Force structure was modified due to two reasons. First, PUPR amended their regulation on organization and work procedure in 2020 (PUPR 2020). Second, the Republic of Indonesia and the International Bank for Reconstruction and Development made a loan agreement on the Central Sulawesi Rehabilitation and Reconstruction Project (Republic of Indonesia 2020).

sectoral recovery efforts for a maximum of three years (Central Sulawesi Provincial Government 2019). Lastly, a task force in the PUPR to construct new permanent housing (*huntap)* sites and other infrastructure was also established in the national department, PUPR (PUPR 2022; Tada 2020).

The structure of reconstruction governance reveals the opportunities and limitations of hazard-related spatial enforcement (e.g. Iuchi, Jibiki, and Tamayose 2020). In the reconstruction of the Central Sulawesi region, national-level departments and agencies had multiple responsibilities supporting the affected regional governments. For instance, revision of the PASIGALA's hazard map, to be included in the recovery and reconstruction master plan for risk reduction, was developed in a collaborative effort by 11 entities, including six ministries/national agencies (BAPPENAS, ESDM, ATR, PUPR, BNPB, BMKG), provincial governor (Central Sulawesi) and provincial legislature, and three affected regional governments (Palu City, Sigi Regency, and Donggala Regency) (See Central Sulawesi Provincial Government 2018). Involving different levels of governments in revising the map was particularly important; higher-level government – such as national level ministries and agencies – shared existing hazard information they owned and provided technical expertise for regional governments in the state of post-disaster disruption, and regional governments comprehended their hazard exposure to incorporate in their rebuilding efforts. However, while various ministries and national agencies were tasked to conceptualize rebuilding strategies with hazard risk reduction efforts, the Central Sulawesi government and three affected regional governments were, in fact, responsible for the actual planning, funding, and implementation. Furthermore, financial responsibility fell heavily on the regional governments because the president designated the 2018 Central Sulawesi disaster as a regional disaster (See, for example, Kahfi and Sangadji 2018).

3.1.3. Masterplans and spatial plans for the local recovery and reconstruction

Besides Central Sulawesi's regional recovery and reconstruction master plan, the disaster-affected regional governments developed and approved their detailed recovery plans. Donggala Regency (*PerBup 8/2019*) (Donggala Regency 2019), Sigi Regency (*PerBub 3/2019*) (Sigi Regency 2019), and Palu City (*Kep Walkot 360/294.a/BPBD/2019*) (Palu City 2019) consecutively approved their plans by their mayors on January 31, Februraly 28 2018, and March 25 2019. With these approved plans, Palu City, Sigi Regency, and Donggala Regency were ready to rebuild more safely. In the process, regional governments were responsible for deciding and enforcing hazard-map-based land use. To advance, they were required to develop their spatial plans (RTRW), referring to the PASIGALA's revised hazard map found in the reconstruction and recovery master plan. Palu City, for example, revised and adopted its spatial plan that reflected the new hazard information for 2021–2041 (*Perda 2/2021*) on July 21, 2021 (Palu City 2021a).

3.2. Recovery timeline and key events

A review of documents related to governmental information, academic literature, and newspaper articles for three and a half year between September 2018 to April 2022 suggests a recovery development narrative with three main categories of government decisions/plans, zoning/housing, and infrastructure.

3.2.1. Overall recovery development

Official reconstruction efforts had initiated three months after the earthquake with the Presidential Instruction (*INPRES 28/2018*) and Presidential Decree (*KEPPRES 20/2018*) in effect (see Figure 3 for detailed events by time). For the first six months, decisions and events concentrated on regulatory and governance issues that led to framing the reconstruction activities.

			Citation #
2018			
28-Sep		2018 Central Sulawesi Earthquake	
17-Oct	B	Minister of Agrarian and Spatial Planning (ATR) / Head of the National Land Agency (BPN) Sofyan Djalil states about relocation of Palu residents	1
28-Oct	C	World Bank and ADB announce $1 billion in financial support for recovery	2, 3
20-Nov	C	ADB approves $ 500 million for emergency assistance	2, 4
28-Nov	A	Inpres 28/2018: Concerning Acceleration of Rehabilitation and Reconstruction of the Post-Disaster Region of Central Sulawesi Province and its surroundings put in effect (Presidential Instruction)	5
28-Nov	A	Kepres 10/2018: Disaster Management Task Force in West Nusa Tenggara Province, Central Sulawesi Province, and other Affected Areas, establishes (Presidential Decree)	6
31-Dec	A	Master plan for recovery and reconstruction from the Central Sulawesi disasters publicized	7
	B	○ Included PASIGALA's revised hazard map	7
	B	○ Included five planned collective relocation sites in four areas	7
2019			
31-Jan	A	【Donggala Regency】 Rehabilitation and Reconstruction Plan regulated <PerBub8/2019>	8
28-Feb	A	【Sigi Regency】 Rehabilitation and Reconstruction Plan publicized <PerBub3/2019>	9
25-Mar	A	【Palu City】 Rehabilitation and Reconstruction Plan publicized <Kep Walkot No. 360/294.a/BPBD/ 2019>	10
2-Apr	A	【Central Sulawesi】 Provincial Post-disaster rehabilitation and Reconstruction Master Plan Approved (Central Sulawesi Governor Regulation) <Pergub 10/2019>	11
19-Jun	C	World Bank approves a $150 million loan to finance the reconstruction and strengthening of housing and public facilities	2, 12
26-Jun	C	ADB approves $300 million for MPWH and the Ministry of Transportation and $ 3 million for infrastructure design	2
2020			
1-Jan	B	Phase I housing construction begins publicly: Large-scale Huntaps	13
9-Jan	C	Japan and Indonesia sign the Infrastructure Reconstruction Sector Loan (about $320 million) for (1) Roads, bridges, and coastal dykes, (2) irrigation, river improvement, and liquefaction measures, and (3) public facilities	14
2-Apr	B	Red zone residents are asked to decide on their relocation plans (Collective/Individual Huntap)	15
24-Apr	B	Palu city begins to publicize the Palu Satellite City plan	16, 17
5-Jun	A	Republic of Indonesia and International Bank for Reconstruction and Development (IBRD-WB) agree on a loan to begin Central Sulawesi Rehabilitation and Reconstruction Project	18
2021			
1-Jan	B	Phase II housing construction begins: Mandiri relocation	13
26-Feb	A	New Palu Mayor (Hadianto Rasyid) takes seat in the office	19
21-Jul	A	Palu City adopts the Regional Spatial Plan for 2021-2041 (RTRW)	20
29-Sep	B	Palu City Mayor publicizes the plan to build a satellite city at the location of Huntaps in Talise Village	21, 22
11-Oct	A	The Mayor of Palu holds pre-Congress Workshop on the establishment of the Disaster Risk Reduction Forum (FPRB)	23, 24, 25
	A	○ The Palu City Government (Pemkot) plans to build a Satellite City or a new city in Tondo Village, Mantikulore District, with a total land area of 182.14 hectares	23, 24, 25
	A	○ Minister of ATR/BPN verbally approves constructing a new "Satellite" city of Palu	23, 24, 25
2022			
6-Jan	A	Vice President Ma'ruf Amin visits Palu city (2 days from January 6th to 7th) and attends a meeting on post-disaster recovery	26
	C	○ Vice President suggests PUPR prioritize the construction of the strategic roads (connecting relocation sites and the downtown) for Palu city	26
	B	○ Vice President instructs regional governments to finish acquiring Tondo 2 huntap land	26
	A	○ The Vice president encourages tourism development in Palu to utilize the red zone, e.g., Taipa Beach	26
11-Feb	C	Ministry of Sea Transport starts Donggala Port rehabilitation and reconstruction	27
May end	B	The deadline date of President Ma'ruf Amin's instructions for Tondo 2 on land dispute resolution	26
	B	Construction of housing on relocation sites to finish	28
2024			
End	C	Roads, bridges, and seawalls supported by international donors to finish	26

Legend: A: Government decisions/Plans; B: Zoning/Housing; C: Infrastructure

Citations: 1. Kulsum 2018; 2. JICA 2020a; , 3. JICA 2020b; 4. Tang 2018; 5. President of Indonesia 2018a; 6. President of Indonesia 2018b; 7. Central Sulawesi Provincial Government 2018; 8. Donggala Regency 2019; 9. Sigi Regency 2019; 10. Palu City 2019; 11. Central Sulawesi Provincial Government 2019; 12. World Bank 2019; 13. PUPR 2021; 14 JICA 2020b; 15. Newsurban Editor 2020; 16. SKP-HAM 2020; 17. Nugracha 2020;18. Republic of Indonesia and International Bank for Reconstruction and Development 2020; 19. Ruliansyah 2021; 20. Palu City 2021a; 21. Sulteng Raya 2021; 22. Husain 2021; 23. Palu City 2021b; 24. Sinar Pagi Baru 2021; 25. Editor of Sulteng Terkini 2021; 26. VOI Editorial Team 2022; 27. Directorate General of Sea Transportation 2022; 28. Fauzian 2022

Figure 3. Recovery timeline. Source: created by authors

Then, concerns shifted to zoning, housing and large-scale infrastructure to reduce hazards. Overall, the timeline confirmed that Indonesia's national, provincial and regional governments led decisions, plans, and activities related to recovery and reconstruction, as well as to zoning and housing issues involving interactions with local communities. The timeline also highlighted that international agencies were involved in the discussions on the large-scale hazard-mitigation infrastructure from the early stage.

3.2.2. Events related to the idea of building the region back better, safer, and sustainable

While we are limited in understanding the full range of reconstruction activities, the timeline confirms that recovery and reconstruction The idea of minimizing hazard risk upon rebuilding the safety and sustainability of the region through hazard-sensitive zoning, housing and infrastructure projects, and developing a resilient city concept.

3.2.2.1. Events regarding hazard-sensitive zoning and housing. The idea of minimizing hazard risk upon rebuilding was a priority from the beginning. For instance, on October 17 2018, the ATR minister publicly commented about relocating affected residents (see Kulsum 2018). This idea of minimizing future risk was translated into a revised hazard map of the region in the recovery and reconstruction

master plan announced on December 31 2018. The plan also included the idea of accommodating the population whose former houses fell in the newly identified highly hazardous zone into the newly developing permanent relocation sites (*huntaps*). The first phase of the housing construction on the large-scale *huntaps* officially began on January 1 2020 (PUPR 2021). Variations of the relocation programs emerged with the phase 1 progress (See for example Newsurban Editor 2020); one of which is the satellite *huntaps* program, which targets the population of affected rural communities with a smaller number of families to relocate into locations near their original villages. The other is the individual (*mandiri*) relocation program, to individually relocate households to a location of the family's preference. This *mandiri* relocation option became available in April 2020, and its construction (Phase II construction) began in January 2021 (PUPR 2021).

3.2.2.2. Events regarding infrastructure projects.

International donors pledged their support for infrastructure to reduce the future impact from hazards. Support came from various institutions and governments, including multi-lateral agencies (e.g. the World Bank (WB) and Asian Development Bank (ADB)), bi-lateral agencies from countries of Japan, Switzerland, Germany, New Zealand, and South Korea (Central Sulawesi Provincial Government 2018). Among these donors, ADB, Japan International Cooperation Agency (JICA), and the WB had a significant engagement with Central Sulawesi's rebuilding as per their pre-earthquake relationships with the country. In late October 2018, ADB and the WB announced they would each fund US$1 billion to support the affected region (Tang 2018; JICA 2020a). On June 19 2019, the WB approved a US$150 million loan to finance the reconstruction through building *huntaps* and community facilities on the relocation sites (World Bank 2019; JICA 2020a), which was later signed on June 5 2020 (Republic of Indonesia and International Bank for Reconstruction and Development 2020). On June 26, ADB approved US$300 million for PUPR and Ministry of Transportation to support reconstructing water resource management facilities and US$3 million for designing coastal protection facilities (JICA 2020a). Finally, on January 9, Japan and Indonesia signed the Infrastructure Reconstruction Sector Loan (about US$320 million) for (1) roads, bridges, and coastal dikes; (2) irrigation, river improvement, and liquefaction measures; and (3) public facilities (JICA 2020a). This loan included the reconstruction of Palu VI Bridge, a symbolic bridge treasured by residents in the mouth of Palu bay pre-earthquake, and an elevated road (sea dike).

3.2.2.3. Events regarding Palu's resilient city conceptualization.

Over time, the concept of creating a model resilient city on one of the relocation sites emerged. The concept was softly announced for the first time in April 2020 as the Palu Satellite City plan by Palu's then-Mayor Hidayat, to make the Tondo-Talise area as a future economic center of the city SKP (2020); Nugracha (2020). Lands in that area had been left unmanaged for decades due to their distance from the city center; thus, the city government promoted the idea of creating a new economic center as a model of a resilient city that would encourage both original and relocating residents (Nugracha 2020).

The plan was consolidated after Mayor Rasyid took office in February 2021 (Ruliansyah 2021). On September 29 2021, the Mayor announced the location of the Satellite City will be the Talise Village *Huntap* site (Husain 2021; Sulteng News 2021). The Palu city government explained the detailed plan of the satellite city on October 11 2021, when the Palu Mayor held a disaster risk reduction forum. In the forum, the minister of ATR/BPN verbally announced its construction (City 2021b; Pagi Baru 2021; Editor of Sulteng Terkini 2021). The Satellite City concept was promoted to gain public support for the relocation project that was stalled at the time.

3.2.3. Timeline beyond 2022

The rehabilitation and reconstruction master plan envisions the PASIGALA region's recovery for five years, between 2019 and 2023 (Central Sulawesi Provincial Government 2019). Some recovery activities, such as housing provisions for the affected residents, were thus considered to begin completing as early as 2020 SKP (2020). However, interpreting hazards to create regulations and zoning, and implementing projects based on hazard-based zoning required much longer time than the initial timeline planned. To inspect the recovery status, on January 6 2022, Indonesian Vice President Ma'ruf Amin visited the PASIGALA region and made several suggestions to accelerate recovery actions (VOI Editorial Team 2022). He emphasized the need to ensure that relocated residents' lives would be similar to their pre-disaster state and requested an early resolution on the construction delay in one of the five relocation sites. Complicated negotiations on land ownership between the Palu city government and the current owners and the unsolved issue of the planned administrative boundary on *Huntap* Tondo 2 have been the main reasons for this delay (Kompas Editor 2022). All other large-scale relocation sites (see Section 3.5 for details on locations and sizes), under construction at the time of our review in early 2022, were planned to be completed by May 2022 (Fauzian 2022). Large-scale infrastructure projects, including elevated roads, bridges, and coastal dykes financed

by international donors, are expecting completion in 2024.

3.3. PASIGALA's hazard map: methodology and revised outputs

Risk evaluation in Indonesia began in 2010, but the nation-wide hazard risk map only became available in 2016 as a part of the national risk evaluation project (BNPB 2016). One of the reasons for the needed time to finalize the evaluation was the lack of a national-level agreement on the evaluation methods. While various stakeholders of ministries and agencies, universities, and donors, were involved in the evaluation process, their data types, scales, and maps accumulated were inconsistent, and having a uniform evaluation methodology was not easy (BNPB 2016, 11). Revising the Central Sulawesi's hazard map after the earthquake thus, based on the information gathered in 2015 for the national evaluation project, fundamentally followed the methodology agreed upon during that time. Revising PASIGALA's hazard map in a short time, however, was not easy due to limited data availability and lacking an established methodology.

3.3.1. National-wide hazard evaluation: evaluation methodology and interpretation

As a part of the commitment to the National Disaster Management Law No. 24 of 2007 (President of Indonesia 2007b), BNPB, for the first-time, compiled the country's national-level disaster risk information in 2016.[1] The analysis scale of this report was 1:250,000 – a scale that can only highlight the provincial risk and represent three high, medium, and low risk levels. Key indicators for the risk assessment included three variables related to hazards, vulnerabilities, and capacity.

Ten different types of hazard information (i.e. earthquake, tsunamis, volcanic eruption, flood, landslide, drought, land and forest fires, extreme weather, extreme tidal waves and sea abrasion, and flash floods) were gathered for the evaluation. The risk evaluation book explains different disaster types, methodologies, and results based on geophysical characteristics. For instance, earthquake risk assessment follows JICA's method[2] that was developed earlier for the country's earthquake preparation study, landslide and volcanic eruption risk assessment used a guideline prepared by the PVMBG (Volcanological Survey of Indonesia), assessment on flash floods used PUPR guidelines, and many other hazards risk evaluations relied on BNPB's methods developed in 2012 (*Perka BNPB 2/2012*) (BNPB 2012).

Meanwhile, vulnerability assessment included other indexes beside geophysical hazards. These included social, physical, economic, and environmental indexes. The assessment further included regional capacity, where key indexes from the Hyogo Framework for Action and the national disaster management law were selected to measure regional governments' capacity. While this national-level disaster risk information included evaluating both geophysical and social risks, geophysical information was particularly beneficial for sharing hazards and risk that each province faces across the country.

3.3.2. The national-level earthquake hazard assessment efforts

Earthquake hazard information was one of the critical areas to review and revise after the 2018 earthquake. Nationally, the effort to identify earthquake sources and mapping took place in 2010 for the first time by a national team with 11 earthquake experts from ministries and academia (Irsyam et al. 2020). The result of this effort had a significant effect – in 2012, the government revised the National Building Standard Code in an effort to upgrade buildings to be more resistant to earthquakes. Later in 2017, the National Center for Earthquake Studies (PuSGeN) revised the earthquake source map under coordination led by PUPR (PuSGeN 2017; Irsyam et al. 2020). The map well identified the Palukoro fault, and showed a precise location of the previous paleoseismology trenching (PuSGeN 2019; Natawidjaja et al. 2021). However, it did not map the offshore segment that crosses Palu Bay, which overlooked the possibility of a rapid onset tsunami, which occurred in 2018.

After the 2018 event, experts mapped in detail the full extent of the Palukoro Fault on land and offshore to explore the earthquake and tsunami mechanisms. The experts conducted a bathymetry survey to map the fault and identify the submarine landslide locations (Natawidjaja et al. 2021). BIG also used Light Detection and Ranging (Lidar) technology to examine the precise ground elevation and accurately identify the fault (PuSGeN 2019; Natawidjaja et al. 2021).

3.3.3. Hazard map revision for Palu city and the surrounding area

For the hazard map revision of Palu city and the surrounding areas, hazard information collected for the national risk evaluation project (scale 1:50,000) and some immediate new hazard information collected were used. The national risk evaluation information was mainly utilized because its

[1] Following this initial effort, BNPB published the Indonesian Disaster Risk Index (IRBI) in 2018 to show the levels of risk in each district/city and province throughout Indonesia. In this analysis, Central Sulawesi province was identified as an area with high risk, with an index value of 146.39 (where the highest is 173.81 and lowest is 44.80). This considers of all hazard risks, exposure, economic impact, environmental impact, and government capacity.

[2] JICA classifies the earthquake hazard level by the calculated peak ground acceleration. This analysis used a combination of response levels of bedrock and soil amplification by topographic class to certain shocks (see page 38 of the Disaster Risk in Indonesia book (BNPB 2016) for more details).

information was the region's most updated pre-earthquake,[3,4] As in the case of the hazard map development in 2015, all 11 ministries, agencies, and governments[5] involved collectively bore responsibility for revising the region's map. Since the hazard map information is incorporated into the spatial planning, the national ATR was tasked to lead and coordinate multiple entities and overlay the information they provided. BMKG was the ATR's key counterpart, as the earthquake caused massive geophysical damage.[6] For the hazard map revision, field investigations were carried out to assess flowslide (*nalodo*), tsunami, and ground movement damages.[7] These individual hazards were then revised to be integrated into the region's hazard map. The updated map was then incorporated into the 2018 reconstruction and rehabilitation master plan.[8]

While scientists continued exploring the complex geophysical phenomenon induced by the Central Sulawesi earthquake, the 11 ministries, agencies, and governments revised PASIGALA's hazard map (Appendix 2) within the first three months after the earthquake. Given time constraints, the revised hazard map (scale 1:100,000) did not include much of the updated hazard information but designated four levels of hazard zones with associated land use strategies. These are: ZRB 4 (red zone), prohibited zone; ZRB 3 (orange zone), limited zone; ZRB 2 (yellow zone), conditional zone; and ZRB 1 (green zone), development zone. The map was intended to provide risk information to guide local reconstruction paths (See Appendix 3 for details on definitions and criteria for hazard zones). For instance, the red zone (ZRB 4) prohibits any new construction of buildings, instructing residents who had/have residences to relocate. In the orange zone (ZRB 3), construction of new residential buildings and critical/high-occupancy facilities are prohibited. Existing residential buildings in the zone, including those rehabilitated, are instructed to meet the current building code. Having these definitions on the use of land is an effective effort to reduce hazards; however, one of the major challenges lies in the fact that the green zone (ZRB 1) for development is minimally available in the region.

[3]Interview with an ATR staff, Jakarta, November 15, 2019.
[4]Interview with a head of the Provincial ATR, Palu, November 18, 2019.
[5]These included national ministries (BAPPENAS, ESDM, ATR/BPN, PUPR), national agencies (BMKG, BNPB), Central Sulawesi provincial governor and provincial legislature and affected local governments (Palu, Donggala, and Sigi).
[6]Interview with an ATR staff.
[7]Interview with a head of the Provincial ATR.
[8]The scale of the hazard map currently used in the PASIGALA governments are: 1:60,000 for Palu City, 1:200,000 for Sigi Regency, and 1:450,000 for Donggala Regency.

3.4. Tsunami mechanisms, impacts and preventive measures

The magnitude of the tsunami was unexpectedly large for a lateral displacement (strike-slip) fault. This uniqueness made geophysical scientists explore the tsunami mechanisms developed in Palu Bay further. Various papers examining this so far conclude that first, co-seismic tsunami induced by the earthquake alone cannot explain the generated tsunami height, and second, submarine landslides were the primary factor explaining the generation of the tsunami and the resulting coastal damage and significant human loss (e.g. Heidarzadeh, Muhari, and Wijanarto 2019; Sassa and Takagawa 2019; Carvajal et al. 2019; Takagi et al. 2019; Aránguiz et al. 2020; Sepúlveda et al. 2020; Nakata, Katsumata, and Muhari 2020; Nagai et al. 2021).

According to Liu et al. (2020) and Somphong et al. (2022), at least 15 landslide locations were identified around Palu bay. The submarine landslide that occurred on the foreshore of the Buluri area is one of the largest slips among those identified, causing 3.2 million m^3 of seafloor change and making the generated tsunami reach Palu's city center within just a few minutes (Takagi et al. 2019). Figure 4 shows the tsunami heights measured along Palu bay using the survey results by three reconnaissance teams (Omira et al. 2019; Mikami et al. 2019; JICA 2019a). The tsunami heights exhibit irregular patterns, explained by the causal relationship of localized landslides to the tsunamis. For example, the landslide in front of Buluri caused a 10 m high splash right behind it, instantly hitting the coast. Further away, the generated tsunami reached Talise on the opposite shore, causing massive damage due to inundation (Takagi et al. 2019).

As shown in Figure 4, the red zone (ZRB 4) prohibiting rebuilding and new construction is designated throughout the bay with a width of 100 to 200 m. The width of the buffer zone is almost uniformly designated and does not necessarily reflect either the actual or possible future tsunami inundation. Immediately after the earthquake, ADB and JICA proposed two structural measures for the innermost part of the bay (see Figure 3). The first structure, funded by ADB, is a 4 km coastal protection along the coastline, mostly completed three and half years after the earthquake. The structure is a stone revetment with its crest to be set slightly higher than the original ground elevation, aiming to prevent erosion by waves but not expected to significantly reduce future tsunami impacts (see Figure 5). The second structure is a 7 km planned elevated road funded by JICA, which is aimed at reducing tsunami impacts. The road height is 6.5 m above mean sea level, which was determined by referring to the past

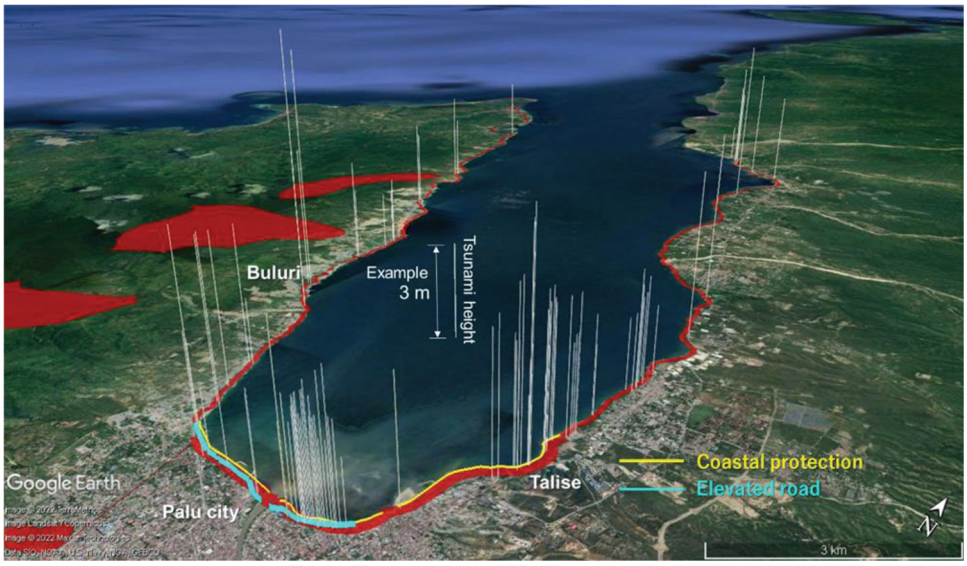
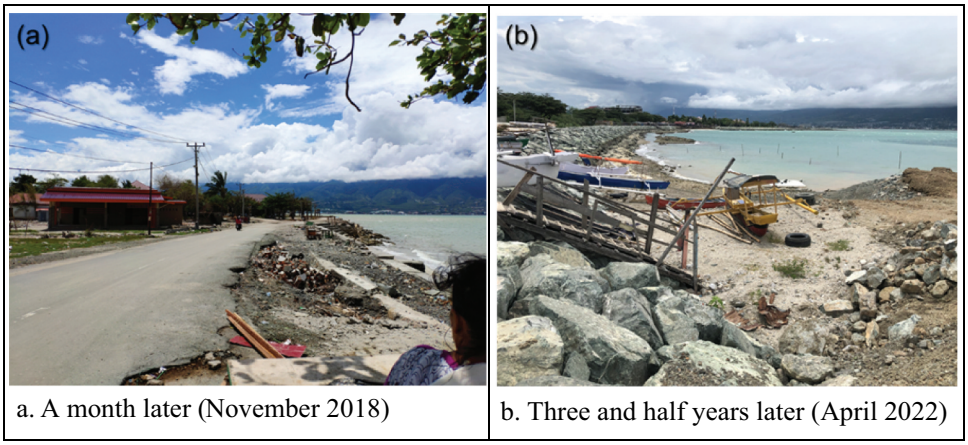


Figure 4. Palu Bay's hazard risk with integrated information of the 2018 tsunami heights (from sea level), coastal protection, elevated road, and designated red zone.



a. A month later (November 2018)

b. Three and half years later (April 2022)

Figure 5. Changes of the Talise coastal area with coastal protection.

records of tsunami inundation depth (PUPR 2019b; JICA 2019b). Because a future tsunami could overtop the elevated road, the design anticipates an inundation of up to 1 m. Thus, for instance, the first floor of the Islamic State Institute (Institut Agama Islam National – IAIN) – Campus I in Palu, is planned to be an open space because it will be built near the coast (Ministry of Public Works and Housing 2020).

In sum, 2018 tsunami heights along Palu Bay determined after more scientific analysis explain that hazard reduction measures (i.e. land use control by red zone enforcement and the two new coastal structures) would only be partially effective in protecting Palu's coastal lands and livelihoods. This shows that a gap exists between the intended outcome of hazard reduction efforts and the actual tsunami impacts that may occur in the future. One of the prominent reasons why PASIGALA's revised hazard map was only able to accommodate a few scientific findings was because of the urgent need to proceed quickly with recovery.

3.5. Hazard-based zoning and zoning enforcement

Higher level governments considered translating hazards into land use zoning critical to rebuilding more safely (Moerwanto and Pratiwi 2019). To apply this, regional governments needed several steps: i) drawing a detailed, local-scaled red zone (ZRB 4) boundary; ii) enforcing the red zone policy; and iii) providing alternative lands to accommodate red zone residents. While PASIGALA's hazard map revision and zone definitions were developed quickly at the higher level, applying them to zoning was difficult. Furthermore, the current red zone situation is different from the original intention to restrict the land from use – residents are using the restricted lands because they have nowhere else to go and to run businesses.

3.5.1. Zoning processes to reduce hazards

Regional governments took two steps to reduce hazards through land use control. The first step was

the designation of the prohibited zone in RTRW. The development scale of this RTRW is suggested at the scale of 1:25,000 and 1:50,000[9] (as per the 2007 National Spatial Act (Law No. 26/2007)); the regional governments needed to incorporate the hazard information represented at the scale of 1:100,000 in the PASIGALA's revised hazard map.[10] In an effort to provide key reference points to define the red zone, national ATR, together with ATR Sulawesi Province, BNPB, BPBD Sulawesi Province, BPBD Palu City, BPBD Sigi Regency, TNI, Police, BMKG, and PuSGeN, held a benchmark survey of the Palukoro fault that crosses Palu City and the coastal areas of Palu Bay between February and March 2019 (PuSGeN 2019). To accurately benchmark the earthquake fault, aerial photo assessment, GPS measurement, and a topographic survey were included in the survey. Given this hazard information, the regional governments had to define the red zone carefully, especially because the land will no longer be available for future use once the zone is set. While the requirements are fairly clear, lack of previous experience in creating such land use zones, lack of consensus, and lack of data at a scale appropriate for zoning made them struggle to develop the RTRW.

The second step was to relocate families who owned a residence pre-earthquake in the newly designated red zone area. Based on an initial verification by the PUPR task force, about 7,097 families, or about 21,000 people, living in the red zone suffered damage to their homes and needed permanent housing in the resettlement sites (Nugracha 2020). This did not include residents who were living in intact houses in the red zone. As for the accommodation sites, the 2018 recovery and reconstruction master plan identified five relocation sites in four locations totaling 922.93 ha following several criteria for site selection. Criteria included: i) least hazards (avoiding ZRB 4 and ZRB 3 lands); ii) in areas classified for development (as opposed to areas classified for protection) with land use; iii) in gentle land-sloped areas (steepness less than 15%); iv) with access to water sources, and v) near the original location of living (See appendix 3 for the selection criteria) (Central Sulawesi Provincial Government 2018). Identified sites are located in, and called: i) Duyu, Palu City (*Huntap* Duyu), ii) Tondo-Talise, Palu City (*Huntap* Tonodo-Talise), iii) Pombewe, Sigi Regency (*Huntap* Pombewe), and iv) + v) a border area of Ngatabaru, Sigi Regency and Petobo, Palu City (*Huntap* Tondo 1 and *Huntap* Tondo 2).

Created by authors using information from PUPR (2021)

Four relocation sites officially began construction[11] in January 2020 to accommodate more than 6,100 housing units (See Figure 6) (PUPR 2021). The last site for construction, *Huntap* Tondo 2, is currently in limbo with an unresolved land ownership issue (Mercusuar Daily Editor 2022).

3.5.2. Issues upon implementation and the current status

Regional governments adopting the red zone boundary faced several issues in enforcing it. First, the national and regional governments used inconsistent approaches to defining the boundary. This ambiguity was due to several legal bases that address hazards in recovery and development from different angles. These included the national spatial act (UU 26/2007), presidential instruction, and the recovery-related decrees (i.e. INPRES 10/2018 and KEPPRES 10/2018). While the national spatial act mandates regional governments to develop their RTRW and update hazard information, the way to define and translate it into zoning are not well-defined (See ATR 2018a) and ATR (2018b).

Second, the hierarchical structure of the government affected the regional governments in leading the red zone decisions. This was evident between the national ATR and the disaster-affected regional governments. ATR believed in its responsibility to reduce future hazard risk, as cited in the recovery and rehabilitation master plan.[12] Consequently, the ATR supported the idea of making the red zone border as large as possible. People would then be out of the unsafe zone and safe from future hazard risks. On the other hand, regional governments sought to keep the red zone area at a minimum because losing so much land for potential future use is disadvantageous. Many areas that newly fell into the red zone – the tsunami-affected coastal and flowslide areas – had premier aesthetic, leisure and livelihood values. Thus, it was socially and financially beneficial for the region to keep these areas usable.

Third, technical issues made the boundary decisions complicated. The red zone scale defined in the PASIGALA's revised map was too small (1:100,000) to be reflected in the local spatial plan (1:25,000/1:50,000). As a result, 3,890 buildings without damage fell inside the ATR's suggested red zone, and those who continued to live in such buildings were reluctant to relocate (Tada 2020). For the regional governments, restricting new buildings and providing houses for those who needed support were acceptable, but pushing households out from their unharmed establishments in the red zone seemed unrealistic.

[9]In section II Paragraph 7, the Local Spatial Plan adopted by the Palu City (Kota Palu RTRW 2021–2041) is explained as the scale of 1:25,000.

[10]Interview with the head of Task Force Coordinator, Palu, November 18, 2019.

[11]Initial construction of some housing on the *huntap* Tondo I site were confirmed in late 2019 during the field investigation by the team members of the EERI LFE program.

[12]Interview with an ATR staff.

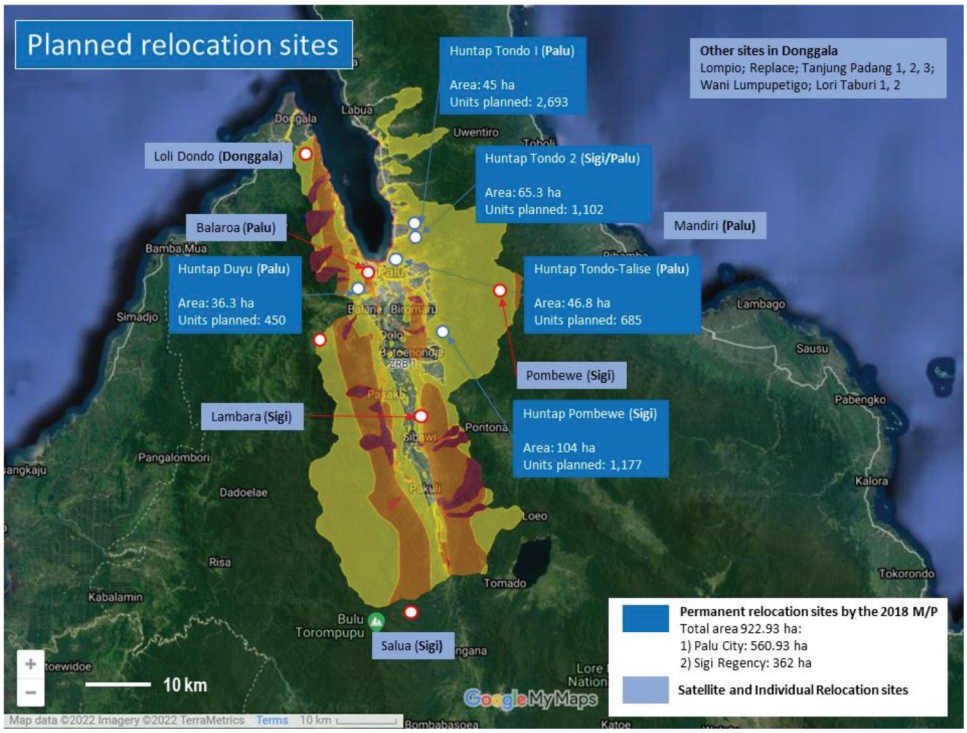


Figure 6. Planned relocation sites and housing units.

Additionally, the 2018 hazard map did not have an opportunity to update geophysical knowledge, as the map revision took place immediately after the disaster.

In sum, the President designated the 2018 Central Sulawesi earthquake a non-national, regional disaster; thus, regional governments were legally responsible for most of the rebuilding effort, including zoning decisions. Yet, the national government agencies in many ways had much more power than the regional governments in making zoning decisions due to the established power balance and the cultural norm.

3.5.3. Current red zone status

While the local spatial map approval continued to take time (Nadjemudin 2021), residents gradually restarted their life post-earthquake. While most of the affected residents were either in the *huntap* or had plans to be relocated to the permanent site, some communities were in limbo. For example, the Kaili resident community in the southern part of Palu Bay (i.e. Kampung Lere) as of March 2022 did not have a government-supported option for permanent residency because of unresolved decisions regarding the appropriate location. With their status in limbo, Lere residents began settling back in their original location after two years, now in the red zones (ZRB 4). Residents who lost their houses constructed shelters on their original properties temporarily (See Figure 7a), and those who could identify their former structures rehabilitated their buildings on site (Figure 7b). These houses are found to be more durable with permanent structures as time passes by (Figure 7c).

New structures also have been built in public spaces in the red zone areas. For instance, in the Talise area in the southeastern part of Palu Bay, many cafe businesses established their stores with lightweight materials behind the ADB's coastal protection infrastructure (Figures 7d, 7e). Furthermore, buildings constructed pre-earthquake (i.e. SMK Talise (Palu State Vocational High School)) in the red zone and damaged by the tsunami were rehabilitated and currently in use (Figure 7F). The current state in which people are using the red zone areas shows that the lives of affected residents are much more complex than the reconstruction design derived from the scientifically-based hazard map information.

3.5.4. Discussion

All the agencies involved in rebuilding from the 2018 earthquake placed a high priority on hazard-risk reduction. This is evident from the explicit hazard-reduction goals of the various recovery and reconstruction plans made by the national and regional governments. Our review of reconstruction activities, however, shows differences between the recovery and rehabilitation master plans and the actual development. There were four reasons for this (See Figure 8 for a discussion summary).

First, the initial hazard map was created before knowing the tsunami's causes. Even now, knowledge of potential future tsunami hazards is still evolving, and the relevant agencies lack a method for evaluating them to incorporate into a revised hazard map. As a result, the hazard map was improvised without time to

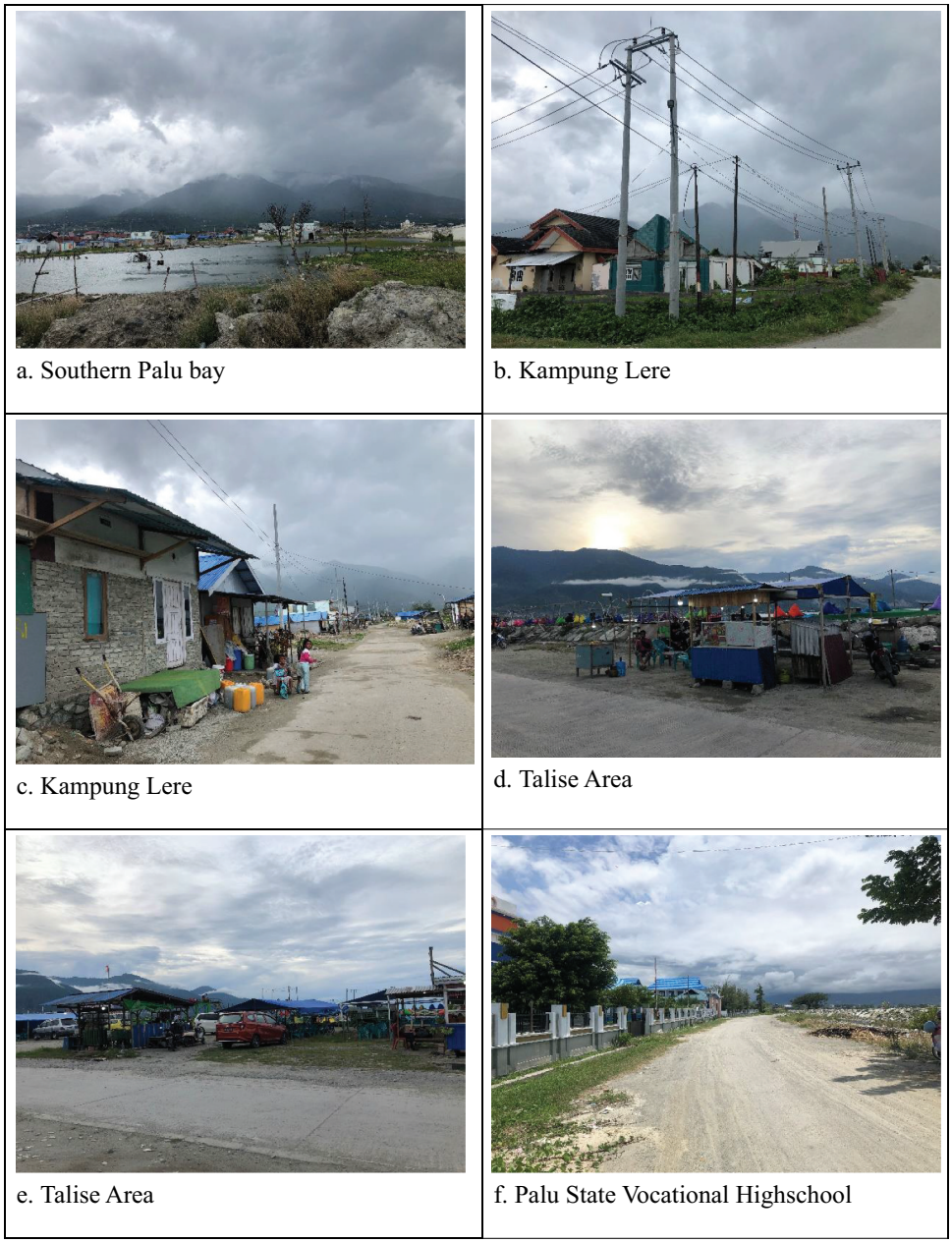


Figure 7. Current red zone status. Note: All photos taken in April 2022.

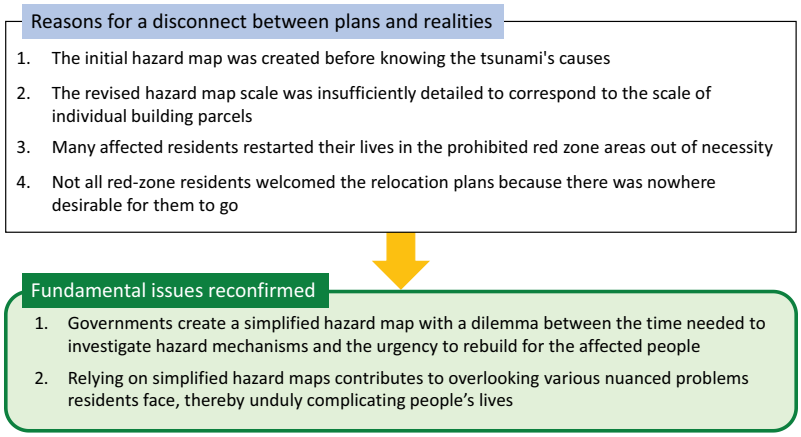


Figure 8. A summary of discussion.

develop accurate data and incorporate new scientific knowledge (as shown in section 3.4).

Second, the hazard map scale was insufficiently detailed to correspond to the scale of individual building parcels. This made it difficult for it to affect building decisions. Local governments found it challenging to delineate a red zone in their zoning maps because the 2018 hazard map scale was smaller than the one adopted for the local zoning (e.g. 1:25,000 for Palu City). As a result, many houses without much damage fell inside the newly designated prohibited zone, which created additional policy challenges.

Third, the reality is that, out of necessity, many affected residents have restarted their lives in the prohibited red zone areas. Although residents are aware of the tsunami risk, they are also concerned about risks to their livelihoods. For example, Hidayah, Satyarno, and Saputra (2020) earlier reported that residents constructed temporary housing in the prohibited areas to continue fishing. Some of the temporary structures are now becoming permanent buildings. Some affected residents had no choice but to return to their original land as their outlook on government-provided permanent housing was uncertain. For many businesses, waterfront locations are essential. On the southeast side of Palu Bay, for example, businesses are returning to access its aesthetics.

Fourth, not all red zone residents welcomed the relocation plans, because there was nowhere desirable for them to go. Many residents expressed reluctance to move into large-scale, distant *huntaps*, that have poor access to services. Acquiring large pieces of land has also been difficult; one planned relocation site is yet to begin construction. As a result, the local governments needed to devise other strategies, including satellite *huntaps* and *mandiri* relocation.

These findings reveal the challenges of hazard map-based rebuilding can boil down to two overriding issues. First, even if one wanted to take a scientific approach by applying probabilistic hazard maps, it is not possible in this instance because the hazard is still under ongoing investigation. But residents cannot afford to wait; they need to rebuild. As a result, officials created simplified maps that could only partially and imperfectly reduce the risk.

Second, relying on simplified hazard maps contribute to overlooking various nuanced problems residents face, thereby unduly complicating people's lives. Livelihoods require proximity to the waterfront, and residents' social and economic networks rely on proximity to each other. As a result, residents resisted relocation that may disrupt their livelihood. This suggests negotiating alternative ways to both protect livelihoods while also substantially reducing (though not necessarily eliminating) tsunami risk is important, but it would require a process and planning instruments more nuanced than these maps. The hazard maps are rigidly based on one variable, which makes it difficult to negotiate an improvement of people's actual lives and livelihoods.

The effort to build back more safely after a terrible disaster by various national and regional agencies was laudable, well-intentioned, and well-coordinated; but relying on a hazard map alone has not, to date, been the best solution for reducing the risks in residents' lives.

3.5.5. Conclusion

In this paper, we described the hazard map-based rebuilding process following the 2018 Central Sulawesi earthquake. In particular, we documented the rebuilding decisions and processes and identified complications when attempting to incorporate hazards into plans, land use, and projects. In addition, we discussed many reasons for the apparent disconnect between the plans and the realities that emerged.

Officials involved in the PASIGALA's rebuilding effort – under great pressure to act after an enormous disaster – are to be commended for placing a high priority on hazards, and this was an admirable attempt, put together under the time pressures and challenges of the aftermath of this unprecedented disaster, and in the context of the nation's risk mapping system. But we also found complications emerging from pursuing the goal of reducing hazard risks, which also applies to other recovery cases across the globe. Fundamental issues on the hazard map-based rebuilding process – governments creating a simplified hazard map for rebuilding under time pressure overlook the complicated lives of the affected people, thus resulting in further disrupting their living – suggests the need to question and revise the current approach to a more sophisticated, flexible, and evolutionary approach. Thus, we suggest that policymakers, planners, and engineers revisit the limitations and opportunities of basing rebuilding decisions on hazard maps alone. We also suggest, from the case we explored, deterministic maps based on a single event can be misleading. The PASIGALA's hazard map was revised based on recent disasters and certain assumptions, but the next disaster could be different. Probabilistic maps that consider long-term hazard would be ideal, but many more years of scientific study of the region would be needed before this can be accomplished.

Our review of the recovery processes in the PASIGALA region raised another layer of questions, regarding how best to balance scientific risk assessments and residents' realities in life recovery. The answer is yet to be provided, but we suggest several future research topics to unpack this issue. First, it is essential to continue exploring the 2018 earthquake mechanism and its physical impacts to understand the complex geophysical dynamics of the region scientifically; this will provide a better scientific foundation for reducing future risks. Second, it is critical

to continue documenting recovery decisions and actions to better understand reconstruction in a region faced with hazards. One of these aspects would be to more deeply explore the successes and setbacks of recovery governance because previous studies (e.g. Iuchi, Jibiki, and Tamayose 2020) suggest that governance structure, such as the initial task forces, could influence recovery outcomes. Third, it is essential to study affected residents' life reestablishment over time to understand the evolution of risk and risk perceptions in the region. For example, it would be valuable to study the effects of housing – whether *in-situ* or *ex-situ* and whether with or without government-led housing supports – on residents' life rebuilding. Although the World Bank conducted a panel survey to explore the recovery status of Central Sulawesi communities, their timeframe was limited to a year and a half (see Purnamasari et al. 2021). Longer-term observation could provide an understanding of the post-disaster adaptive dynamics of the region. Fourth, it is essential to understand how coastal projects implemented by donor agencies will affect the lives of residents. Although international donors seek to support local plans for infrastructure development for disaster risk reduction, infrastructure may not reduce all natural hazard risks, and it can sometimes create new risks for the environment and for residents.

Although we gain benefits from natural science knowledge on risk, these advances take time. Each new disaster event adds significantly to our knowledge, but perhaps not in time to improve recovery from that event. Scientific knowledge evolves over time, but people need to make decisions regarding their daily lives. Thus, at this time of increased awareness of disasters worldwide, we must revisit the limitations and opportunities of natural scientific knowledge, as exemplified through this hazard map-based rebuilding process of the PASIGALA region.

Acknowledgments: This work was supported by the Japan Society for the Promotion of Science under KAKENHI 20H02320 and the Earthquake Engineering Research Institute through its Learning from Earthquakes Program. We are grateful to all the stakeholders who were consulted in Indonesia and to Ghazala Naeem, a member of the EERI LFE team. We also extend our gratitude to anonymous reviewers who provided important comments to improve this manuscript.

Declaration of interest statement: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the Japan Society for the Promotion of Science under KAKENHI 20H02320 and the Earthquake Engineering Research Institute through its Learning from Earthquakes Program. Tohoku Univeristy's Co-creation Center for Disaster Resilience, partially supported this work. We are grateful to all the stakeholders who were consulted in Indonesia and to Ghazala Naeem, a member of the EERI LFE team.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

The work was supported by the Earthquake Engineering Research Institute [LFE program]; (JSPS) Japan Society for the promotion of science [KAKENHI 20H02320]

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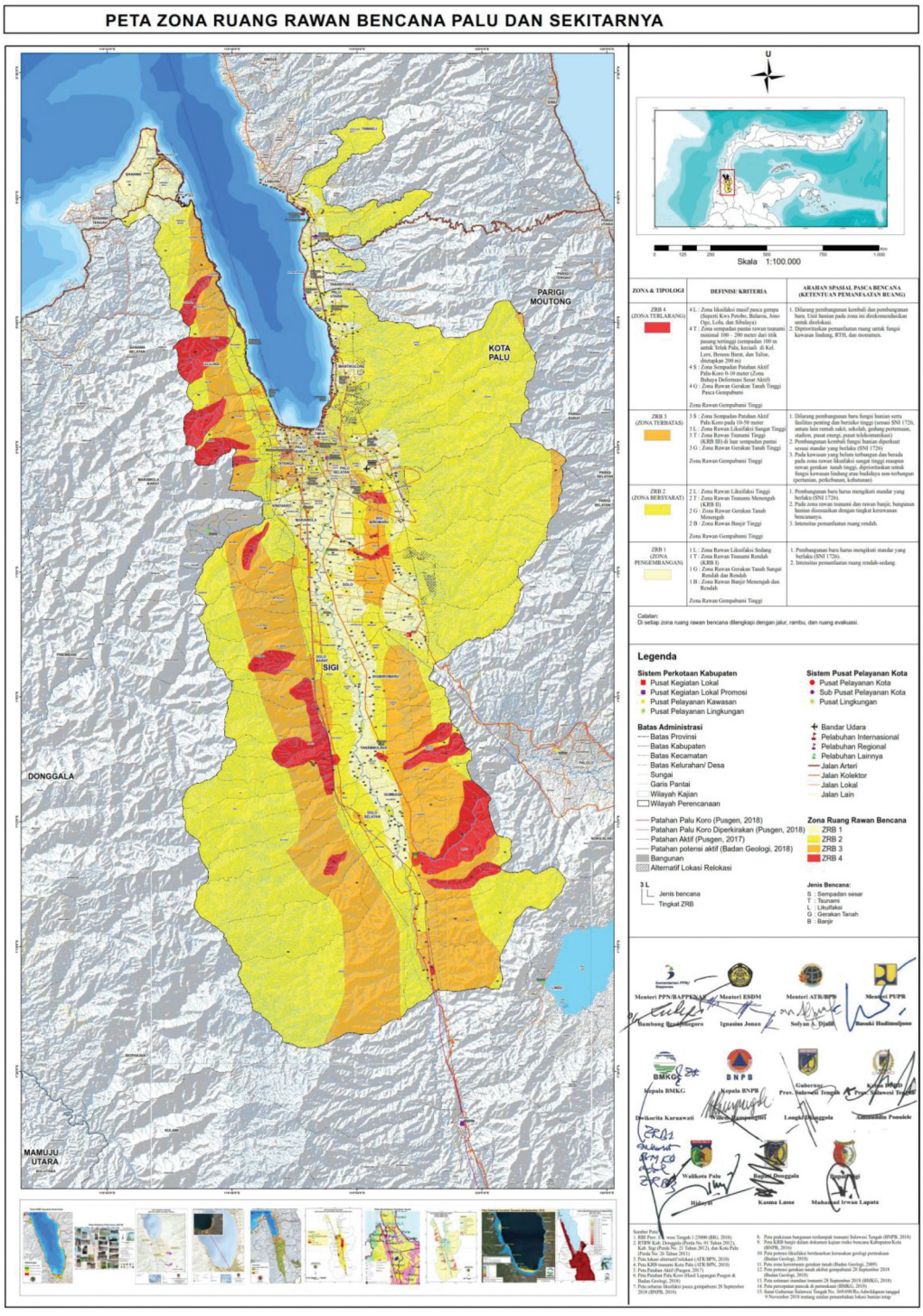
Appendices

Appendix 1. List of abbreviations on Indonesian and English names

Abbreviation	Indonesian	English
ATR	Kementerian Agraria dan Tata Ruang	Ministry of Land and Spatial Planning
BAPPENAS	Badan Perencanaan Pembanguna Daerah	National Development Planning Authority
BIG	Badan Informasi Geospasial	Agency for Geospatial Information
BMKG	Badan Meteorologi, Klimatologi dan Geofisika	Agency for Meteorology, Climatology and Geophysics
BNPB	Badan Perencanaan Pembangunan Nasional	National Disaster Management Authority
BPN	Badan Pertanahan Nasional	National Land Agency
ESDM	Energi dan Sumber Daya Mineral	Ministry of Energy and Mineral Resources
Huntap	Hunian Tetap	Permanent Housing
IMPRES	Instruksi Presiden	Presidential Instruction
KAPP	Tim Koordinasi dan Asistensi Pemulihan dan Pembangunan	Coordination and Assistance Team for Recovery and Development
KEPRES	Keptusan Presiden	Presidential Decree
Kep Walkot	Keptusan Walikota	Decision of City Mayor
KRB	Kawasan Rawan Bencana	Disaster Prone Area
Perka BNPB	Peraturan Kepala BNPB	Regulation of the Head of BNPB
Permen	Peraturan Menteri	Ministerial regulation
PerBup	Peraturan Bupati	Regulation of Regent
PUPR	Kementerian Pekerjaan Umum dan Perumahan Rakyat	Ministry of Public Works and Public Housing
PuSGeN	Pusat Studi Gempa National	National Center for Earthquake studies
RTRW	Rencana Tata Ruang Wilayah	Local Spatial Plan
Satgas	Satuan Tugas	Task Force
SMK	Sekolah Menungah Kejuruan	State Vocational High School
SNI	Standar Nasional Indonesia	Indonesian National Standard
TAA-RR	Tim Adhoc Rehabilitasi dan Rekonstruksi	an *adhoc* rehabilitation and reconstruction team
TNI	Tentara Nasional Indonesia	Indonesian National Armed Forces
UU	Undang-undang	National Law
ZRB	Zona Rawan Bencana	Disaster Prone Zone

Appendix 2: Disaster-Prone Zone Map for Palu City and Surrounding areas



Source: Recovery and Rehabilitation Master Plan (Central Sulawesi Provincial Government 2018)

Appendix 3: Definitions and Criteria on Hazard Zones for the Revised Hazard Map

Zone and typology	Definition/Criteria	Strategies on the post-disaster spatial use (Definitions on the criteria)
ZRB4 (Forbitten Zone)	4 L: Massive post-earthquake liquefaction zone (i.e. Petobo, Balaroa, Jono Oge, Lolu, and Sibalaya areas) 4T: Tsunami-prone coastal border zone, at least 100–200 m from the highest tide point (100 m zones for Palu Bay, excepting Lere, West Besusu, and Talise setting at 200 m) 4S: Active fault border zone, Palu-Koro 0–10 m 4 G: Post-earthquake high ground movement prone zone High Earthquake Prone Zone	1. Rebuilding and new construction are prohibited. Residential units in this zone are recommended to be relocated. 2. Prioritize the use of space for functions as protected areas, green and open space, and monuments.
ZRB 3 (Restricted Zone)	3S: Active Fault Border Zone Palu-Koro at 10–50 m 3 L: Very High Liquefaction Prone Zone 3T: High Tsunami Prone Zone (KRB III) outside the beach border 3 G: High Ground Movement Prone Zone High Earthquake Prone Zone	1. New residential buildings, high-occupancy facilities, and critical buildings are prohibited for building (according to SNI 1726, including hospitals, schools, conference halls, stadiums, energy centers, telecommunications centers) 2. Redevelopment of residential buildings need to meet the current building code (SNI 1726). 3. Undeveloped areas prone to liquefaction and ground movement are prioritized for green use (agriculture, plantation, forestry)
ZRB 2 (Conditional zone)	2 L: High Liquefaction Prone Zone 2T: Medium Tsunami Prone Zone (KRB II) 2 G: Intermediate Ground Movement Prone Zone 2B: High Flood Prone Zone High Earthquake Prone Zone	1.New developments must adopt the standard required in the building code (SNI 1726). 2. In tsunami-prone and flood-prone zones, residential buildings are adjusted to the level of disaster vulnerability. 3. Low intensity on the use of space.
ZRB 1 (Development zone)	1 L: Medium Liquefaction Prone Zone IN: Low Tsunami Prone Zone (KRB I) 1 G: Low Ground Movement Prone Zone 1B: Medium and Low Flood Prone Zone High Earthquake Prone Zone	1.New developments must adopt the standard required in the building code (SNI 1726). 2. Low-medium intensity on the use of space

Source: Disaster-Prone Zone Map for Palu City and Surrounding areas (Central Sulawesi Provincial Government 2018).