National Development Planning Agency (BAPPENAS)

Project for Development of Regional Disaster Risk Resilience Plan in Central Sulawesi in the Republic of Indonesia

FINAL REPORT
(Volume I)

November 2021

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

JICA Expert, Comprehensive Disaster Risk Reduction, BNPB
JICA Expert, Integrated Water Resources Management, PUPR

Yachiyo Engineering Co., Ltd.
Oriental Consultants Global Co., Ltd.
Nippon Koei Co., Ltd.
Pacific Consultants Co., Ltd.
PASCO CORPORATION

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JR
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Preface

In response to a request from the Government of Indonesia, the Japan International Cooperation Agency (hereinafter referred to as “JICA”) assisted on understanding the disaster situation and formulated a Reconstruction Master Plan. The assistance started by dispatching the first survey team to collect information on the disaster situation and emergency assistance in October 2018. In addition, discussions on future seamless recovery and reconstruction assistance measures were held with related Indonesian organizations, such as Bappenas. As a result, the Indonesian government requested JICA to implement a technical cooperation project for the recovery from the disaster, and it has been decided to implement this project (implementation period: December 2018 to November 2021): “Project for Development of Regional Disaster Risk Resili ence Plan in Central Sulawesi in the Republic of Indonesia” (hereinafter referred to as “the Project”). JICA entrusted the Project to Yachiyo Engineering Co., Ltd., Oriental Consultants Global Co., Ltd., Nippon Koei Co., Ltd., Pacific Consultants Co., Ltd., and PASCO CORPORATION.

Regarding the assistance for formulating the Reconstruction Master Plan, after the first survey team was dispatched immediately after the disaster in October 2018. Naoto TADA, JICA Expert of Comprehensive Disaster Risk Reduction, BNPB, and Jun HAYAKAWA, JICA Expert of Integrated Water Resources Management, PUPR (hereinafter referred to as "JICA Experts"), led the formulation of the Reconstruction Master Plan. To continue the seamless and reliable knowledge transfer from this Reconstruction Master Plan formulation assistance, JICA experts also provided guidance to the study team of the Project. The Project cited some charts created by the JICA experts during the Reconstruction Master Plan formulation.

This final report summarizes the results of JICA experts and the study team’s activities in the Project, and the findings from Japanese experts who participated in Japanese Support Committee.

In addition, using a part of the Project results as basic data, in June 2019, during the implementation period of the Project, a Grant Agreement (G/A) was signed for “The Programme for the Reconstruction of Palu 4 Bridges in Central Sulawesi Province”, which is the core infrastructure in the disaster area. Furthermore, in January 2020 an ODA Loan Agreement (L/A) was signed for the “Infrastructure Reconstruction Sector Loan in Central Sulawesi”, to promote infrastructures reconstruction such as roads, bridges, irrigation facility, rivers, and reconstruction of public facility (hospital).

Final Report Structure

The final report consists of a summary, main report and appendix. The detail results of the project are described in the main report. The main report consists of Volume I to Volume V.

Summary (English)

* Essential part from summary (Outline and Recommendation) is translated to Bahasa Indonesia and included in the report.

Main Report (English)

Volume I	Outline of the Project
Volume II	Disaster Hazard Assessment and Hazard Map
Volume III	Formulation of Spatial Plan Based on Disaster Hazard and Risk Assessment
Volume IV	Resilient Infrastructure and Public Facilities
Volume V	Livelihood Recovery and Community Restoration

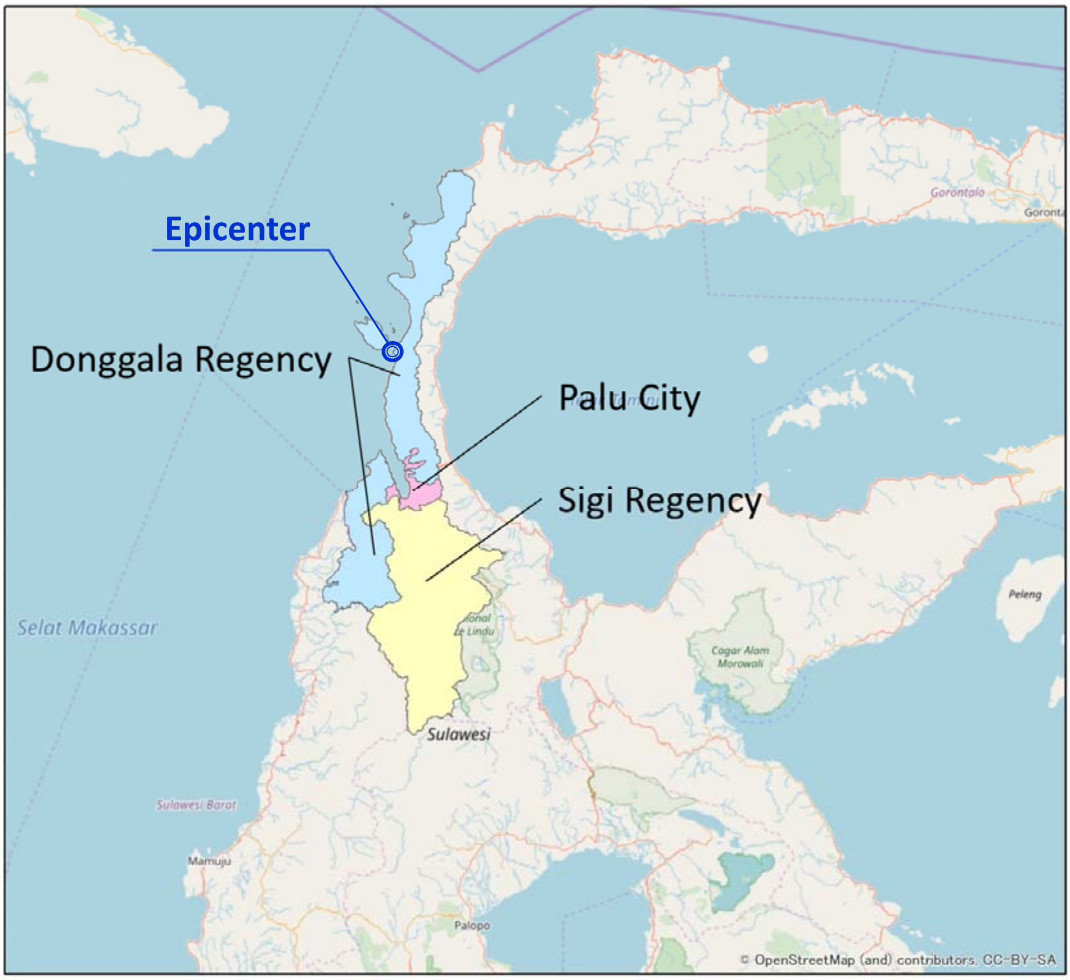
Appendix

US Dollar $ 1.00 = Indonesia Rupiah IDR 14,021.59 = Japanese yen ¥ 103.90
(February 2021)

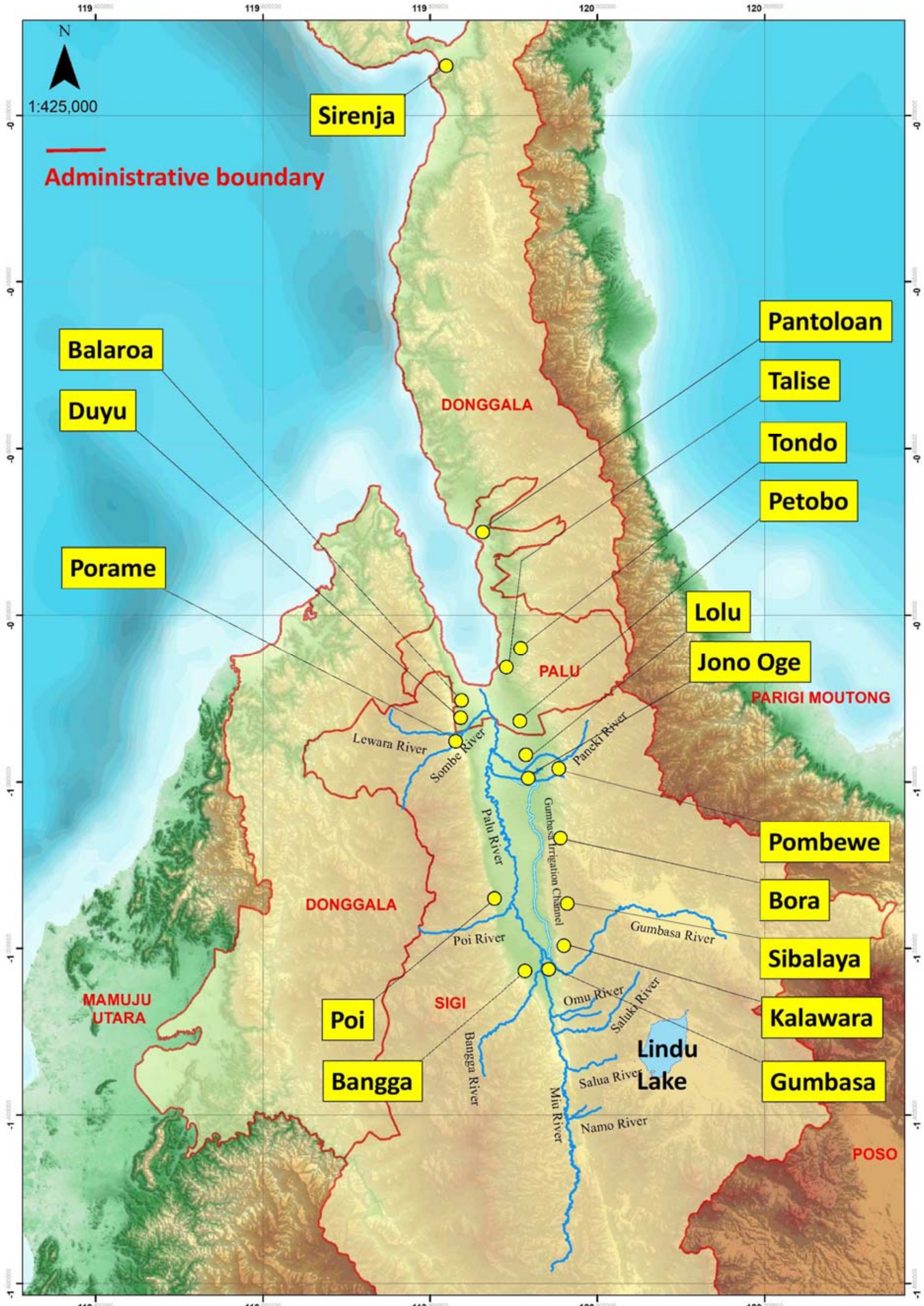
Location Map of the Project Area

Location of Central Sulawesi Province

Location of Disaster Affected Area and Epicenter (Palu City, Sigi Regency and Donggala Regency)



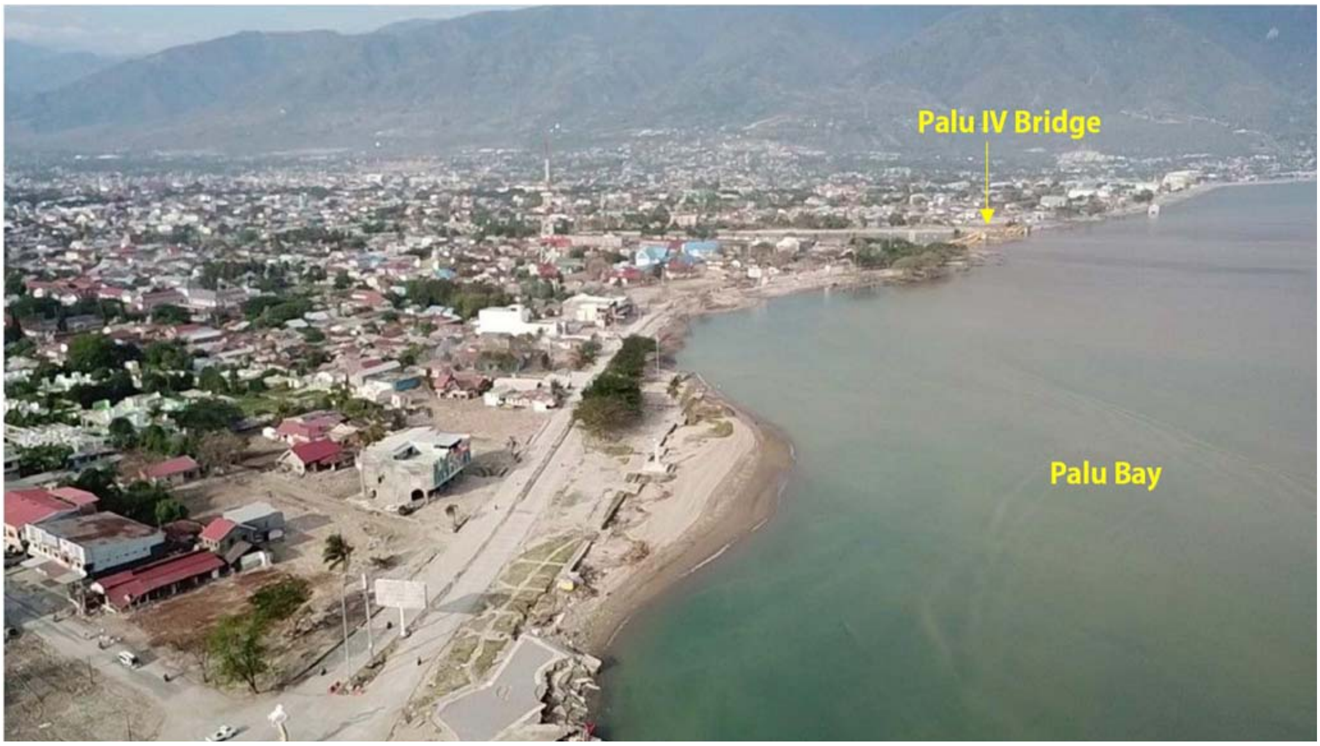
Location of Target Area in the Project



Source: Prepared by JICA Study Team based on Data from the Geospatial Information Authority of Indonesia (BIG)

Lead-off Photos (1/7)

Damage Conditions



Condition of the Coastal Area of Palu Bay After the Disaster (Right Shore Side, Drone Shooting)

Condition of the Coastal Area of Palu Bay After the Disaster (Left Shore Side, Drone Shooting)

Lead-off Photos (2/7)

Damage Conditions

The Palu IV Bridge located at the Palu River Estuary was Collapsed by the Earthquake.

Collapsed Coastal Road along the Palu Bay

Damaged Buildings by Tsunami Inundation (100m to 450m from the Coast) (On the Right Shore of Palu Bay)

Damaged Port Facilities in the Palu Bay

(The Photo is SAMAS Container Jetty on the Left Shore of Palu Bay)

Damaged Road by Nalodo (Palu City)

Damaged in Sibalaya Area by Nalodo (Sigi Regency, Drone Shooting)

Lead-off Photos (3/7)

Damage Conditions

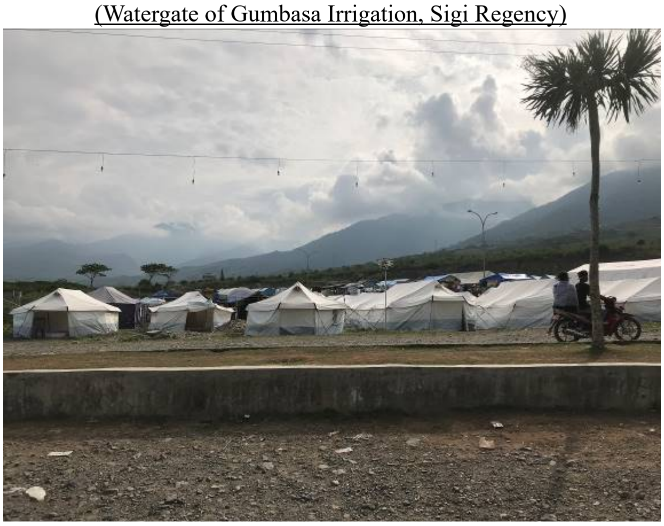
Damaged Caused by Floods and Landslides (Bangga River, Sigi Regency)

Sediment Disaster Caused by Debris Flow (Salua River, Sigi Regency)

Collapsed buildings by the Earthquake (Pal City)

Damaged Irrigation Facilities by Ground Deformation (Watergate of Gumbasa Irrigation, Sigi Regency)

Damaged in Sirenja Area by Inundation (Donggala Regency)



Evacuation Shelter Built in Balaroa District of Palu City After the Disaster

Lead-off Photos (4/7)

Stakeholder Discussions and Field Surveys

The First Joint Coordinating Committee (February 17, 2019)

Discussions with the Ministry of Land and Spatial Planning (ATR) and the National Land Agency (BPN)
(March 21, 2019)

Discussions on Infrastructure Reconstruction Plans with the Ministry of Public Works and National Housing (PUPR)
(February 18, 2019)

The Second Joint Coordinating Committee (August 6, 2019)

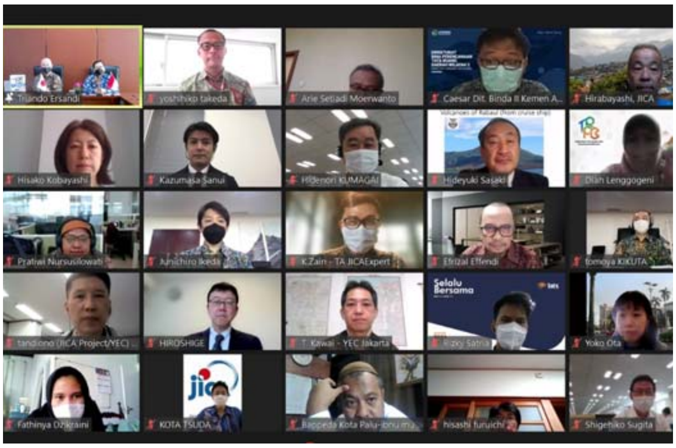
The Third Joint Coordinating Committee（December 11, 2019）

Discussion on the Japanese Support Committee (Nalodo)
(March 25, 2019)

Lead-off Photos (5/7)

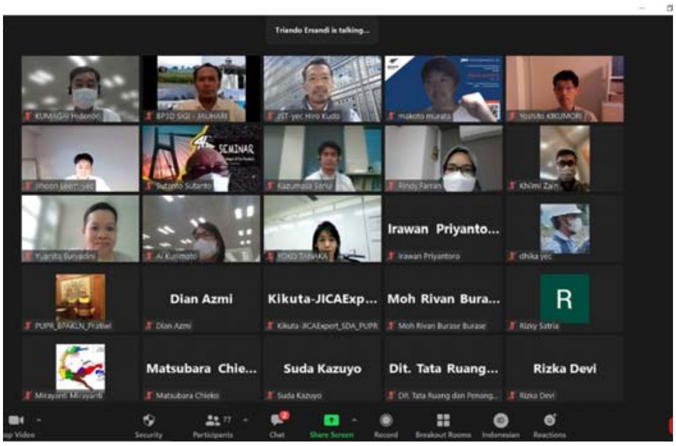
Stakeholder Discussions and Field Surveys

The Final Joint Coordinating Committee (October 6, 2021)
In Bappenas Meeting Room (Onsite participation)



The Final Joint Coordinating Committee (October 6, 2021)
By web communication tool (Online participation-1)

The Final Joint Coordinating Committee (October 6, 2021)
By web communication tool (Online participation-2)



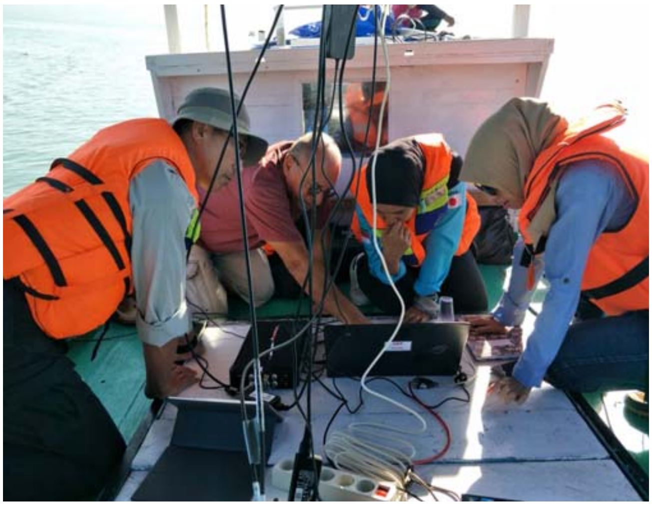
The Final Joint Coordinating Committee (October 6, 2021)
By web communication tool (Online participation-3)

Closing Ceremony – Handover report (October 6, 2021)

Closing Ceremony – Group picture (October 6, 2021)
(left-right); Mr. Ikeda; Mr. Kikuta; Mr. Fukushima; Mr. Tsuda, Mr. Sumedi, Ms. Lenggo

Lead-off Photos (6/7)

Stakeholder Discussions and Field Surveys



Reflection seismic survey of Palu Bay (Output 1 Activity)

A survey conducted to understand the geological composition and structure of the seabed at the southern of the Palu Bay, including the area around the Palu River Estuary (total 29.6 km).

Discussion with the Ministry of Land and Spatial Planning (ATR)
(Output 1 and Output 2 Activities, April 11, 2019)

Discussion with Local Government (Central Sulawesi)
(Output 2 Activity, March 18, 2019)

Discussion on Anutapura Hospital Design Review
(Output 3 Activity- Public Facilities Sector, April 9, 2019)

Palu IV Bridge Field Survey (Output 3-Road and Bridge Sector)

Survey for reconstruction of the collapsed Palu IV Bridge (January-May 2019).

Pilot Project Activities in Balaroa Shelter (Output 4 Activity)

Training was conducted twice to introduce Silar leaves weaving as an activity to obtain income in a short term.

Lead-off Photos (7/7)

Stakeholder Discussions and Field Surveys

Pilot Project Activities in Balaroa Shelter (Output 4)

Small culinary business activities were carried out by the groups of victims of the Balaroa evacuation shelter

Pilot Project Activities in M'panau Village (Output 4)

Training was conducted to improve the construction skills for the victims in the community in collaboration with vocational schools in the Province

Pilot Project Activities in M'panau Village (Output 4)

A MSMEs Centre was built to support the improvement of livelihood through micro business entities

Pilot Project Activities in Lero Tatari Village (Output 4)

20 fishing boats were provided to support the recovery of livelihood activities of a group of 40 fishermen.

Pilot Project Activities in Lero Tatari Village (Output 4)

Training on new processing technology of *Ikan Teri* (White bite) was conducted in cooperation with the department of SMEs in Central Sulawesi Province.

Pilot Project Activities in Lero Tatari Village (Output 4)

DRR education seminar was conducted for the pilot project beneficiaries by BPBD together with inviting BMKG and BASARNAS as lecturers

List of Abbreviation

Abbreviation	Indonesian Language	English
Organization / Institution		
AASHTO	ー	American Association of State Highway and Transportation Officials
ACT	Aksi Cepat Tanggap	Quick Response Action
ADB	Bank Pembangunan Asia	Asian Development Bank
ADRA	ー	Adventist Development and Relief Agency
AMC	ー	Anutapura Hospital Medical Center
ASB	ー	Arbiter Samariter Bund
ATR	Kementerian Agraria dan Tata Ruang	Ministry of Land and Spatial Planning
AusAID	ー	Australian Agency for International Development
BAPPEDA	Badan Perencanaan Pembangunan Daerah	Regional Development Planning Agency
BAPPENAS	Badan Perencanaan Pembangunan Nasional	National Development Planning Agency
BG	Badan Geologi	Geological Agency
BIG	Badan Informasi Geospasial	Agency for Geospatial Information
BM	Bina Marga	Directorate General of Highways
BMKG	Badan Meteorologi, Klimatologi dan Geofisika	Agency for Meteorology, Climatology and Geophysics
BNPB	Badan Nasional Penanggulangan Bencana	National Disaster Management Authority
BPBD	Badan Penanggulangan Bencana Daerah	Regional Disaster Management Authority
BPN	Badan Pertanahan Nasional	Provincial land agency
BPPW	Balai Prasarana Permukiman Wilayah	Regional Settlement Infrastructure Center
BSN	Badan Standardisasi Nasional	National Standardization Agency
BWS	Balai Wilayah Sungai	River Basin Development Agency
Cipta Karya	ー	Directorate General of Human settlements
CRS	ー	Catholic Relief Services
CWS	ー	Inanta Church World Service
DGST	Direktorat Jenderal Perhubungan Laut (DirJen Hubla)	Directorate General of Sea Transportation
Dinas	ー	Agency
DKP	Dinas Kelautan dan Perikanan	Agency of Marine Affairs and Fisheries (at regional level)[1]
DLH	Dinas Lingkungan Hidup	Environmental Agency (at regional level)
DPMPTSP	Dinas Penanaman Modal dan Perijinan Terpadu Satu Pintu	One-stop office of integrated Investment and Permit Services
DPRP	Dinas Penataan Ruang dan Pertanahan	Local Spatial Planning and Land Service Agency
EA	ー	Executing Agency
ESDM	Energi dan Sumber Daya Mineral	Ministry of Energy and Mineral Resources
FAO	Organisasi Pangan dan Pertanian Dunia	Food and Agriculture Organization
GOI	Pemerintah Negara Republik Indonesia	Government of Indonesia
HAKI	Himpunan Ahli Konstruksi Indonesia	Association of Indonesia construction expert
HATTI	Himpunan Ahli Teknik Tanah Indonesia	Indonesian Society For Geotechnical Engineering[2]

[1] Note: DKP at regional level (D = Dinas); KKP at national level (K=Kementerian/Ministry).

[2] Source: https://www.hatti.or.id/

Abbreviation	Indonesian Language	English
IFRC	—	International Federation of Red Cross and Red Crescent
ILO	Organizasi Pekerja Internasional	International Labour Organization
INGO	Lembaga Swadaya Masyarakat Internasional	International Non-Governmental Organization
INKINDO	Ikatan Nasional Konsultan Indonesia	National association of Indonesian Consultant
JCC	Komite Koordinasi	Joint Coordinating Committee
JFPR	—	Japan Fund for Poverty Reduction
JICA	—	Japan International Cooperation Agency
JST	Tim Studi JICA	JICA Study Team
KfW	Lembaga Pendanaan untuk Rekonstruksi - Jerman (Kreditanstalt für Wiederaufbau)	A German State-owned Development Bank
KKP	Kementerian Kelautan dan Perikanan	Ministry of Maritime Affairs and Fisheries
KPKPST	Kelompok Perjuangan Kesetaraan Perempuan Sulawesi Tengah	Central Sulawesi Women's Equality Group
LNGO	Lembaga Swadaya Masyarakat Lokal	Local Non-Governmental Organization
LTF	Satuan Tugas Lokal	Local Task Force
MCI	—	Mercy Corps Indonesia
MDMC	Pusat Manajemen Bencana Muhammadiyah	Muhammadiyah Disaster Management Center
Ministry of Cooperatives and SMEs	Kementerian Koperasi dan Usaha Kecil dan Menengah, Republik Indonesia	Ministry of Cooperatives and Small and Medium Enterprises
MOT	Kementerian Perhubungan	Ministry of Transport
NGO	Lembaga Swadaya Masyarakat (LSM)	Non-Governmental Organization
OGD	Departemen Kebidanan dan Kandungan[3]	Obstetrics and Gynecology Department
PARCIC	—	PARC Interpeoples' Cooperation
PMI	Palang Merah Indonesia	Indonesian Red Cross Societies
PUPR	Kementerian Pekerjaan Umum dan Perumahan Rakyat	Ministry of Public Works and Public Housing
PuSGen	Pusat Studi Gempa National	National Center for Earthquake Studies
PUSKIM	Pusat Kebudayaan Indonesia	Indonesian Cultural Center
SATGAS	Satuan Tugas	Task Force
SDA	Direktorat Jenderal Sumber Daya Air	Directorate General of Water Resources
SKP-HAM	Solidaritas Korban Pelanggaran Hak Asasi Manusia	Solidarity of Victims of Human Rights Violations
TABG	Tim Ahli Bangunan Gedung	Building Construction Expert Team
TKPRD	Tim Koordinasi Penataan Ruang Daerah	Regional Spatial Planning Coordination Team
UN	Persatuan Bangsa-Bangsa (PBB)	United Nations
UNDP	—	United Nations Development Programme
UNFPA	—	United Nations Fund for Population Activities
UNHCR	—	United Nations High Commissioner for Refugees
UNICEF	—	United Nations International Children's Emergency Fund
WB	Bank Dunia	World Bank
WFP	Program Pangan Dunia	United Nations World Food Programme
WHO	—	World Health Organization
WVI	Wahana Visi Indonesia	World Vision Indonesia
YEU	Unit Gawat Darurat Yakkum	*Yakkum* Emergency Unit

[3] In private hospitals as well as universities, commonly they use the term *Obstetri dan Ginekologi*

Abbreviation	Indonesian Language	English
YPAL	Yayasan Panorama Alam Lestari Kabupaten Poso	*Panorama Alam Lestari* Foundation, Poso Regency
YPI	Yayasan Pusaka Indonesia	Indonesian Heritage Foundation
YSTC	Yayasan Sayangi Tunas Cilik	Save The Children Foundation
Regulation / Plan		
EPMA	Undang-Undang Tentang Perlindungan dan Pengelolaan Lingkungan Hidup	Environmental Protection and Management Law
IMB	Izin Mendirikan Bangunan	Building Permit
KDB	Koefisien Dasar Bangunan	Building Coverage Ratio
KLB	Koefisien Lantai Bangunan	Floor Area Ratio
PERDA	Peraturan Daerah	Local regulation
PP	Peraturan Pemerintah	Government Regulation
PRR	Laporan Kemajuan	Progress Report
RAB	Rancangan Anggaran Biaya	Budget Plan
RDTR	Rencana Detail Tata Ruang	Detailed Spatial Plan
RSNI	Rancangan Standar Nasional Indonesia	Draft Indonesian National Standard
RTRW	Rencana Tata Ruang Wilayah	General Spatial Plan
RTRWN	Rencana Tata Ruang Wilayah Nasional	National spatial plan
RW	Rukun Warga	Neighbourhood unit[4]
SEA	Kajian Lingkungan Hidup Strategis (KLHS)	Strategic Environmental Assessment
SNI	Standar Nasional Indonesia	National Standard of Indonesia
UKL-UPL	Upaya Pengelolaan Lingkungan Hidup dan Upaya Pemantauan Lingkungan Hidup	Environmental Management Efforts and Environmental Monitoring Efforts
ZRB	Zona Rawan Bencana	Disaster Prone Zone
Others		
AP	Rencana Aksi	Action Plan
APBN	Anggaran Pendapatan dan Belanja Negara	State budget
ASTER	—	Advanced Space-borne Thermal Emission and Reflection
Banpem	Bantuan Pemerintah	Government Assistance
BARRATAGA	Bangunan Rumah Rakyat Tahan Gempa	Earthquake Resistant Housing
BBB	Membangun Kembali dengan Lebih Baik	Build Back Better
BCP	Rencana Kelanjutan Bisnis	Business Continuity Plan
BLM	Bantuan Langsung Masyarakat	Community Direct Assistance
BMS	Sistem Manajemen Jembatan	Bridge Management System
BoQ	—	Bill of Quantity
BTP	—	Brownian Passage Time
BUMDes	Badan Usaha Milik Desa	Village-Owned Company
BWP	Bagian Wilayah Perencanaan	Part of the Planning Area
C/P	—	Counter Part
CBD	Kawasan Niaga Terpadu	Central Business District
CCT	Pembayaran Tunai Bersyarat	Conditional Cash Payment
CRED	—	Centre for Research on the Epidemiology of Disasters
CSO	Organisasi Masyarakat Sipil (ORMAS)	Civil Society Organization
CSR	Tanggungjawab Sosial Korporat	Corporate Social Responsibility

[4] In urban area (especially Java Island), RW is a neighbourhood unit below Village Level. Smaller unit is RT (Rukun Tetangga). 1 RT consist of 10-50 Households and 1 RW consist up to 10 RT.

Abbreviation	Indonesian Language	English
DED	—	Detail Engineering Design
DEM	—	Digital Elevation Model
DFR	Draf Laporan Akhir	Draft Final Report
DG	Direktur Jenderal (Dirjen)	Director General
DRR	Pengurangan Risiko Bencana (PRB)	Disaster Risk Reduction
DTM	—	Digital Terrain Model
EIA	Analisis Mengenai Dampak Lingkungan (AMDAL)	Environmental Impact Assessment
EMP	Rencana Pengelolaan Lingkungan	Environmental Management Plan
EMoP	Rencana Pemantauan Lingkungan	Environmental Monitoring Plan
ER	Tanggap Darurat (TD)	Emergency Response
ESMF	—	Environmental and Social Management Framework
EWS	Sistem Peringatan Dini	Early Warning System
EXPO	—	Exposition
FGD	—	Focus Group Discussion
FLSH		
FR	Laporan Akhir	Final Report
F/S	Studi Kelayakan	Feasibility Study
G/A	Perjanjian Hibah	Grant Agreement
GBV	—	Gender-Based Violence
GC	Kondisi Umum	General Conditions
GERTASKIN	Program Gerakan Pengentasan Kemiskinan	Poverty Alleviation Program
GIS	Sistem Informasi Geografis (SIG)	Geographic Information System
GL	Panduan	Guide Line
GRP	Produk Regional Bruto	Gross Regional Product
HIV	—	Human Immunodeficiency Virus
Huntap	Hunian Tetap	Permanent Relocation Site
Huntara	Hunian Sementara	Temporary Housing Site
ICR	Laporan Awal	Inception Report
IDR	Rupiah	Indonesian Rupiah
ITR	Laporan Sementara	Interim Report
IKM	Industri Kecil Menengah	Small and Medium Industries
IMB	Ijin Mendirikan Bangunan	Procedures of building permit
IPAL	Instalasi Pengolahan Air Limbah	Wastewater Treatment Plant
IPLT	Intalasi Pengelolaan Limbah Tinja	Faecal sludge treatment plant
ITB	—	Instructions to Bidders
IUMK	Izin Usaha Mikro Kecil	Micro Small Business Permit
JET	—	Japan Exchange and Teaching
KRK	Keterangan Rencana Kota	City Plan Description
L/A	Perjanjian Pinjaman	Loan Agreement
LGBTQ+	—	Lesbian, Gay, Bisexual, Transgender, Questioning, etc.
LLC	—	Level Luffing Crane
Linsek	Lintas Sektor	Inter Sector
LPG gas	—	Liquefied Petroleum gas
MD	Risalah Diskusi	Minutes of Discussion
MEP	Mekanikal, Elektrikal dan Perpipaan	Mechanical, Electrical and Plumbing
M/M	Risalah Rapat	Minutes of Meeting
MKK	Mengawasi Kondisi Konstruksi	Construction supervising works

Abbreviation	Indonesian Language	English
MOU	Nota Kesepahaman	Memorandum of Understanding
M/P	Rencana Induk	Master Plan
MSMEs	UMKM	Micro Small and Medium Enterprises
MTU	Unit Pelatihan *Mobile*	Mobile Training Unit
ODA	–	Official Development Assistance
OP	Keluaran	Output
PASIGALA	Kota Palu, Kabupaten Sigi dan Kabupaten Donggala	Palu city, Sigi Regency and Donggala Regency
PGA	–	Peak Ground Acceleration
PTHA	–	Probabilistic Tsunami Hazard Assessment
PC	Konsultasi Publik	Public Consultation
Persub	Persetujuan Substansi	Substantial Approval (on the Spatial Plan)
POKJA	Kelompok Kerja	Working Team
POKMAS	Kelompok Masyarakat	
PPP	Kebijakan, Rencana dan Program	Policies, Plans and Program
PPs	Proyek Percontohan	Pilot Projects
PQ	Prakualifikasi	Pre-qualification
PRR	Laporan Perkembangan	Progress Report
PSHA	–	Probabilistic Seismic Hazard Assessment
PV	–	Photo Voltaic System
QGC	–	Quay Gantry Crane
RB	Rusak Berat	Severely damaged
RD	Risalah Diskusi	Record of Discussion
R/D	Riset dan Pembangunan	Research and Development
RKPD	Rencana Kerja Perangkat Daerah	Regional Government Work Plans
LARAP	Rencana Aksi Pembebasan Lahan dan Pemindahan Pemukiman	Land Acquisition and Resettlement Action Plan
RRI	–	Rainfall Runoff Inundation
RS	Rusak Sedang	Moderately damaged
RT	Rukun Tetangga	Neighbor Association
SD	Sekolah Dasar	Primary school
SHMs	–	Stakeholder meetings
SLF	Sertifikat Laik Fungsi	Certificate of Building Performance and Function
SMEs	Usaha Kecil dan Menengah (UKM)	Small and medium-sized enterprises
SMP	Sekolah Menengah Pertama	Middle School
SNS	Layanan Jejaring Sosial	Social Networking Service
SOP	Standar Prosedur Operasi	Standard Operational Procedure
SPPL	Pernyataan Kesanggupan Pengelolaan dan Pemantauan Lingkungan Hidup	Statement of Environmental Management and Monitoring Undertaking
TA	Bantuan Teknis (Bantek)	Technical Assistance
ToR	Kerangka Acuan Kerja (KAK)	Terms of Reference
TPA	Tempat pembuangan akhir	Landfill
WASH	Air, Sanitasi, Kebersihan	Water, Sanitation, Hygiene

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Volume I Outline of the Project

Chapter 1 Project Background

On September 28, 2018, a 7.5-magnitude[1] (Mw 7.4) earthquake (hereinafter referred to as “the earthquake”) struck Palu, the capital city of Sulawesi Province, in Central Indonesia, with an epicenter 80 km north of the city. The main earthquake damage was caused by the liquefaction and landslides in inland areas, and tsunami and seismic activity in coastal areas. In addition, the collapse of bridge, damage of port facilities, water supply facilities, irrigation canals, and disruption of public facilities such as hospitals and schools were mainly observed in Palu City, Sigi Regency, and Donggala Regency. According to the information published by Central Sulawesi Province in April 2019, 4,547 people were dead or missing, 172,999 people were affected, 100,405 houses were damaged, and the economic loss was 5 trillion Indonesian rupiah or IDR (approximately 37 billion Japanese yen).

For the recovery and reconstruction from the Central Sulawesi Province earthquake disaster (hereinafter referred to as “the disaster”), the National Development Planning Agency (hereinafter referred to as “Bappenas”), established a strategic task force (hereinafter referred to as “TF”) in December 2018, and formulated a reconstruction master plan (hereinafter referred to as “reconstruction M/P”). Based on the reconstruction M/P, it was decided to formulate various reconstruction plans and proceed with the reconstruction assistance projects.

In response to a request from the Government of Indonesia, the Japan International Cooperation Agency (hereinafter referred to as “JICA”) assisted on understanding the disaster situation and formulated a reconstruction M/P. The assistance started by dispatching the first survey team to collect information on the disaster situation and emergency assistance in October 2018. In addition, discussions on future seamless recovery and reconstruction assistance measures were held with related Indonesian organizations, such as Bappenas. As a result, the Indonesian government requested Japan to implement a technical cooperation project for the recovery from the disaster, and it has been decided to implement this project: “Project for Development of Regional Disaster Risk Resilience Plan in Central Sulawesi in the Republic of Indonesia”, (hereinafter referred to as “the Project”).

Chapter 2 Project Objective

(1) Objective of the Project

The Project will promote accurate and smooth reconstruction and realize a more resilient reconstruction (Build Back Better, herein after referred to as “BBB”) by formulating and assisting the implementation of post-disaster reconstruction plans in the Central Sulawesi Province. With the aim of contributing to the formation of a resilient society, a technical cooperation for development planning is implemented.

[1] Magnitude (Mw) is calculated based on the displacement of underground rock, and is effective for earthquakes larger than the magnitude (M) observed by seismographs.

(2) Basic Concept and Target Mission

BBB aims to avoid previous vulnerabilities and build a more resilient society by preparing for the disaster recovery, rebuilding, and reconstruction before the disaster, and by incorporating Disaster Risk Reduction (hereinafter referred to as "DRR") into development measures. The BBB is the basic concept of Japan's disaster reconstruction assistance, and it has been recognized worldwide in the field of disaster risk reduction since the 3rd UN World Conference on Disaster Risk Reduction held in Sendai in 2015.

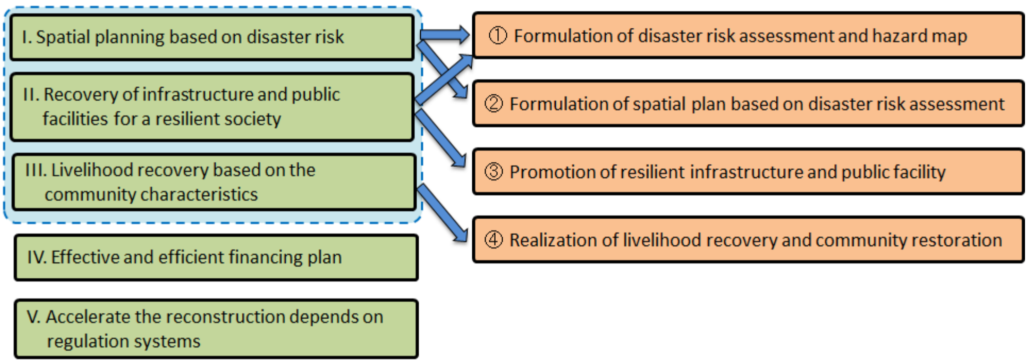
As mentioned earlier, to realize the recovery and reconstruction from the disaster, Bappenas established a TF and formulated reconstruction M/P in December 2018, and based on the M/P, it was decided to formulate various reconstruction plans and proceed with the reconstruction assistance project. The JICA first survey team, which consists of academic researchers, JICA experts, and consultants, was greatly involved in the formulation of the reconstruction M/P, which was developed based on the fundamental principles of BBB, "reconstruction of disaster areas toward realization of safer society". The reconstruction M/P has the five missions listed below for realization of BBB, but the project excluded the last two from its targets: (IV) financial planning, and (V) regulation and institutional system issues.

Five missions of the reconstruction M/P for post-disaster reconstruction:

I. Spatial planning based on disaster risk
II. Recovery of infrastructure and public facilities for a resilient society
III. Livelihood recovery based on the community characteristics
IV. Effective and efficient financing plan
V. Acceleration of the reconstruction based on regulation systems

(3) Assistance Activities Framework

The Project has four outputs to realize mission I to III for BBB as described in the reconstruction M/P. Figure 2-1 shows the relationship between mission I to III of the reconstruction M/P and Output 1 to 4 of the Project.



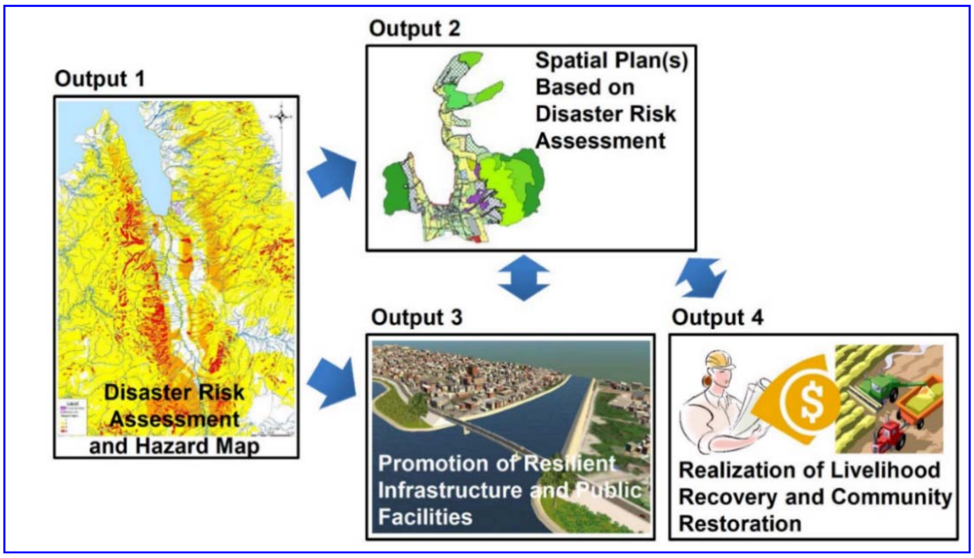
Source: JICA Study Team

Figure 2-1 Relationship between Reconstruction M/P and the Project

Each output has its own mission, as shown in Figure 2-2, including strengthening mutual cooperation, building the capacity of the staff in related organizations, and assistance for the realization of BBB. Specifically, Output 1 includes assistance in disaster situation analysis based on various surveys, and evaluation and assessment of hazard maps. Output 2, which is based on Output 1 results, includes formulation of spatial plan, land use regulations and building regulations. Output 3 includes promotion of resilient infrastructure and public facility recovery plan based on results of Output 1 and Output 2. Furthermore, in Output 4 assists in livelihood recovery and community restoration through pilot projects based on the disaster situation obtained from Output 1 and the spatial plan from Output 2.

The mission of each output is as follows:

- Output 1: Formulation of Disaster Risk Assessment and Hazard Map
- Output 2: Formulation of Spatial Plan Based on Disaster Hazard and Risk Assessment
- Output 3: Promotion of Resilient Infrastructure and Public Facilities
- Output 4: Realization of Livelihood Recovery and Community Restoration



Source: JICA Study Team based on JICA Expert Advice

Figure 2-2 Four Outputs in the Project

(4) Cooperation with Other Organizations

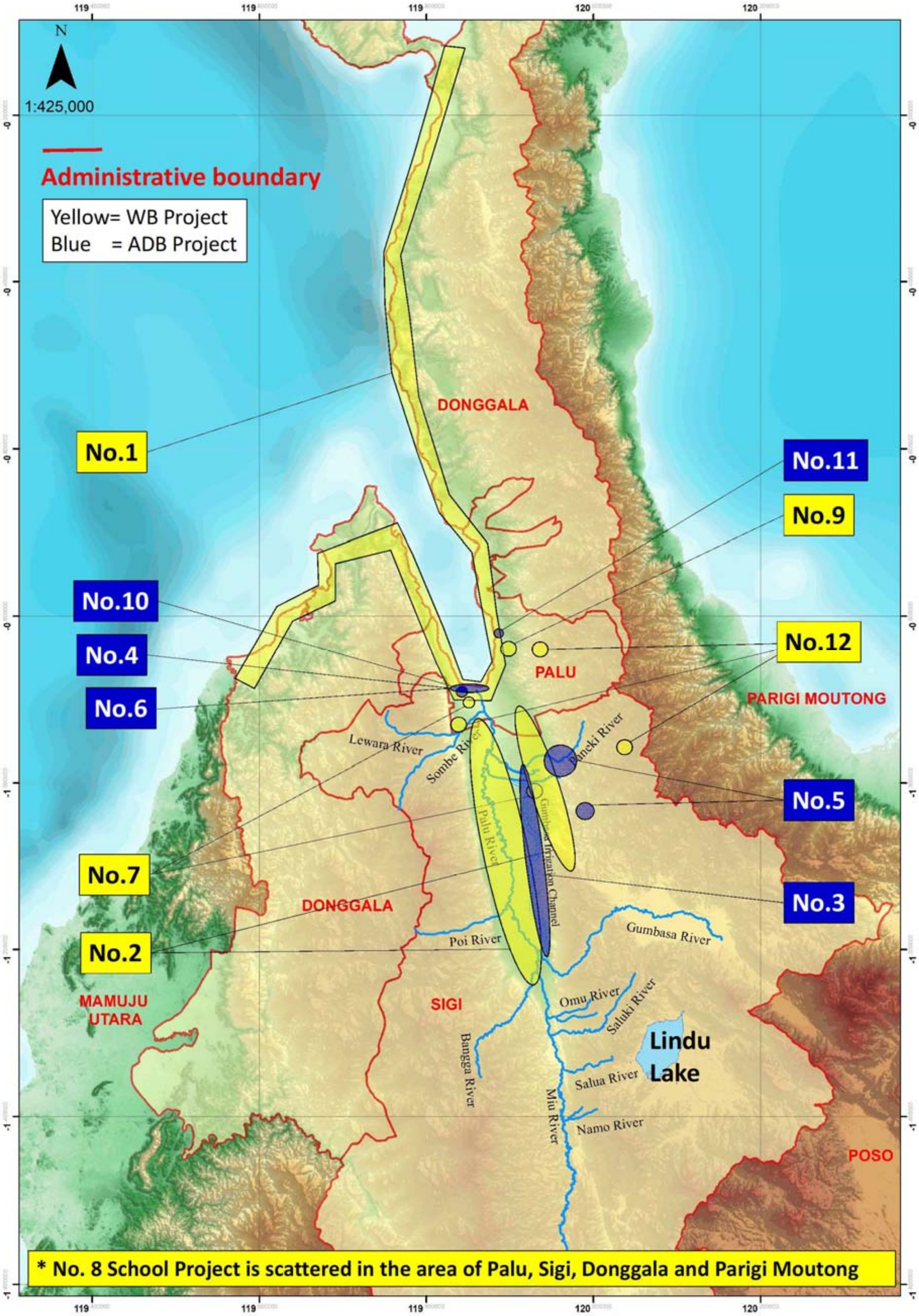
Bappenas requested support from many donors to realize the post-disaster recovery and reconstruction. Table 2-1 is summary of support from each donor. Especially in the infrastructure field, the involvement of multiple donors in the same sector was confirmed, and this includes specific infrastructure sub-projects. To prevent duplication of supports, a list of sub-projects was prepared to clarify the target of the assistance and adjustments were made. JICA is the only donor who provided advice and assistance for the reconstruction M/P prior to the technical cooperation. In particular, in the infrastructure reconstruction plan, to realize BBB concept, technical advice was given to sub-projects supported by other donors in the road sector, river sector, and public facilities sector.

Table 2-1 List of Projects Assisted by other Donors

Classification	Project Name	Related Donor
Road Bridge Sector		
No.1	Reconstruction and major rehabilitation of Tompe - Palu City - Surumana Road	WB[2] (WINRIP)[3]
No.2	Rehabilitation and reconstruction Palupi-Simoro road, Kalukubula-Kalawara, Biromaru- Palolo road, access to permanent housing	Same as above
Water Resources Sector		
No.3	Rehabilitation of Gumbasa Irrigation Networks (massive liquidated area between Petobo and Jono Oge will be financed by JICA's IRSL).	ADB[4] (EARR)[5]
No.4	Rehabilitation and Reconstruction of Palu Coastal Protection	Same as above
No.5	PASIGALA[6] Raw Water Network, Wuno and Paneki Intake	Same as above
No.6	SPAM (Drinking Water) distribution network in Palu City	Same as above
Public Facilities Sector		
No.7	Rehabilitation of Undata, Anutapura, Torabelo Hospital and various public health facilities. (AMC building of Anutapura Hospital will be finance by JICA's IRSL.	WB (NSUP - CERC)[7]
No.8	Rehabilitation of schools in Palu, Sigi, Donggala and Parigi Moutong.	Same as above
No.9	Rehabilitation of Univ. Tadulako	Same as above
No.10	Rehabilitation of IAIN Palu	ADB (EARR)
No.11	Rehabilitation of Pantoloan Port and Palu Airport	Same as above
No.12	Permanent Housing (Huntap incl. their supporting facilities) in Palu, Sigi and Donggala Regency.	WB (NSUP – CERC & CSRRP) and various national NGOs

Source: JICA Study Team

2 World Bank
3 Western Indonesia National Road Improvement Project (World Bank Loan Project)
4 Asian Development Bank
5 Emergency Assistance for Rehabilitation and Reconstruction (ADB Loan Project)
6 Palu, Sigi and Donggala
7 National Slump Upgrading Project - Contingency Response Emergency Component (NSUP -CERC - World Bank Loan Project)



Source: JICA Study Team

Note) Refer to "Table 2-1 List of Projects Assisted by other Donors" for the project name of each number.

Figure 2-3 Location of Other Donor Support Projects

Chapter 3 Assistance Activity Outline

This part describes the objectives of the four Ops (Output 1 to Output 4) of the project, the outline of the activities and the results obtained. In addition, this part also describes the outline activities of visit to Japan and training in Japan, the Domestic Advisory Committee, etc. to ensure a smooth and synergistic project.

3-1 Output 1 Disaster Risk Assessment and Hazard Map

(1) Objective and Content of the Activity

In Japan, hazard map generally refers to a map that display the locations of disaster prevention related facilities such as disaster prone areas, evacuation sites, and evacuation routes, for the purpose of disaster mitigation and disaster prevention measures caused by natural disasters. However, this project hazard map evaluates hazards from various disasters on a four-grade scale evaluation where it can be used as a basic material in formulating spatial plans and land use plans based on the policy of Indonesia. On the other hand, based on this hazard map, after coordination with local governments and residents, and by considering the local aspects and the disaster prone zone (hereinafter referred to as “ZRB”) which was evaluated on a four-grade scale evaluation called ZRB map, the formulation of ZRB map was conducted as an activity in Output 2.

The target disaster types include tsunami, liquefaction landslides (hereinafter referred to as “Nalodo”[8]), earthquake, and sediment disaster. The policy is to evaluate multiple disasters including floods, formulate individual hazard maps, and finally integrate them into one hazard map by taking into consideration the disaster and characteristics of the topography and geology.

The JICA first survey team urgently created a rough hazard map for the five disaster types: tsunami, liquefaction landslide (Nalodo), earthquake, landslide and flood. By referring to these maps, related organizations in Indonesia such as Bappenas prepared the draft ZRB map in December 2018. However, it was not accurate enough to be used as basic data for spatial plan formulation. In Output 1 the JICA Study Team created digital topographic maps, analyzed the disaster conditions, conducted geological surveys, conducted groundwater monitoring, etc. The main assistance activity was to evaluate the five disaster types based on these survey results, refine the hazard maps and assist on manual creation for the refinement works.

The main activities of Output 1 were as follows:

- Analyze the damage situation
- Conduct geological survey
- Evaluate five types of disaster (tsunami, Nalodo, earthquake, landslide and flood)
- Technical support for refining hazard maps
- Create a reference manual for the hazard map refinement

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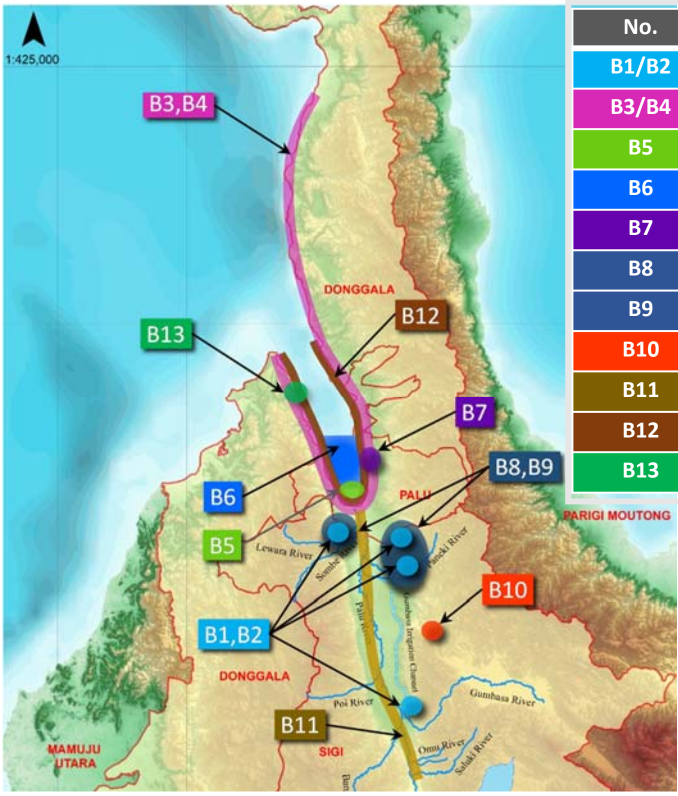
[8] Nalodo means "buried in mud" and "sneaking into the ground" in local Kairi language. Local people call large-scale liquefaction landslides as "Nalodo", which is a unique phenomenon in the world. Therefore, in the Project, liquefaction landslides are called "Nalodo".

(2) Outline of the Activity

First, the JICA Study Team conducted field survey to understand the disaster and damage situation. As basic data for analyzing disaster occurrence mechanism and possible risks in the future, along with the creation of digital topographic maps, various surveys such as geological surveys and geological test, tsunami trace and inundation survey were conducted as shown in Figure 3-1. In addition, the groundwater monitoring which requires long-term data observation and accumulation, was continuously observed for 5 months from the end of February 2020 to the end of July 2020. The automatic groundwater measuring device has been taken over by the related Indonesian organization, and observation data is still being collected. In addition, for the field survey and soil test, the JICA Study Team invited the relevant ministries and agencies in Indonesia, local governments, and some relevant people including from research institutes and students to participate in the survey. While sharing the technical knowledge, the data was collected and shared smoothly.



No.	Survey Items
B1/B2	Investigation of liquefaction landslide in inland area
B3/B4	Boring survey for coastal area
B5	Boring survey for Palu IV Bridge
B6	Reflection seismic survey of Palu bay
B7	Radioactive dating test of sediments
B8	Water quality analysis of groundwater and surface water
B9	Monitoring of groundwater level
B10	Survey of government facility Sites in Sigi
B11	Palu-Koro fault Survey
B12	Survey of Tsunami Inundation Depth
B13	Survey of Mangrove Density, Trunk, and Height

Source: JICA Study Team

Figure 3-1 Field Survey Contents and Locations (Output 1)

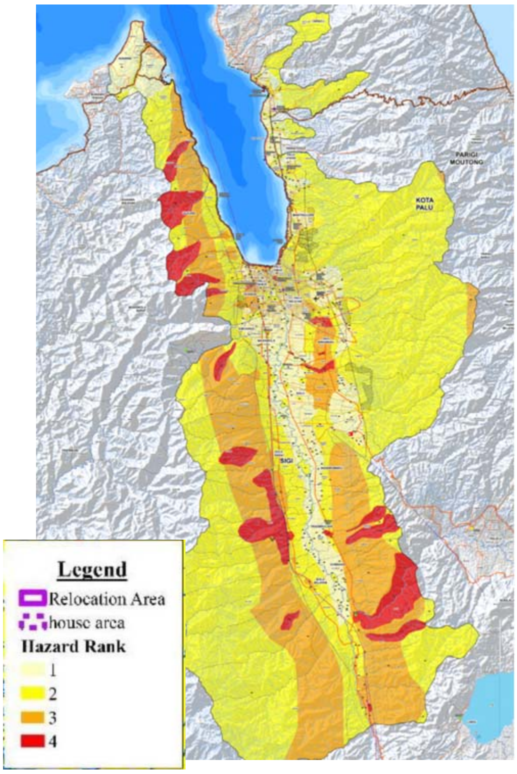
Based on the results of these various surveys, the JICA Study Team evaluated and analyzed the risks of tsunami, Nalodo, earthquake, landslide, and flood, and refined the hazard map. In the hazard map, before and after measures were taken for risk reduction, and the after measures were reflected as disaster mitigation in the Output 3 effect on infrastructure measures.

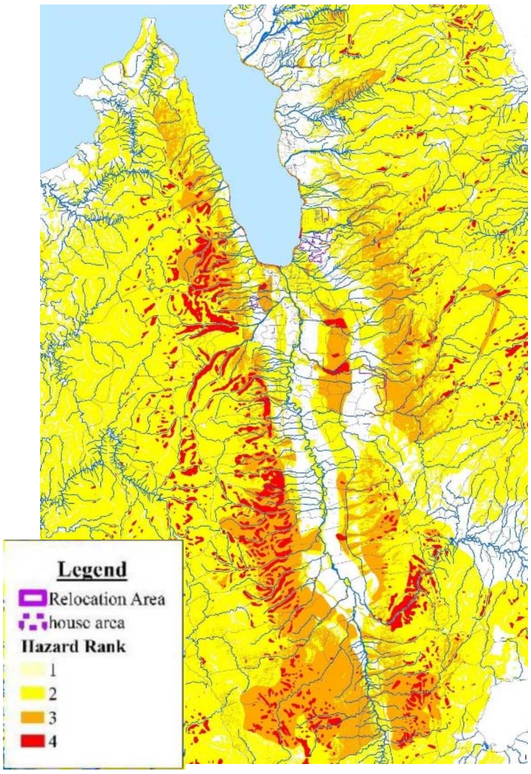
In addition, when creating the hazard map, it is necessary to estimate the disaster scale, but due to lack of scientifically supported historical data records, in this project the scale was set with the same level as the main earthquake. In particular, Nalodo and tsunami, which have special causes in the earthquake, were examined with advice from the Japanese Advisory Committee consisting of multiple Japanese academicians. For tsunami, to promote consensus building among stakeholders for the disaster mitigation, JICA experts repeatedly explained to the Indonesian government and trainees that the JICA proposal is the best mixed plan which consists of road raising, covering with vegetation, land use regulations, building regulations, etc. The JICA Study Team also provided explanatory materials to promote understanding among the stakeholders. In addition, understanding of the Indonesian government was obtained through model experiments such as verification of the elevated road geometry, and effectiveness of introduction of vegetation (currently the experiments are ongoing). However, Nalodo is a unique phenomenon in the world, and a high degree of expertise is required for the factor analysis and mitigation measures. JICA experts and Japanese academicians conducted several discussions at the Japanese Advisory Committee on the hypothesis of the mechanism created by the JICA experts based on the survey results conducted immediately after the earthquake. As a result of these discussions, the JICA Study Team received advice that controlling the groundwater level is an effective disaster mitigation measure against Nalodo. The JICA Study Team provided this advice to the Indonesian government.

(3) Results Obtained

In Output 1, the following results were obtained through analysis of damage conditions, implementation of geological surveys, risk assessment of various disasters, assistance in creating hazard maps, and assistance activities related to the formulation of reference manuals.

- The damage situation and the geological survey results, which are the basic information for risk assessment of various disasters were shared with the person in charge of the related Indonesian organizations. Risk assessment of various disasters and refinement of hazard maps need to be more scientifically based. For example, for tsunami risk, the inundation depth and the degree of damage to buildings should be clarified by tsunami trace survey, while for Nalodo, the cause and the amount of ground movement should be clarified.
- In conducting an interview survey of the situation immediately after the disaster, which is important for analysis of the disaster outbreak mechanism, the JICA Study Team was able to analyze the mechanism of the occurrence by taken into consideration of gender and diversity through hearing opinions from women, elderly, and people from diverse households.
- The draft hazard map and reference manual were shared with the person in charge of the related Indonesian organizations. Their understanding of refined hazard maps (refer to Figure 3-2), hazard map formulation methods, hazard criteria, risk mitigation policies, etc. was improved.

<table>
<tr>
<td>

Source: Indonesian Government</td>
<td>

Source: JICA Study Team based on advice from JICA Experts</td>
</tr>
<tr>
<td>ZRB map formulated by the Ministry of Land and Spatial Planning (hereinafter referred to as "ATR"), December 2018 edition</td>
<td>Refined hazard map in the project, December 2019 version</td>
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</table>

Figure 3-2 Refinement of Hazard Map (Output 1 Achievements and All Hazards are Reflected)

- For tsunami and Nalodo, field surveys and model experiments were done in collaboration between Indonesia and Japan. In addition, academicians from both countries participated in the panel meetings, opinions on the peculiarities of disasters and risk mitigation measures were shared, and consensus building on the policies and directions of countermeasures was promoted.
- Hazard maps have been refined by the Indonesian government agencies and basic data have been provided for considering land use regulations for the spatial planning. Within ATR and the Geological Agency (hereinafter referred to as "BG"), which have responsibility over the refinement of hazard maps, there is a large number of female members, from staff in charge to executives, who were also responsible in the process and decision making of hazard map refinement. The JICA Study Team was able to carry out assistance activities from the perspective of gender and diversity.

3-2 Output 2 Formulation of Spatial Plan Based on Disaster Hazard and Risk Assessment

(1) Objective and Content of the Activity

In Indonesia, the 2007 Spatial Planning Act (Law No.27 / 2007) stipulates the formulation of general spatial plans (hereinafter referred to as "RTRW") at the national, provincial, city and regency levels, respectively. It is also stipulated that detailed spatial plans (hereinafter referred to as "RDTR") will be formulated for urbanized areas of cities and regencies. Such formulated spatial plans are statutory plans and become legally effective with the approval of the assembly of individual local governments. Each spatial plan is updated every 5 years with a target year of 20 years from the time of formulation. It will also be updated even after the occurrence of abnormal situations, such as if a major disaster occurs. A guideline for the formulation of RTRWs for provinces, cities and regencies (ATR Ministerial Ordinance No. 1 /2018) and another one for the formulation of RDTRs (ATR Ministerial Ordinance No. 16/ 2018) have been established. Although these guidelines state the importance of considering disaster hazards and risks when formulating spatial plans, they do not sufficiently provide any specific ideas and methodologies for that purpose. Although it is known that there are hazards and risks due to various disaster types (tsunami, active fault, earthquake, flood, sediment disaster, etc.) in the target areas of the project, any spatial plans which substantially incorporated measures against disaster hazards and risks have not yet been formulated. At the same time, the earthquake in Palu was accompanied by serious damages caused by a new disaster called "Nalodo".

In Output 2, the JICA Study Team provided technical assistance to promote "reconstruction of the disaster area toward the realization of a safer society". The land use regulations and building regulations were set based on opinions of local governments and local residents considering the hazard map formulated and assisted in Output 1, and incorporating disaster mitigation measures to be examined in Output 3. The main activities of Output 2 were as follows:

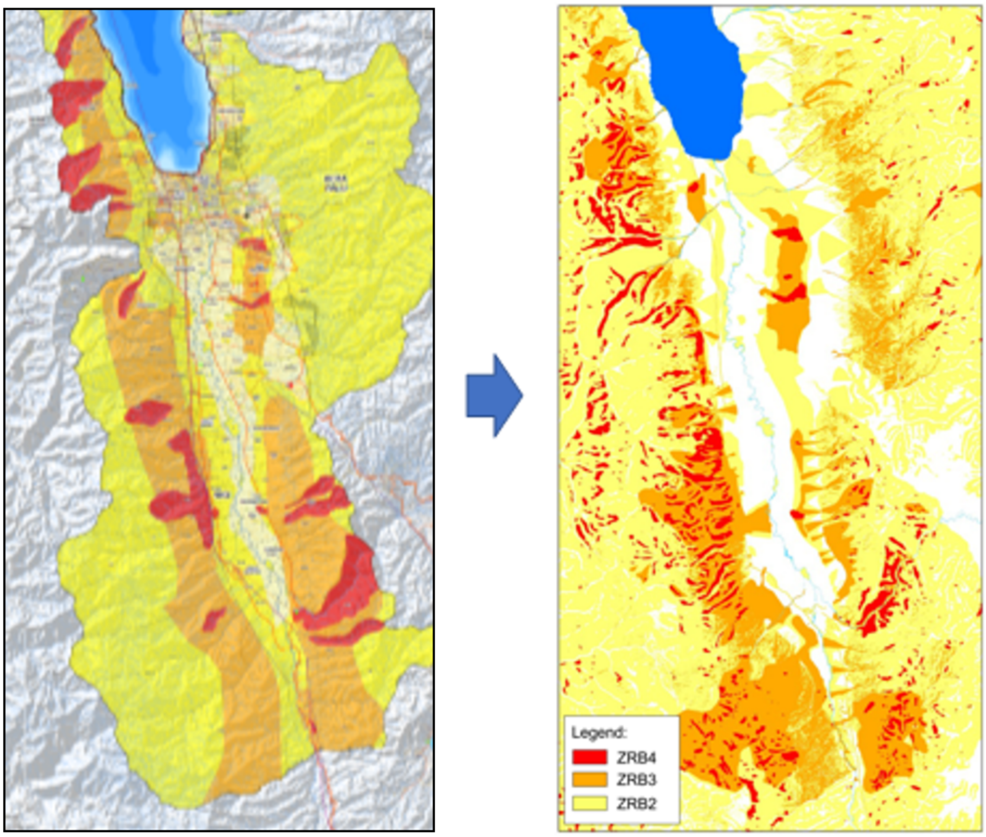
- Reviewing of existing and draft spatial plans
- Providing support to the Ministry of Land and Spatial Planning (ATR) and local governments in formulating RTRWs and RDTRs
- Providing support to ATR and local governments in formulating, improving, and enforcing land use regulations and building regulations
- Preparation of reference manuals (guidelines) for formulating spatial plans based on disaster risk reduction

(2) Outline of the Activity

Review of the existing and draft spatial plans was mainly focused on the contents of the disaster hazard risk analysis and the concept of disaster mitigation (DRR). The results of the review were presented and discussed at a mini-workshop held by each local government and the JICA Study Team. The land use plan proposed in the existing and draft spatial plans is visualized by overlaying the ATR's ZRB map with the hazard map formulated by the JICA Study Team. It was identified that areas with high disaster risk are residential area or commercial area. To curb the development, the JICA Study Team presented an alternative on conversion of land use to agricultural land.

In the technical assistance for the formulation of RTRW and RDTR, as a preparatory work before the official spatial planning process started, the related parties discussed the analysis of future development directions and the examination of alternatives for the urban reconstruction concept. In the official spatial planning process, based on the hazard map formulated and supported in Output 1, the JICA Study Team conducted building damage surveys, provided advice on how to determine and create ZRB boundary line, land use regulations, building regulations, and Strategic Environmental Assessment for spatial planning (hereinafter, "SEA"). Regarding land use regulations, building regulations, etc., JICA experts mainly provided ideas and made policy decisions, and the JICA Study Team proceeded with work such as surveys and document preparation. In the process of formulating the spatial plan, in addition to the direction and degree of future development by population analysis, urbanization area analysis, etc., the JICA Study Team examined land use regulations for a disaster-resilient city by setting up spatial structure based on the characteristics of the disaster and risk mitigation measures.

Furthermore, the JICA Study Team refined the ZRB map of Palu City and the surrounding areas based on scientific evidence (refer to Figure 3-3), and formulated a reference manual summarizing the refinement methodologies. In particular, consensus building among stakeholders was important for the proposal of ZRB4 (a zone that prohibits all land use and recommends relocation), and JICA experts took a lead in repeatedly explaining to and discussing with Bappenas, ATR, and local governments the importance of taking all precautions to prevent the emergence of human rights issues due to resident relocation. In addition to the local governments, the JICA Study Team repeatedly followed up with the Bantek consultant, who was entrusted for the spatial planning work by ATR. To avoid human rights problems, the JICA Study Team investigated the damage to buildings, the actual living conditions, and presented concrete boundaries of ZRB4 so that non-damaged and lightly damaged buildings can be excluded. As a result, the local governments agreed with the content of the JICA proposal. On the other hand, ATR did not approve the ZRB map published in December 2018 because it should not be reviewed. As of March 2021, the ZRB boundaries and regulations of the spatial plan have not been approved by the central or local governments.



Source: (Left) ATR, ZRB Map for Palu and Surrounding Areas, as of December 2018
(Right) JICA Study Team based on advice from JICA Experts

Figure 3-3 ZRB Map and Refined ZRB Map, December 2018 Version

(3) Results Obtained

In Output 2, the following results were obtained through the review of the draft spatial plans, assistance for the formulation of RTRW and RDTR, assistance for the formulation of land use regulations and building regulations, and assistance on activities related to the formulation of reference manuals:

- Regarding the results of the review of existing and draft spatial plans, and spatial plans concept that take disaster hazards and risks into consideration, disaster hazards and risk assessments were reflected in spatial planning through discussions in workshops and mini-workshops. The understanding of the Indonesian organizations on the need for land use and infrastructure development plans that contribute to DRR was improved. And their basic knowledge on the formulation of RTRW and RDTR was also improved.

- Regarding the results of assistance in the spatial planning process, the importance of discussions involving the residential community, including women and youth groups, through group discussions and public consultations, the necessity of building damage survey for refining the ZRB map, the necessity of reviewing the ZRB boundary line based on the survey results and its concrete method, and the setting of a spatial development concept that comprehensively evaluates potential urban development and disaster hazards were incorporated into some of the RTRWs and RDTRs formulated by the local governments.

- Monitoring of the SEA process took place in parallel with the formulation of the spatial plan. The JICA Study Team advised that participation of stakeholders including women and youth groups in the exchange of opinions should be promoted. The improvement of the SEA process for RTRW and RDTR was promoted.
- Dialogue and consensus building with residents are important in the refinement of land use regulations and building regulations according to the ZRB level evaluated in four stages. Utilizing the ZRB map, the understanding on the concept and method of incorporating land use regulations and building structure requirements by disaster type hazard level into land use zoning was improved, and it will be incorporated in the land use regulations and building regulations formulated by local governments.
- The reference manual was shared with the related Indonesian organizations in the form of Recommendation Report, and it was used in the formulation of RTRW and RDTR, land use regulations, and refinement of building regulations.

3-3 Resilient Infrastructure and Public Facilities

(1) Objective and Content of the Activity

Major infrastructure including roads and bridges, irrigation facilities, water supply and sewerage systems, airport and port facilities, and other public facilities such as schools and hospitals were damaged by the earthquake, tsunami, Nalodo and landslide. This revealed the vulnerability of infrastructure and public facilities, and a paralysis of transportation and public facilities functions in the isolated villages were observed. As a result, the draft of the reconstruction M/P included “Recovery of infrastructure and public facility for a resilient society” as one of its five missions. To realize this mission, this activity focused on assistance on the recovery and reconstruction of infrastructure and public facilities based on the disaster risk assessment results (Output 1) and the spatial plan (Output 2). The main activities in Output 3 were as follows:

- Determining target sector for the infrastructure and public facility
- Analyzing damage condition in the target sector
- Reviewing the laws, guidelines, and manuals related to structural design and construction
- Formulating a reference manual on structural design to strengthen the infrastructures and public facilities
- Assisting the local government and PUPR on formulation of basics reconstruction concept
- Assisting the local government and PUPR on basic design in the target sector
- Assisting the local government and PUPR on construction of the infrastructures and public facilities
- Assisting the related ministries and agencies on improvement of the current laws, guidelines, and manuals
- Assisting on the facilitation of the National Expert Panel
- Assisting on Implementation of Strategic Environmental Assessment (SEA)/ Environmental

Impact Assessment (EIA)

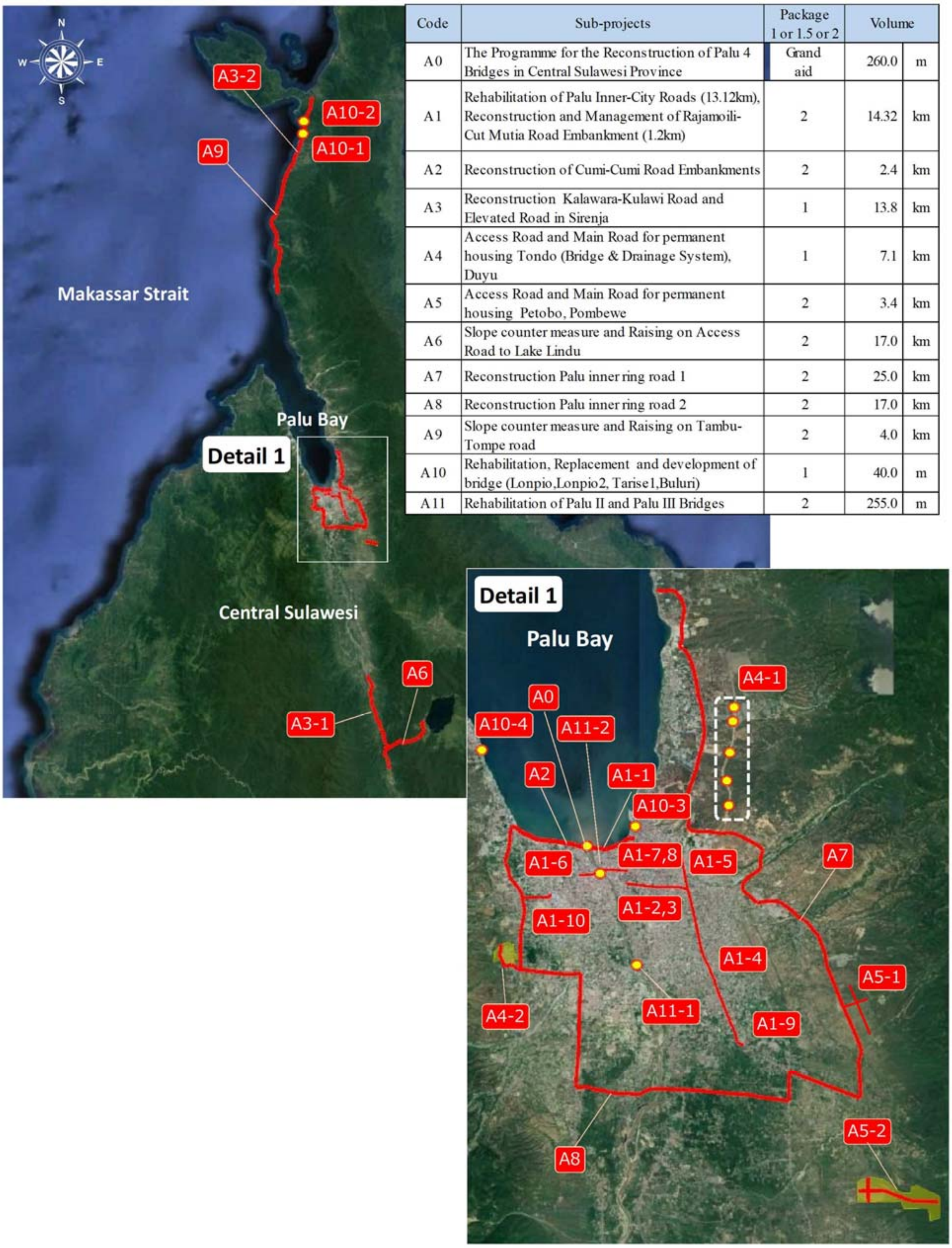
(2) Outline of the Activity

Based on the discussions with Bappenas and PUPR - the implementing agencies of the infrastructure project, local governments, etc., three sectors under PUPR jurisdiction namely road and bridge, river, and public facility sectors are selected as the target of the project. The above three sectors were selected because before this project, the JICA experts played a leading role in providing advice on realization of the BBB concept during the formulation of the reconstruction M/P; and there was a discussion on assisting infrastructure that should be revised to reflect the results of the disaster risk analysis. The discussion brought about the contents of the project. As shown in Table 3-1, the target assistance of infrastructure reconstruction projects was comprehensive. For the main infrastructure projects under the jurisdiction of the three sectors included not only recovery of the damaged roads, bridges and river structures, but also tsunami risk mitigation measures, Nalodo risk mitigation measures, flood and sediment disaster countermeasures, etc. Regarding the target infrastructure projects, a Grant Agreement (G/A) was signed for the "The Programme for the Reconstruction of Palu 4 Bridges in Central Sulawesi Province" in June 2019, during the implementation of the project. The grant aid, which targets the reconstruction of the core infrastructure in the targeted areas like the Palu IV Bridge and raising road levels, used part of the project result as basic data. Furthermore, in January 2020, an ODA Loan Agreement (L/A) was signed for the "Infrastructure Reconstruction Sector Loan in Central Sulawesi". The purpose of the L/A is to promote the reconstruction of infrastructure such as roads and bridges, irrigation facilities, rivers, and public facilities (hospitals), besides sediment disaster countermeasures.

Table 3-1 Sector and Infrastructure Projects for Target Assistance

Target Sector	Target Infrastructure Project	Representative of Sub Project
Road and Bridge Sector Directorate General of Highways (Bina Marga)	➢ Tsunami countermeasures projects related to the coastal road ➢ Road and bridge recovery and reconstruction project for the purpose of recovery and revitalization of people and logistic network	➢ Palu IV Bridge reconstruction project that crosses Palu River Estuary and elevated road project to reduce tsunami damages ➢ Seismic resistance enhancement project for bridges on highways (seismic retrofitting) ➢ Ring road network strengthening project ➢ Access road maintenance project for the relocation area
Water Resources Sector Directorate General of Water Resources (Sumber Daya Air)	➢ Nalodo countermeasure project ➢ Irrigation recovery project which is closely related to local industry ➢ Flood and sediment disaster countermeasure project	➢ Nalodo countermeasure project by controlling groundwater ➢ Gumbasa irrigation canal water level control and leakage enhancement measures project ➢ Flood and landslide countermeasure project by improving the river and sediment control dam
Public Facilities Sector Directorate General of Human Settlement (Cipta Karya)	➢ Reconstruction project of major medical institutions (buildings)	➢ Reconstruction project of Anutapura General Hospital

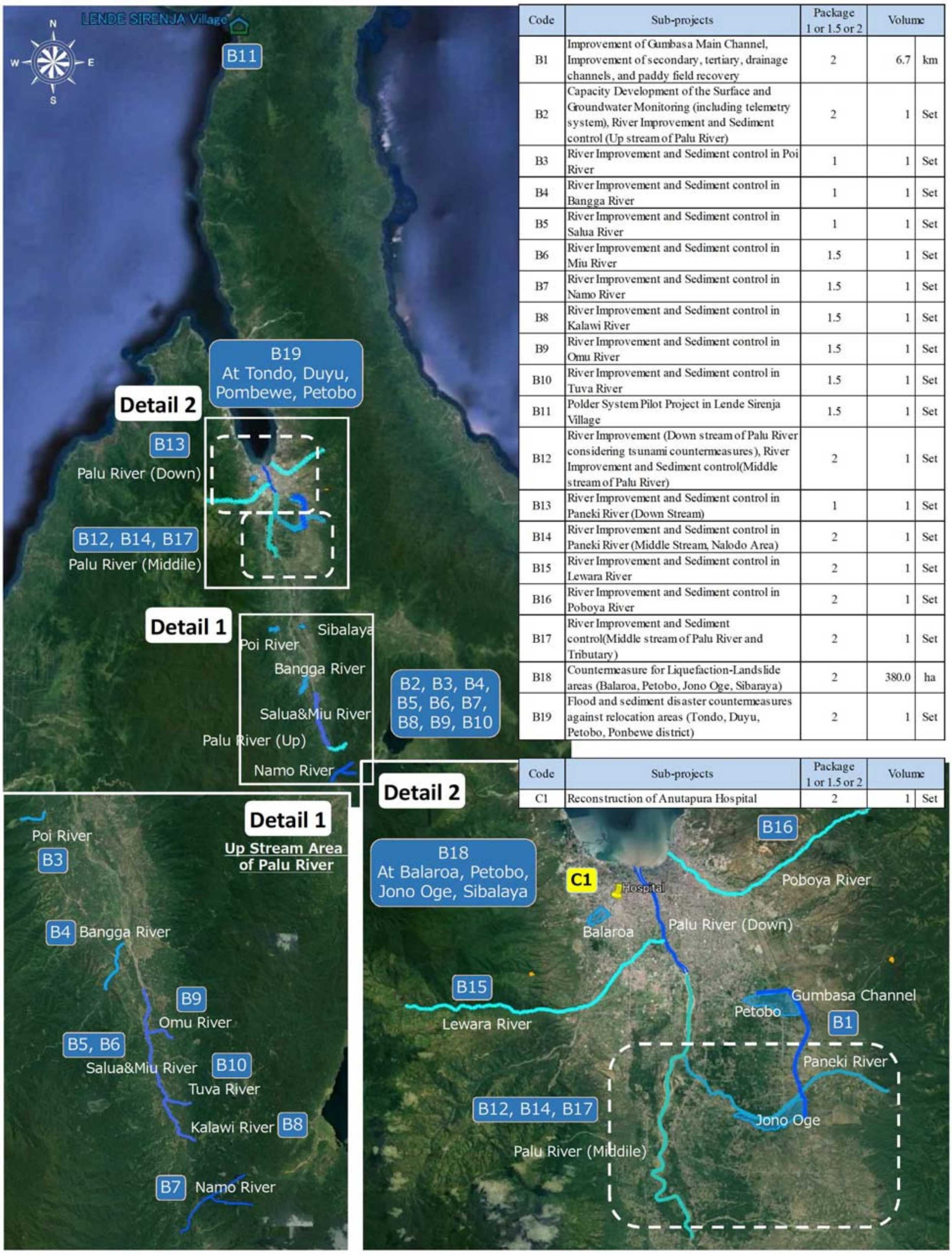
Source: JICA Study Team



Code	Sub-projects	Package 1 or 1.5 or 2	Volume	
A0	The Programme for the Reconstruction of Palu 4 Bridges in Central Sulawesi Province	Grand aid	260.0	m
A1	Rehabilitation of Palu Inner-City Roads (13.12km), Reconstruction and Management of Rajamoili-Cut Mutia Road Embankment (1.2km)	2	14.32	km
A2	Reconstruction of Cumi-Cumi Road Embankments	2	2.4	km
A3	Reconstruction Kalawara-Kulawi Road and Elevated Road in Sirenja	1	13.8	km
A4	Access Road and Main Road for permanent housing Tondo (Bridge & Drainage System), Duyu	1	7.1	km
A5	Access Road and Main Road for permanent housing Petobo, Pombewe	2	3.4	km
A6	Slope counter measure and Raising on Access Road to Lake Lindu	2	17.0	km
A7	Reconstruction Palu inner ring road 1	2	25.0	km
A8	Reconstruction Palu inner ring road 2	2	17.0	km
A9	Slope counter measure and Raising on Tambu-Tompe road	2	4.0	km
A10	Rehabilitation, Replacement and development of bridge (Lonpio,Lonpio2, Tarise1,Buluri)	1	40.0	m
A11	Rehabilitation of Palu II and Palu III Bridges	2	255.0	m

Source: JICA Study Team

Figure 3-4 Location Map of the Sub-projects (Road and Bridges Sector)



Code	Sub-projects	Package 1 or 1.5 or 2	Volume	
B1	Improvement of Gumbasa Main Channel, Improvement of secondary, tertiary, drainage channels, and paddy field recovery	2	6.7	km
B2	Capacity Development of the Surface and Groundwater Monitoring (including telemetry system), River Improvement and Sediment control (Up stream of Palu River)	2	1	Set
B3	River Improvement and Sediment control in Poi River	1	1	Set
B4	River Improvement and Sediment control in Bangga River	1	1	Set
B5	River Improvement and Sediment control in Salua River	1	1	Set
B6	River Improvement and Sediment control in Miu River	1.5	1	Set
B7	River Improvement and Sediment control in Namo River	1.5	1	Set
B8	River Improvement and Sediment control in Kalawi River	1.5	1	Set
B9	River Improvement and Sediment control in Omu River	1.5	1	Set
B10	River Improvement and Sediment control in Tuva River	1.5	1	Set
B11	Polder System Pilot Project in Lende Sirenja Village	1.5	1	Set
B12	River Improvement (Down stream of Palu River considering tsunami countermeasures), River Improvement and Sediment control(Middle stream of Palu River)	2	1	Set
B13	River Improvement and Sediment control in Paneki River (Down Stream)	1	1	Set
B14	River Improvement and Sediment control in Paneki River (Middle Stream, Nalodo Area)	2	1	Set
B15	River Improvement and Sediment control in Lewara River	2	1	Set
B16	River Improvement and Sediment control in Poboya River	2	1	Set
B17	River Improvement and Sediment control(Middle stream of Palu River and Tributary)	2	1	Set
B18	Countermeasure for Liquefaction-Landslide areas (Balaroa, Petobo, Jono Oge, Sibaraya)	2	380.0	ha
B19	Flood and sediment disaster countermeasures against relocation areas (Tondo, Duyu, Petobo, Ponbewe district)	2	1	Set

Code	Sub-projects	Package 1 or 1.5 or 2	Volume	
C1	Reconstruction of Anutapura Hospital	2	1	Set

Source: JICA Study Team

Figure 3-5 Location Map of the Sub-projects (River and Public Facilities)

The JICA Study Team surveyed the damage situation of infrastructure and public facilities in the target sector. As a result, the vulnerabilities of each infrastructure were clarified, such as lack of seismic performance of roads, bridges and public facilities, there were no structural and non-structural measures for disaster prevention and mitigation against tsunami and Nalodo. The JICA Study Team also reviewed existing manuals related to structural design and construction, and extracted the current situation and issues as shown in Table 3-2.

Table 3-2 Summary of the Review of existing Regulations and Guidelines

Sector Type	Summary of Existing Manual Review Results
Road and Bridge Sector	➢ Current status: The design standard for geometric structures, seismic design, etc. have been developed and are being used. ➢ Issue: There is lack of guidance on pavement inspection methods, liquefaction countermeasures, slope excavation and countermeasure based on the soil characteristics, and seismic reinforcement methods for existing bridges.
Tsunami Countermeasure	➢ Current status: The design standards for port facilities are in place and being used. ➢ Issue: The design standard for tsunami has not been developed. There is lack of guidelines on design policy, conditions, and countermeasures.
Irrigation, Nalodo, Sediment Countermeasures	➢ Current status: The design standards for irrigation facilities have been developed and are being used. The Indonesian National Agency is developing seismic standards for irrigation facilities. ➢ Issue: The design standard for liquefaction landslide has not been developed. There is lack of guidelines on design policy, conditions, and countermeasures.
Public Facility Sector	➢ Current status: The design standards for public facilities building, including earthquake resistance standards, have been developed. The standards have been compared and verified with other countries such as Japan and the United States. ➢ Issue: The damage factor analysis indicates that the design standards might not be serving properly.

Source: JICA Study Team

Based on the vulnerabilities of these various infrastructure and the issues of existing manuals, the JICA Study Team provided advice on the basic reconstruction concept for the formulation of the reconstruction M/P and reference manual (draft) to achieve recovery of infrastructure for a resilient society. The reference manual (draft) includes strengthening of earthquake resistance of various structures, reinforcement of cut slopes based on the ground situation that are prone to collapse, design policies for tsunami countermeasures, and management methods for high-quality concrete, etc.

In addition, based on the reference manual (draft), the JICA Study Team provided assistance on the basic design and construction of the target subprojects. The main points of the assistance on the basic design and construction are shown below.

- Assistance on basic design and construction is classified into basic design, draft detailed design, and technical assistance (hereinafter referred to as "TA").
- Basic design was implemented for the target projects in the road sector and the water resources sector. For projects with high urgency, draft detailed design was also carried out, and the JICA Study Team provided PUPR reference materials for preparing detailed design documents.
- The TA implemented the BBB concept shared in the reconstruction M/P before the project started. In addition to the JICA Study Team target assistance, the TA also implemented assistance for infrastructure development projects which were supported by the other donors.
- Using the basic materials in assisting the draft detailed design, the construction procurement

procedure by PUPR is continued. However, due to the impact of multiple sediment disasters, etc., and as a result of PUPR request on additional assistance for advice on the design revision of the subprojects and advice on construction supervision of bridge construction that had already started, the assistance activities will be continued until the end of June 2021 (refer to Chapter 4, (4-8-2 and 4-8-3) for details).

- The reference manual added and finalized the lessons learned from the series of basic design and construction assistance activities, specifically on the first aid methods after a disaster, maintenance system for irrigation canals, and methods for determining the damage degree on bridges.

However, the earthquake happened this time was a disaster with a very special occurrence mechanism. It caused a tsunami and a landslide in the coastal area and a liquefied landslide in the inland area called Nalodo. Therefore, in the process of considering tsunami and Nalodo risk mitigation countermeasures in Output 1, the JICA Study Team worked closely with the person in charge of disaster risk assessment. Additionally, the concept of BBB was shared with researchers in Indonesia and to facilitate consensus building on infrastructure plans among Indonesian organizations, the JICA Study Team supported tsunami model experiments using PUPR's experimental facilities, and held a tsunami expert panel consisting of tsunami researchers from Indonesia.

Regarding environmental and social considerations, based on the fact that this project is under the special condition of emergency disaster support, the JICA Study Team provided assistance on formulation of environmental and social considerations, and resident relocation/land acquisition framework which was decided between the Japanese and Indonesian governments. Based on the framework, the JICA Study Team provided assistance on the procedures of Environmental Protection and Environmental Management Plan (UKL-UPL) based on the EIA law of Indonesia.

(3) Results Obtained

In addition to the recovery of damaged and collapsed infrastructure, discussions were held with related organizations to ensure disaster risk mitigation measures would contribute to the sustainable development of the local community and economy. Assuming that the project implementation entity would shift to the central government-Ministry of Public Works and the local government public works-development department, a joint discussion with the task force (Satgas), PUPR and the department in charge of local government was held. It focused on technical discussion for each of the three sectors supported by the Central Government and the Regional Development Bureau, as well as advice on prioritization of reconstruction projects, process plans, and project scale.

The following results were obtained in the Output 3:

- The local governments and PUPR’s understanding on the BBB concept and the basic reconstruction concept was improved, and sub-projects for each infrastructure were selected to reflect the concept.
- The reference manual was shared with the local governments and PUPR, and the understanding

of necessary design items for disaster risk mitigation measures based on the BBB concept was improved.

- Various tender documents were shared with local governments and PUPR through assistance activities related to basic design, draft detailed design, TA, etc. The procurement procedure for the detailed design and construction supervision consultant that reflected the contents was smoothly undertaken by PUPR.
- Through the TA activities related to infrastructure construction, the draft detailed design was reviewed, and the understanding of local governments and PUPR regarding the technology required for construction supervision was improved.

3-4 Output 4 Livelihood Recovery and Community Restoration

(1) Objective and Content of the Activity

In addition to the damage to infrastructure and public facilities described in Output 3, the local society and economy were also damaged by the earthquake. Based on the situation of the disaster, Bappenas took the lead in formulating the recovery M/P, in which "III. Recovery of livelihoods according to the characteristics of the community" was one of the five missions. In order to contribute to the realization of this mission, the main purpose of the activities is to conduct "support activities for the Livelihood Recovery and Community Restoration" based on the survey of the disaster situation (Output 1) and the spatial plan (Output 2). The main activities of Output 4 were as follows:

- Review of the Livelihood Restoration and Community Restoration Action Plan developed by the Government of Indonesia
- Selection of pilot projects
- Support to local governments for implementation of pilot projects
- Preparation of a reference manual for livelihood recovery and community revitalization from disasters

(2) Outline of the Activity

To confirm the situation on the field, the Recovery Action Plan was reviewed at first. This recovery action plan was formulated based on the disaster needs assessment conducted by the local government, and the missions for accelerating social and economic recovery and reconstruction were presented. Among them, it was confirmed that the mission related to this Output 4 has the following contents:

- Improving the quality of mental and physical health of communities in affected areas
- Restoration of social and economic activities of communities, governments and public service organizations, satisfaction of specific needs of women and other socially disadvantaged groups in the affected areas
- Strengthening and expanding the resilience of affected areas and community groups in various social, economic, and cultural sectors
- Broad community participation and use of relevant institutions in the social, economic, and

cultural sectors that operate in the affected area

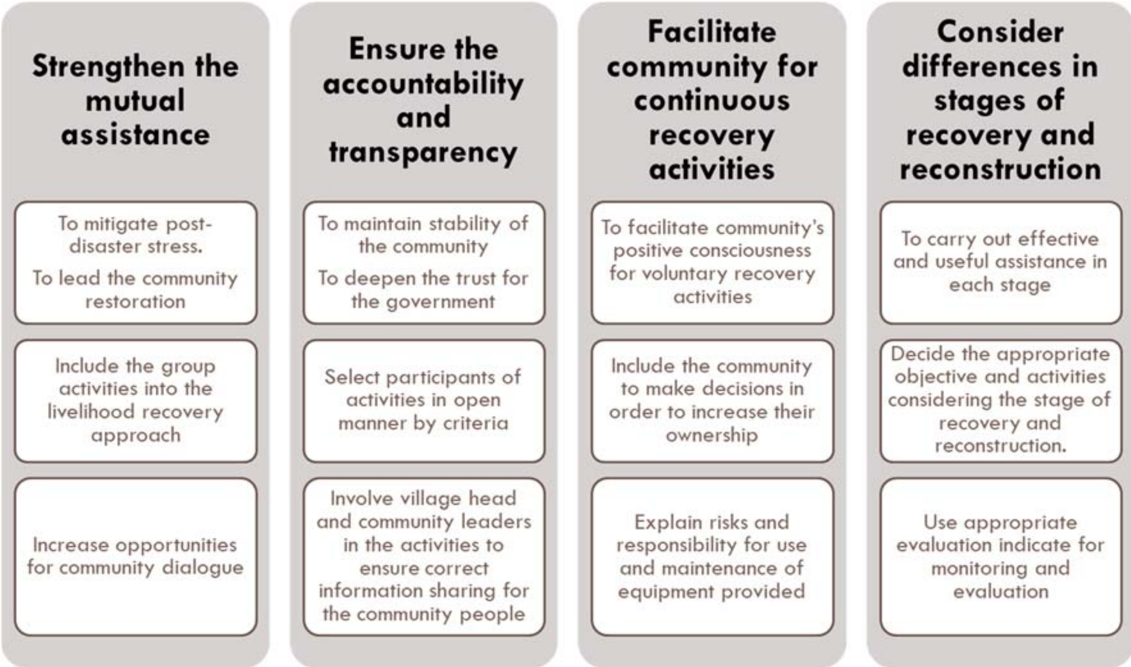
Based on the results of the review of that action plan and the disaster situation of each municipality and community, the pilot projects to be implemented in FY2019 were selected. The criteria for the selection of pilot projects were discussed with the relevant agencies in Indonesia and included: consistency with the recovery M/P, high priority projects included in the recovery action plan, speed, contribution to the promotion of joint activities by disaster victims, support for socially disadvantaged groups, leveling of target areas, synergy with other donor activities, and synergy with other donor activities. As a result, the three projects listed in Table 3-3 below were selected as the pilot projects to be implemented in FY2019, and support was provided to local governments for the implementation of these pilot projects.

Table 3-3 Pilot Projects in 2019

Local Government/ Responsible Department	Project Title and Purpose
Palu City / Dept. of Trade and Industry	Pilot Project on Livelihood Recovery of Women in Balaroa district Evacuation Shelter Through Work Training and Community Activities Objective: To empower the economic activities of women in Balaroa district shelter and to create and strengthen the unity of women communities as well as all evacuees in the shelter through community activities.
Sigi Regency/ Dept. of Cooperatives and SMEs	Pilot Project on Installation and Operation of Community MSMEs (Micro, Small and Medium Enterprises) Center and Providing Vocational Training for Livelihood Recovery at Temporary House Sites Objective: To recover the livelihood of SMEs (male and female) and to improve the access of the community to daily essentials through the operation of community MSMEs centers established in the temporary house sites; and to increase revenue opportunities for both women and men through the provision of training support related to livelihood recovery.
Donggala Regency/ Dept. of Fishery and Marine Affairs and Dept. of Cooperatives and MSMSs	Pilot Project on Livelihood Restoration of Affected Fishermen (fishing ikan teri) through building of boats and provision of fishing equipment, and livelihood recovery of women processing ikan teri products. Objective: To restart the economic activities through providing training support and equipment for the community in Lero Tatari and to aim for the sustainable restoration of livelihoods by improving the quality of ikan teri processed products.

Source: JICA Study Team

The experience of recovery and reconstruction in Central Sulawesi Province, mainly from the pilot projects, was compiled in the form of a manual that can be referred to by future disaster-affected municipalities when developing and implementing their recovery work plans. This reference manual was developed as a reference manual (first edition) on livelihood restoration and community restoration in recovery and reconstruction based on the experience of the pilot project activities conducted in 2019. Subsequently, in 2020, the reference manual was updated and finalized through the implementation of a pilot project, support for national programs, recovery case studies, and the activities of a working group to revise the manual with counterparts. The key approaches for livelihood restoration and community restoration presented in the reference manual are shown in Figure 3-6.



Source: JICA Study Team

Figure 3-6 Key Approaches to Livelihood Recovery and Community Restoration

(3) Results Obtained

Based on the consultations with relevant organizations of the Government of Indonesia and the basic policy decided by the local task force, activities closely related to local residents in working with local government was developed and a pilot project for livelihood restoration was implemented. This pilot project was implemented in collaboration with the local government departments of Palu City, Sigi Regency, and Donggala Regency, wherein one project was carried out in each municipality. In this context, discussions were held on insights and lessons learned regarding the nature of the target communities and means of livelihood restoration with a number of relevant departmental officials from the Central Sulawesi Provincial Government, Palu City, Sigi Regency, and Donggala Regency in addition to Bappenas and the Union Ministry of Small and Medium Enterprises. In addition, a reference manual (first version) was prepared based on this exchange of opinions and monitoring results. This reference manual (first edition) was repeatedly discussed by the local task force from the draft stage, in collaboration with Bappenas and the Union Ministry of Small and Medium Enterprises, and the overall structure and layout were finally designed to be easily understood by the Indonesian side. A dissemination seminar of the manual was held in Jakarta and Palu, Central Sulawesi in December 2019, and the finalized manual was printed and distributed with Bappenas' budget. In 2020, a pilot project was conducted to apply the developed manual to a program actually implemented by the Union Ministry of Small and Medium Enterprises. The results were reflected through discussions in the working group, and the revised manual was implemented in January 2021.

In Output 4, the following results were obtained through the support activities for the review of action plans, selection and implementation of pilot projects, and preparation of reference manuals:

- Through the implementation of the pilot project, the restoration of livelihoods of 9 groups (52 women and 3 men) in Palu City, 8 groups (11 women and 25 men) in Sigi Regency, and 3 groups (38 women and 40 men) in Donggala Regency were supported. As a result, in Palu City, the target groups in the Balaroa District Evacuation Shelter were able to generate short-term income, and for some, a basis for continuing their economic activities afterwards. In Sigi district, livelihoods of small businesses were restored through the establishment of MSME centers in temporary housing areas, and income opportunities were improved through vocational training on livelihood restoration. In Donggala Regency, the training and provision of equipment to the community of Lero Tatari Village has enabled them to resume their economic activities of fishing and processing of whitebait, thereby improving their livelihoods.
- Through the implementation of the pilot project, counterparts in Palu City, Sigi Regency, and Donggala Regency have come to understand livelihood restoration, disaster victims and community-centered approach to community restoration support, and reconstruction support that takes into account the socially vulnerable, etc.
- In the pilot project in Donggala Regency, disaster prevention education in communities was conducted in cooperation with the prefectural disaster prevention bureau. Subsequently, similar activities were carried out in other areas under the initiative of the prefectural disaster prevention bureau, which was able to understand the idea of strengthening local disaster prevention capacity.
- Through discussions in the working group, the central government and local government officials discussed the problems of reconstruction assistance activities, issues related to coordination and collaboration among related organizations were highlighted. Based on these experiences, the reference manual has been revised and organized so that the knowledge gained in Central Sulawesi can be used for disaster recovery activities in other regions.
- The reference manual developed through the pilot project was actually applied in a program funded by the Indonesian government's budget from the Union Ministry of Small and Medium Enterprises, and the concept of reconstruction support organized through the project was implemented in the field.

3-5 Other Assistance Activities and Results

As mentioned in the previous parts, in Output 1, the JICA Study Team analyzed the causes of the disaster and assisted disaster hazard assessment for several disasters such as tsunami, Nalodo, earthquake, landslide, flood, etc. In Output 3, based on the evaluation in Output 1, the JICA Study Team assisted the infrastructure recovery and reconstruction plans. However, through an investigation by the survey team conducted immediately after the disaster, especially for Nalodo and tsunami, it was clear that it happened in an unprecedented scale and cause in the world. For this reason, a Japanese Advisory Committee was established with the aim to implement a more effective and smooth project, along with receiving opinions from experts on the countermeasure policies from the evaluation of each disaster occurrence mechanism. In addition, in the livelihood recovery and community restoration assistance, which is one of the pillars in the Output 4 activities, a Japanese Advisory Committee was established. It consist of relevant persons from domestic administrative agencies who have a lot of knowledge from the reconstruction of the Great East Japan Earthquake.

In addition, as an assistance activity mainly related to Output 3 and Output 4, for the purpose of promoting understanding and sharing issues to the Indonesian government on disaster countermeasures in the recovery activities after the Great East Japan Earthquake and knowledge on the process of forming residents' consensus until the implementation, a visit to Japan and training in Japan were held.

The activities for each assistance and the outline of the visit to and training in Japan are described below.

(1) Japanese Advisory Committee

Japanese Advisory Committee for the Liquefaction Landslide (Inland)

The main members of Japanese Advisory Committee are Kenji Ishihara (Professor Emeritus, the University of Tokyo), Takaji Kokusho (Professor Emeritus, Chuo University), Susumu Yasuda (Professor Emeritus, Tokyo Denki University), Ikuo Towhata (Professor Emeritus, the University of Tokyo), Takashi Kiyota (Associate Professor, the University of Tokyo), and Tetsuya Sasaki (Senior Researcher, Public Works Research Institute). In addition, Hemanta Hazarika (Professor, Kyushu University), Mitsu Okamura (Professor, Ehime University), and Kenji Watanabe (Associate Professor, the University of Tokyo) participated in this committee as experts.

Table 3-4 shows the main activities and discussions of the committee. The committee members and experts provided advice on the mechanism of Nalodo, how to set the hazard level, and the outline plan of the disaster countermeasures through the field survey and the seven meetings held by this committee. In addition, Professor Emeritus Ishihara and Professor Emeritus Yasuda attended the National Panel held in Indonesia (October 2019) to present joint field survey and survey results. The JICA Study team invited the researchers to Japan, and through opinion exchange meetings, sufficient understanding and common understanding of the Nalodo occurrence was obtained.

Table 3-4 Outline of Japanese Advisory Committee Activity on the Liquefaction Landslide (Inland Areas)

Event	Implementation Date	Work and Discussion
JICA First Survey Team*	2018/10/17-18	Nalodo field survey in the inland areas and coastal areas
JICA Second Survey Team*	2018/11/2-4	Same as above
Japanese Advisory Committee (1st)	2018/12/19	First boring survey implementation stage
Field Survey and Survey Report with Indonesian Side	2019/1/5～2019/1/10	First boring survey completed, and soil test (not completed)

Event	Implementation Date	Work and Discussion
Japanese Advisory Committee (2nd)	2019/1/29	First boring survey (completed), laboratory test (not completed), and added trench survey
Japanese Advisory Committee (3rd)	2019/3/19	Report the result of liquefaction survey (FL method and energy method)
Opinion Exchange Meeting in Japan	2019/4/27	Explanation of policy for countermeasure
Japanese Advisory Committee (4th)	2019/6/3	Explanation of policy for countermeasure, and second boring survey plan
Japanese Advisory Committee (5th)	2019/8/8	Explanation of the second boring survey results
Japanese Advisory Committee (6th)	2019/9/30	Completed the second boring survey, liquefaction study, and explanation of two-dimensional osmotic flow analysis
National Panel	2019/10/5 ～ 2019/10/10	Field survey Presentation to the National Panel
Technical Meeting (Before the Final Committee)	2020/11/11	Coordinating policy as a committee on long-distance flow
Japanese Advisory Committee (7th)	2020/12/11	Confirmation of draft JICA report

Activities marked with * were handled as an emergency response before the start of this project.
Source: JICA Study Team

Japanese Advisory Committee for Tsunami and Liquefaction Landslide (Coastal Areas)

The main members of this committee are Fumihiko Imamura (Professor, Tohoku University), Taro Arikawa (Professor, Chuo University), and Shinji Sassa (Head of Tsunami and Storm Surge Group, Port and Airport Research Institute). Table 3-5 shows the main activities and discussions of this committee. Furthermore, Professors Imamura and Arikawa conducted not only the committee activities but also the field surveys immediately after the earthquake, and made efforts to identify the main cause of the tsunami. During the five meetings of the committee, they gave a great deal of advice on the reproduction of the tsunami generation mechanism and the construction of damage mitigation measures based on the experience of the Great East Japan Earthquake.

In addition, Professor Arikawa provided a great deal of cooperation in tsunami survey proposals, guidance on model experiments for the Coastal Research Center of the Ministry of Public Works, and analysis of tsunami reproduction simulations. Initially, the central government officials in Indonesia expressed reluctance to JICA's tsunami countermeasure proposal, but by continuing to organize and explain the results of the survey and analysis reflecting the policy of this committee, eventually, a basic agreement was reached in a panel of tsunami experts organized by Bappenas.

Table 3-5 Outline of Japanese Advisory Committee Activity on the Tsunami and Liquefaction Landslide (Coastal Area)

Event	Implementation Date	Work and Discussion
Field survey*	2018/10/4-5	The tsunami damage situation survey, and estimation of the tsunami's occurrence cause
Japanese Advisory Committee (1st)	2018/12/20	Status of reconstruction M/P proposals, tsunami damage simulation, and coastal risk assessment
Japanese Advisory Committee (2nd)	2019/1/29	Target level of tsunami embankment, linear concept of tsunami embankment, how to set height of tsunami embankment, and points to note for model

Event	Implementation Date	Work and Discussion
		experiments
Japanese Advisory Committee (3rd)	2019/3/20	Mechanism and outbreak period of the tsunami, how to proceed with infrastructure planning, and handling of hazard maps
Japanese Advisory Committee (4th)	2019/6/22	Handling of tsunami trace survey for embankment height setting, and handling of mangroves as a tsunami countermeasure
Tsunami Expert Panel (1st)	2019/6/26	Tsunami countermeasure basic policy, target tsunami, tsunami mitigation measures, etc.
Tsunami Expert Panel (2nd)	2019/8/8	Elevated road height, and tsunami model experiment
Visit to the Coastal Research Institute (Balai Pantai)	2019/8/10	Confirmation of experimental facility and experimental plan
Visit to the Coastal Research Institute (Balai Pantai)	2019/11/15-11/16	Checking the operation of measuring instruments and inspecting the experimental status
Japanese Advisory Committee (5th)	2020/9/14	Confirmation of final policy for Palu Bay tsunami countermeasures
Tsunami Expert Panel (3rd)	2021/2/9	Discussion on model experiments, simulation analysis, and recommendations from the JICA Study Team

Activities marked with * were handled as an emergency response before the start of this project.
Source: JICA Study Team

Japanese Advisory Committee for the City Reconstruction

The main members of the committee from the MLIT (Ministry of Land, Infrastructure, Transport and Tourism) and local government are as follows;

- Shoichi Suzuki (Director for Overseas Road Project, Planning Division, Road Bureau, MLIT),
- Hiroshi Fukuyama (Director of Architectural Research Department, National Institute for Land and Infrastructure Management, MLIT),
- Tsutomu Murakami (Director for International Cooperation and Projects, Urban Development and Improvement Division, City Bureau, MLIT),
- Takashi Suzuki (Deputy Director, International Affairs Office, River Planning Division, Water and Disaster Management Bureau, MLIT),
- Takashi Okuda and Hiroshi Tanaka (Director for International Policy, Industrial Port Policy Division, Ports and Harbours Bureau, MLIT),
- Kazunori Ishii (General Manager, Open City Promotion, Kamaishi City, Iwate Prefecture),
- Hisashi Konno (Chief of General Policy Division, Kamaishi City, Iwate Prefecture),
- Takafumi Kawaguchi (Chief of Reconstruction Policy Group, Higashi-Matsushima City, Miyagi Prefecture).

Table 3-6 shows the main activities of the committee and the content of discussions. Each member of MLIT advised on each draft report, and each member from Kamaishi City, Iwate Prefecture, and Higashi-Matsushima City, Miyagi Prefecture gave a reconstruction seminar held in Indonesia. In the training program in Japan for government officials, there was knowledge sharing on reconstruction from the Great East Japan Earthquake, advice on reconstruction activities in Indonesia, and advice on livelihood recovery pilot projects related to the Output 4 activities. As a result, at each seminar, the Indonesian government officials expressed their gratitude for the advice on reconstruction assistance based on the practical experience of the Japanese side.

Table 3-6 Activity Overview of the Japanese Advisory Committee for the City Reconstruction

Event	Implementation Date	Content
Japanese Advisory Committee (The 1st)	2019/1/22	Explanation of work outline, local society, economic situation and livelihood recovery, and discussion on community revitalization pilot project proposal
Reconstruction experience sharing seminar (Indonesia)	2019/2/11-12	Lectures and questions by staff from Higashi-Matsushima City, Miyagi Prefecture and Kamaishi City, Iwate Prefecture, who worked on recovery from the Great East Japan Earthquake
Training in Japan for government officials, World Disaster Prevention Forum	2019/11/5-14	Issues and responses in the reconstruction of the Tohoku region, and tsunami countermeasure embankment maintenance project
City planning seminar (Indonesia)	2019/12/17-18	Sharing experience in spatial planning and disaster relocation for BBB
Livelihood Recovery / Community Revitalization Seminar	2019/12/18-20	Lectures and questions by staff from Higashi-Matsushima City, Miyagi Prefecture and Kamaishi City, Iwate Prefecture, who worked on recovery from the Great East Japan Earthquake
Japanese Advisory Committee (The 2nd)	2020/3/4	Report on work progress, confirm the hazard maps and risk maps, relocate residents to permanent housing, and progress in spatial planning
"Livelihood Recovery / Community Revitalization Support Manual after Disaster" Web Seminar	2021/1/20	Cooperation with local governments, communities and countries, and efforts for recovery from the Great East Japan Earthquake

Source: JICA Study Team

(2) Training in Japan Program

The project aims to share and smoothly promote the recovery and reconstruction issues that Indonesia will face in the future and the countermeasures through lessons learned from recovery and reconstruction cases of earthquake and tsunami damage in Japan. The project included visits to Japan and training program in Japan. Table 3-7 summarizes the outline and opinions from the participants, and Figure 3-7 shows photos of each activity.

Table 3-7 Visit to Japan and Training Program in Japan

Title and Target C/P	Activity
Visit to Japan	- Date: 24th-28th April 2019 - Participants: 16 persons from BAPPENAS, PU, Mayor of Palu City, etc. High-level government officials are invited to visit Japan to see the areas hit by the 2011 disaster; namely Higashi-Matsushima City and Miyagi Prefecture. Site visit to coastal area, bridge, tsunami dike, evacuation facilities and memorial center, etc. was organized followed by explanatory session. Meeting on disaster countermeasures was held, and with the attendance of experts, there were active exchange of views and Q&As. Through the above-mentioned opportunities, the participants' understanding on how to work on disaster management/recovery was deepened, and they became able to have clearer image of reconstruction.
First Training Program in Japan	- Date: 16th-25th June 2019 - Participants: 14 persons from Bappenas, ATR, Spatial Planning Agency in local governments, BAPPEDA in local governments, and Balai PU The 1st Training Program in Japan was organized to further facilitate the understanding and knowledge sharing on disaster countermeasures and reconstruction through lectures, discussion, and site visit. The program's main participants were local government officials from related agencies such as BAPPEDA, infrastructure-related departments and departments responsible for spatial planning. The contents of training program include lecture, discussion and site visit to disaster-struck areas such as Iwanuma City, Higashi-Matsushima City, Kamaishi City, and Hiroshima City. The topics include local administration of Japan, reconstruction support of JICA, forming agreements with residents, earthquake-resistant design of the infrastructure, etc. Positive feedback was obtained by participants stating that there have been many insights that could be applied to Indonesia in managing the reconstruction efforts.
Second Training Program in Japan	- Date: 5th-14th November 2019 - Participants: 14 persons from Bappenas, ATR, and representatives from the local governments The 2nd Training Program took place in November 2019. In contrast to the first one which focused on the technical aspects, the second one primarily focused on the aspect of livelihood restoration, community empowerment and relocation. The outline is as follows: Schedule: 5th November to 14th November, 2019 (10 Days) * 11th November: World BOSAI Forum 2019 (International Disaster and Risk Conference) in Sendai A few selected representatives from training participants mad a presentation on the reconstruction of Central Sulawesi in this Conference. Destination: JICA HQ, World BOSAI Forum (Sendai City), Higashi-matsushima City, Kesennuma City, Iwanuma City Purpose: To know Japan's experience of recovery and reconstruction from natural disasters through site visit and interaction with related Japanese local officer To know Japan's experience on livelihood and industrial recovery. To know Japan's experience on consensus building with citizens for relocation To share outline and progress on reconstruction activities in Central Sulawesi at the World BOSAI Forum

Source: JICA Study Team

■ Visit to Japan/24-28 April 2019

Ishinomaki City Bridge Site Visit (4/25)

Exchange of opinions on tsunami countermeasures (4/27)

■ Training Program in Japan (The 1st)/16-25 June 2019

Lecture on earthquake reconstruction by Kamaishi City (6/21)

Hiroshima City Sabo Dam Site Visit / Lecture (6/24)

■ Training Program in Japan (The 2nd)/5-14 July 2019

Lecture on reconstruction town development by Higashi-Matsushima City (11/7)

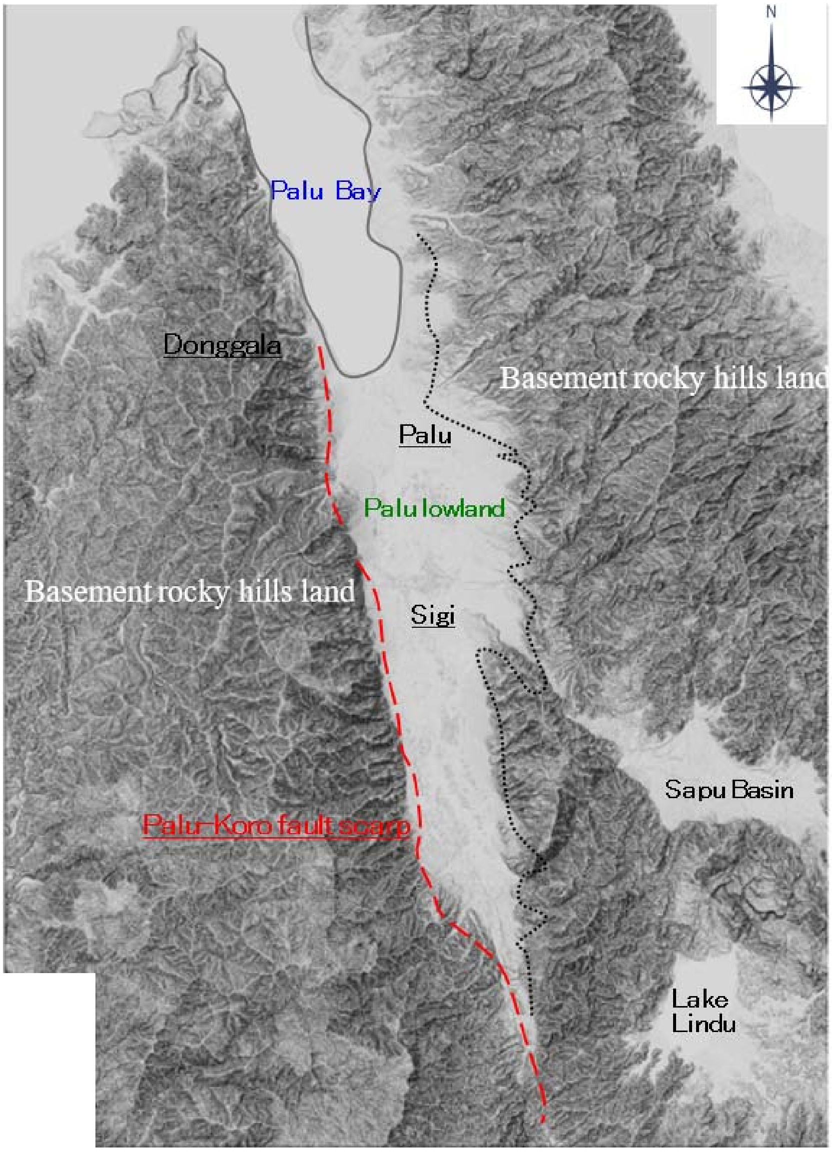
Higashi-Matsushima City Reconstruction Site Visit / Lecture (11/9)

Source: Taken by the JICA Study Team

Figure 3-7 Photos of the Activities of Visit to Japan and Training Program in Japan

Chapter 4 Topographical Condition of the Target Area

The target areas of the Project are Palu City, Sigi Regency and Donggala Regency in Central Sulawesi Province. These cities and regencies are called PASIGALA, and they are located about 1,550 km from the capital city, Jakarta. The terrain around PASIGALA is roughly divided into steep mountains and the Palu lowlands bordered by the Palu-Koro fault. The Palu lowlands, in which the Palu City is located, are formed by alluvial fans with various sizes between 1 and 5% distributed by the Palu River. The topography of Palu Bay is a steep submarine canyon with a depth of over 500 m, and the coastal area is composed of offshore alluvial fans created by rivers flowing from the west-east, terraced and dissected alluvial fans, and basement of rocky and hilly terrain.



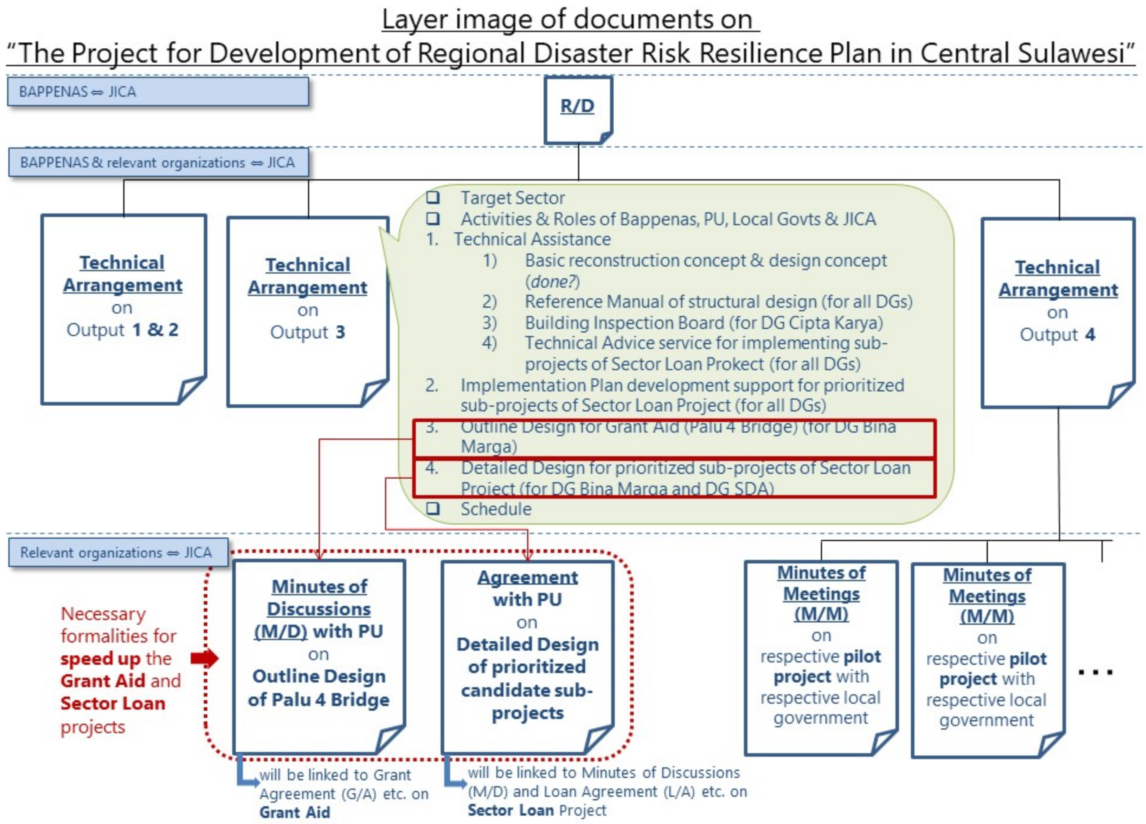
Source: JICA Study Team

Figure 4-1 Topographical Condition Map around the Target Area

Chapter 5 Implementation System

(1) Framework for the Project

The framework of this technical cooperation is shown in Figure 5-1 below. First of all, the base of the framework is the Record of Discussion (hereinafter referred to as "RD"), a comprehensive agreement agreed and signed by JICA and Bappenas – the main counterpart of the Indonesian government. The detail activities of each output are based on the technical agreement, which itself is based on the RD. Furthermore, Output 3 is based on Minutes of Discussion (hereinafter referred to as "MD") of Grant Aid for Schematic Design of Palu IV Bridge Reconstruction and the agreement document on the detail design of the prioritized project (displayed in red frames in Figure 5-1). Output 4 is based on the memorandum for each pilot project (M/M). The detail contents of these RD, Technical Agreement, MD, etc. are summarized in Annex I.

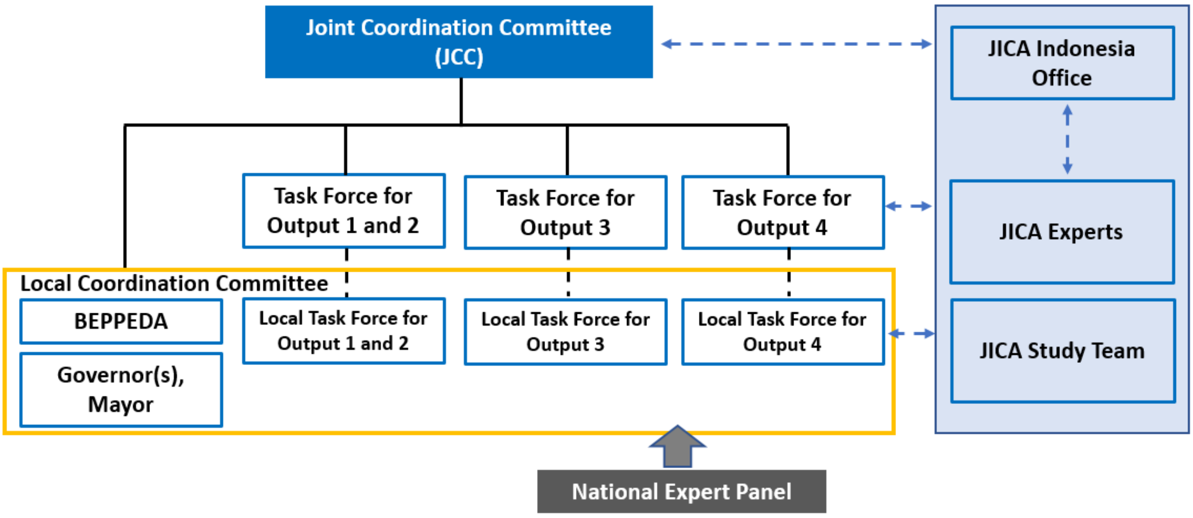


Source: provided by JICA

Figure 5-1 Framework for implementing the Project

(2) Overall Implementation System

The JICA study team proposed an overall implementation system for the Project as shown in Figure 5-2, and obtained approval from Bappenas and related organizations. Under the direction of JICA experts, in addition to the general manager and deputy general manager, the JICA Study Team assigned a team leader for each of the four outputs and established a system that allows the Study Team to work in close cooperation with each counterpart.



Source: JICA Study Team Based on Materials Provided by Bappenas

Figure 5-2 Overall Implementation System of the Project

Table 5-1 shows the members of the Joint Coordinating Committee (hereinafter referred to as "JCC"), a list proposed at the beginning of the survey, and Table 5-2 shows the members and roles of TF and local TF.

Table 5-1 JCC Members

Chairperson	Project Director: Deputy of Regional Development, Bappenas
Members from the GOI Side	・ Central Sulawesi Development Planning Agency ・ Ministry of Agrarian and Spatial Planning/ National Land Agency ・ Agency for Meteorology, Climatology and Geophysics ・ National Disaster Management Agency ・ Ministry of Energy and Mineral Resources ・ Ministry of Public Works and Public Housing ・ Ministry of Transportation ・ Ministry of Cooperatives and SMEs ・ Ministry of Fishery & Marine Affairs ・ Ministry of Social Welfare ・ Ministry of Trade ・ Ministry of Agriculture ・ Ministry of Village, Disadvantaged Region and Transmigration ・ Ministry of Home Affairs ・ Ministry of Finance ・ Indonesian Institute of Science
Members from the Japanese Side	・ Chief Representative, JICA Indonesian Office ・ Japanese Experts ・ Personnel concerned to be decided by the Japanese Side
Others	・ Officials of the Embassy of Japan may attend the meeting ・ Persons who are invited by the Chairperson may attend the meeting

Source: JICA Study Team

Table 5-2 Overview of the TF (Task Force)

<table>
<tr><th></th><th>Member</th><th>Role</th><th>Local TF</th></tr>
<tr><td>TF for Output 1 & 2</td><td>・ Director, Ministry for National Development Planning (Bappenas)
・ Director, Ministry of Land and Spatial Planning
・ Geological Agency (BG)
・ Agency for Meteorology, Climatology and Geophysics (BMKG)
・ Agency for Geospatial Information (BIG)
・ National Disaster Management Authority (BNPB)
・ Representative(s) of local government(s)</td><td rowspan="3">・ Review the progress and report to the JCC

・ Facilitate inter-organization coordination

・ Review the product(s) developed through activities for each output
(TF for Output 1 and 2)
(TF for Output 3)
(TF for Output 4)</td><td rowspan="3">Local task force, which consists of local governments, representative of central government, will be established for smooth implementation of the project and inter-organization coordination.</td></tr>
<tr><td>TF for Output 3</td><td>・ Director for Water Resources and Irrigation, Ministry of National Development Planning (Bappenas)
・ Head of Budget Planning and Foreign Cooperation Bureau, Ministry of Public Works and Housing (PUPR)
・ Director of Road Network Development, Directorate General of Highway, Ministry of Public Works and Housing (PUPR)
・ Director of Water Resources Network Development, Directorate General of Water Resources, Ministry of Public Works and Housing (PUPR)
・ Director of Integration on Settlements Infrastructure, Directorate General of Human Settlement, Ministry of Public Works and Housing (PUPR)
・ Representative(s) of local government(s)</td></tr>
<tr><td>TF for Output 4</td><td>・ Director, Ministry for National Development Planning (Bappenas)
・ Ministry of Cooperative and SMEs
・ Ministry of Fishery and Marine Affairs
・ Ministry of Village, Disadvantaged Region and Transmigration</td></tr>
</table>

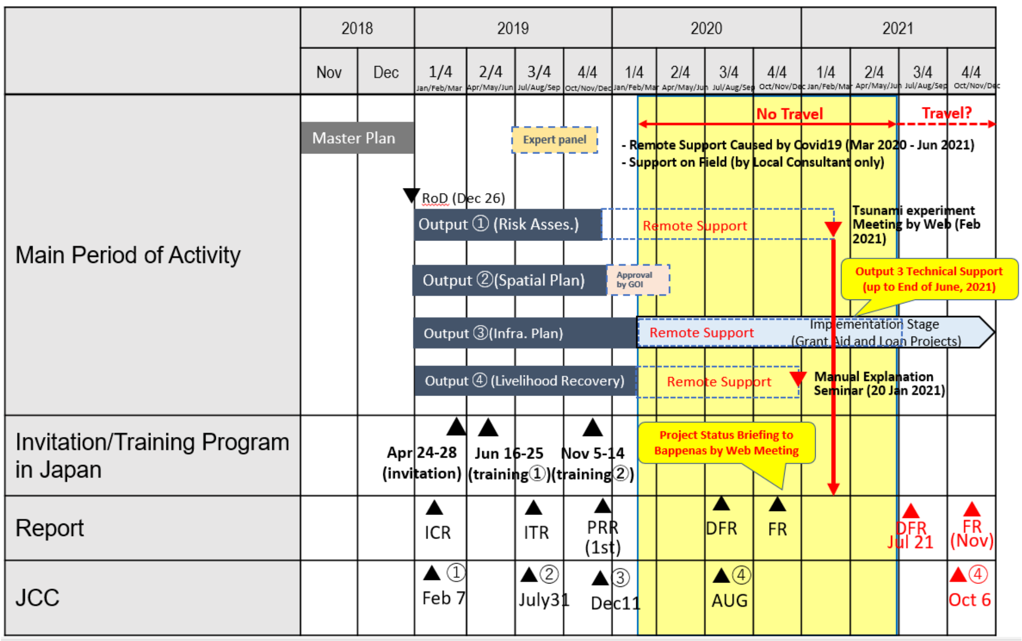
Source: JICA Study Team Based on Memorandum on this Survey

Chapter 6　Project Schedule

The overall process of the Project is shown in Figure 6-1 below. Based on the Indonesian government's plan to complete the infrastructure recovery and reconstruction project at the end of 2021, intensive assistance activities were carried out in 2019. The first JCC meeting was held in Jakarta in February 2019, and the work plan was explained and discussed based on the Inception Report. The second JCC meeting was held in Jakarta in July 2019, and based on the Interim Report, the progress of each output and future issues were explained and discussed. The third JCC meeting was also held in Jakarta in December 2019, and based on the Progress Report, the activities of each output were almost completed, and the remaining tasks and issues were explained and discussed.

Afterward, Bappenas and the Ministry of Public Works and National Housing (hereinafter referred to as “PUPR”), which is the infrastructure implementation agency, requested additional assistances to accelerate infrastructure recovery and reconstruction projects, mainly for Output 3 resilient infrastructure plan, and Output 4 activities related to livelihood recovery. In March 2020, just after the additional assistance activities started, Indonesia issued a large-scale activity restriction order due the COVID-19 pandemic. As result, the activities of the Japanese members of the JICA Study Team have been restricted since April 2020, and it started to work remotely from Japan. The final (fourth) JCC meeting has been implemented in 6 October 2021 to explain and discuss the activity results and recommendations of the Project based on the Draft Final Report.

As of October 2021, construction procurement for infrastructure recovery and reconstruction were in progress, while some infrastructures work have been completed. For infrastructure work which involve with relocation, the local government is continuing the dialogue with the residents on the land compensation. The infrastructure work will be started after reached a consensus.



▲ Original　▲Revised

Remarks: **RoD**: Record of Discussions, **ICR**: Inception Report, **ITR**: Interim Report, **PRR**: Progress Report , **DFR**: Draft Final Report, **FR**: Final Report

Source: JICA Study Team

Figure 6-1　Project Schedule

National Development Planning Agency (BAPPENAS)

Project for Development of Regional Disaster Risk Resilience Plan in Central Sulawesi in the Republic of Indonesia

FINAL REPORT
(Volume II)

November 2021

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

JICA Expert, Comprehensive Disaster Risk Reduction, BNPB
JICA Expert, Integrated Water Resources Management, PUPR

Yachiyo Engineering Co., Ltd.
Oriental Consultants Global Co., Ltd.
Nippon Koei Co., Ltd.
Pacific Consultants Co., Ltd.
PASCO CORPORATION

IM
JR
21-053

Preface

In response to a request from the Government of Indonesia, the Japan International Cooperation Agency (hereinafter referred to as "JICA") assisted on understanding the disaster situation and formulated a Reconstruction Master Plan. The assistance started by dispatching the first survey team to collect information on the disaster situation and emergency assistance in October 2018. In addition, discussions on future seamless recovery and reconstruction assistance measures were held with related Indonesian organizations, such as Bappenas. As a result, the Indonesian government requested JICA to implement a technical cooperation project for the recovery from the disaster, and it has been decided to implement this project (implementation period: December 2018 to November 2021): "Project for Development of Regional Disaster Risk Resili ence Plan in Central Sulawesi in the Republic of Indonesia" (hereinafter referred to as "the Project"). JICA entrusted the Project to Yachiyo Engineering Co., Ltd., Oriental Consultants Global Co., Ltd., Nippon Koei Co., Ltd., Pacific Consultants Co., Ltd., and PASCO CORPORATION.

Regarding the assistance for formulating the Reconstruction Master Plan, after the first survey team was dispatched immediately after the disaster in October 2018. Naoto TADA, JICA Expert of Comprehensive Disaster Risk Reduction, BNPB, and Jun HAYAKAWA, JICA Expert of Integrated Water Resources Management, PUPR (hereinafter referred to as "JICA Experts"), led the formulation of the Reconstruction Master Plan. To continue the seamless and reliable knowledge transfer from this Reconstruction Master Plan formulation assistance, JICA experts also provided guidance to the study team of the Project. The Project cited some charts created by the JICA experts during the Reconstruction Master Plan formulation.

This final report summarizes the results of JICA experts and the study team's activities in the Project, and the findings from Japanese experts who participated in Japanese Support Committee.

In addition, using a part of the Project results as basic data, in June 2019, during the implementation period of the Project, a Grant Agreement (G/A) was signed for "The Programme for the Reconstruction of Palu 4 Bridges in Central Sulawesi Province", which is the core infrastructure in the disaster area. Furthermore, in January 2020 an ODA Loan Agreement (L/A) was signed for the "Infrastructure Reconstruction Sector Loan in Central Sulawesi", to promote infrastructures reconstruction such as roads, bridges, irrigation facility, rivers, and reconstruction of public facility (hospital).

Final Report Structure

The final report consists of a summary, main report and appendix. The detail results of the project are described in the main report. The main report consists of Volume I to Volume V.

Summary (English)

* Essential part from summary (Outline and Recommendation) is translated to Bahasa Indonesia and included in the report.

Main Report (English)

Volume I	Outline of the Project
Volume II	Disaster Hazard Assessment and Hazard Map
Volume III	Formulation of Spatial Plan Based on Disaster Hazard and Risk Assessment
Volume IV	Resilient Infrastructure and Public Facilities
Volume V	Livelihood Recovery and Community Restoration

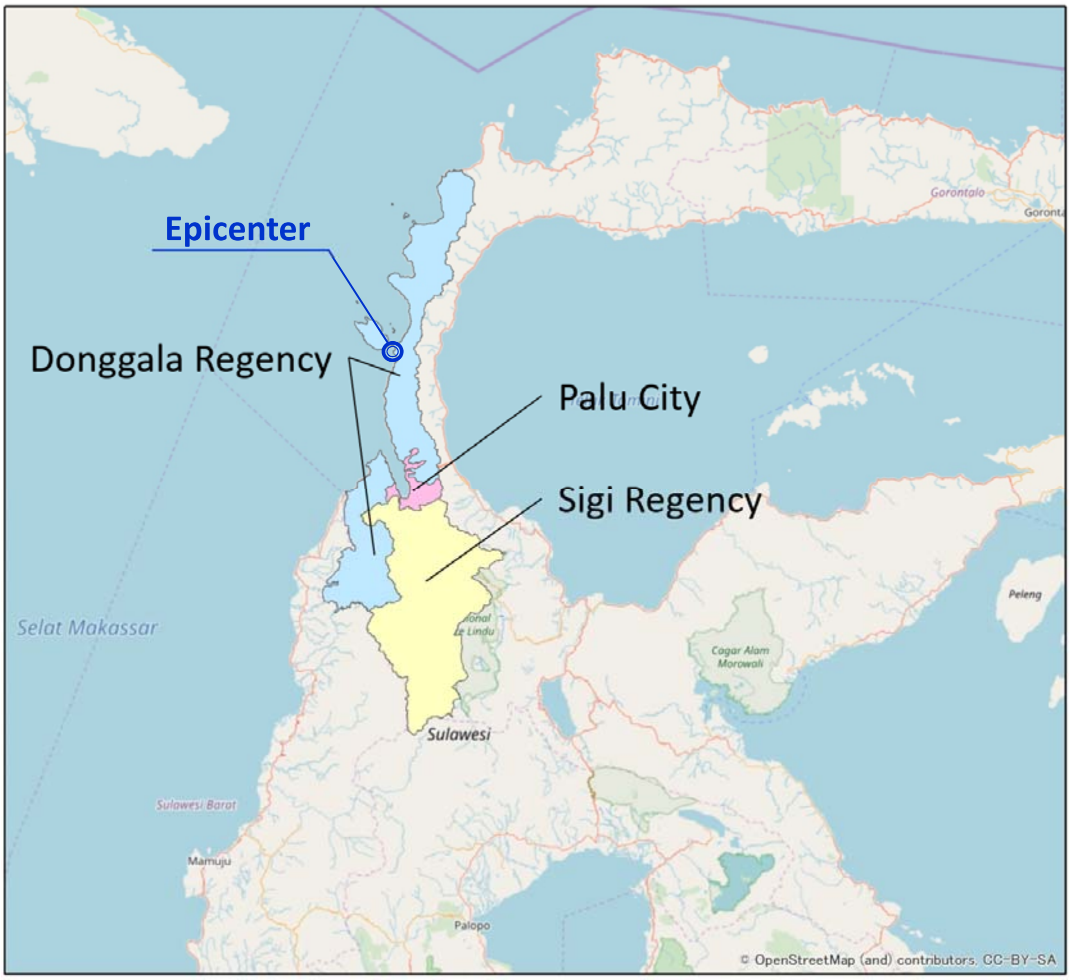
Appendix

US Dollar $ 1.00 = Indonesia Rupiah IDR 14,021.59 = Japanese yen ¥ 103.90
(February 2021)

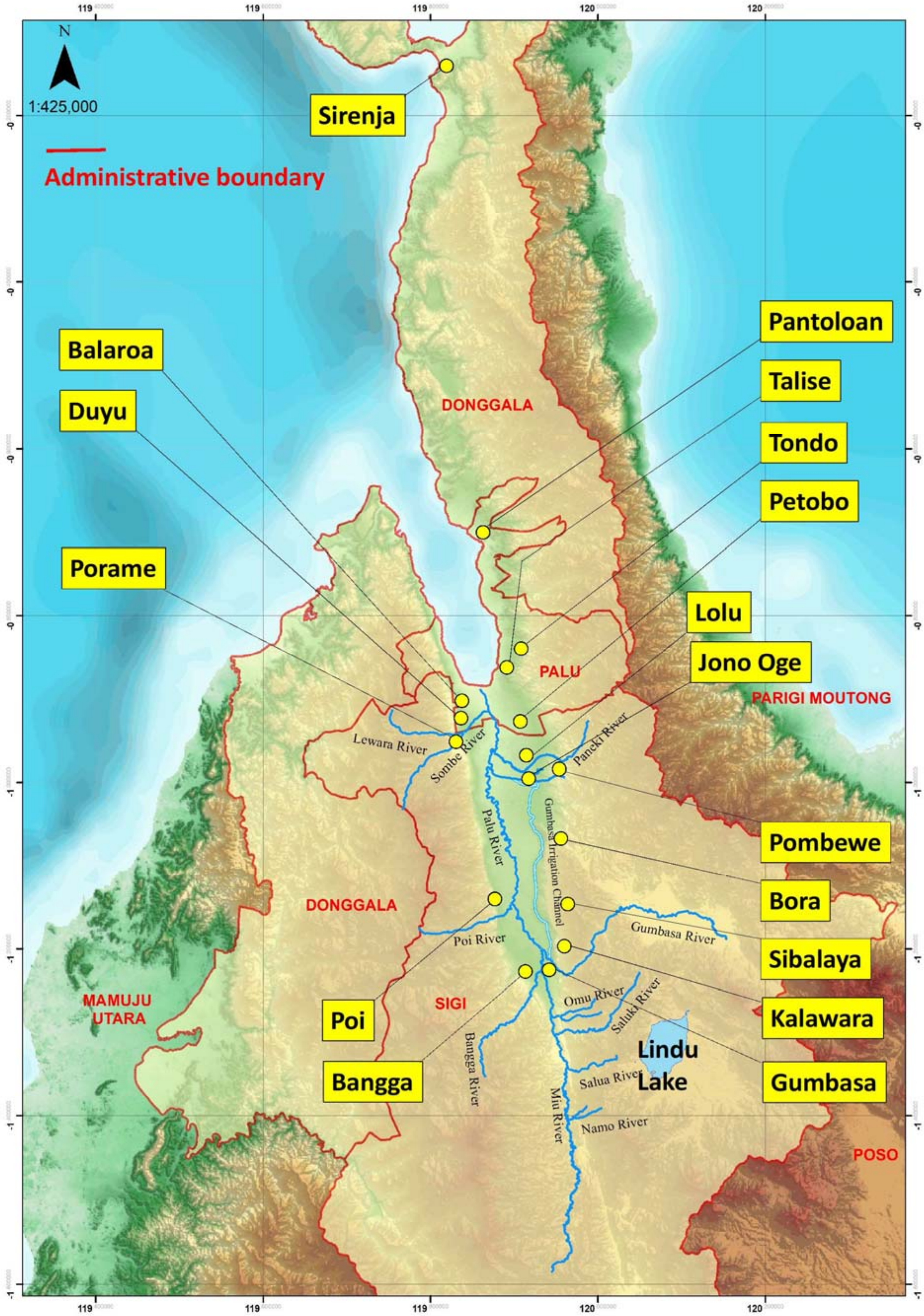
Location Map of the Project Area

Location of Central Sulawesi Province

Location of Disaster Affected Area and Epicenter (Palu City, Sigi Regency and Donggala Regency)



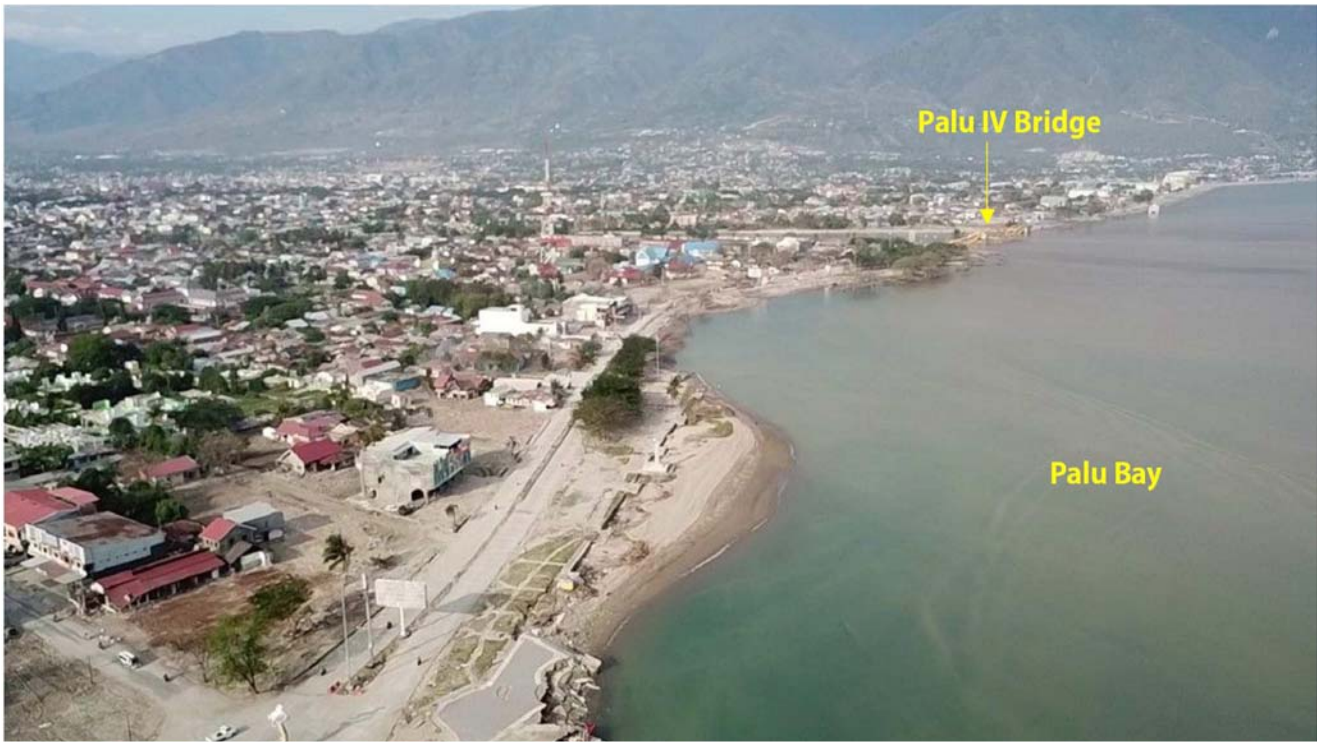
Location of Target Area in the Project



Source: Prepared by JICA Study Team based on Data from the Geospatial Information Authority of Indonesia (BIG)

Lead-off Photos (1/7)

Damage Conditions



Condition of the Coastal Area of Palu Bay After the Disaster (Right Shore Side, Drone Shooting)

Condition of the Coastal Area of Palu Bay After the Disaster (Left Shore Side, Drone Shooting)

Lead-off Photos (2/7)

Damage Conditions

The Palu IV Bridge located at the Palu River Estuary was Collapsed by the Earthquake.

Collapsed Coastal Road along the Palu Bay

Damaged Buildings by Tsunami Inundation (100m to 450m from the Coast) (On the Right Shore of Palu Bay)

Damaged Port Facilities in the Palu Bay

(The Photo is SAMAS Container Jetty on the Left Shore of Palu Bay)

Damaged Road by Nalodo (Palu City)

Damaged in Sibalaya Area by Nalodo (Sigi Regency, Drone Shooting)

Lead-off Photos (3/7)

Damage Conditions

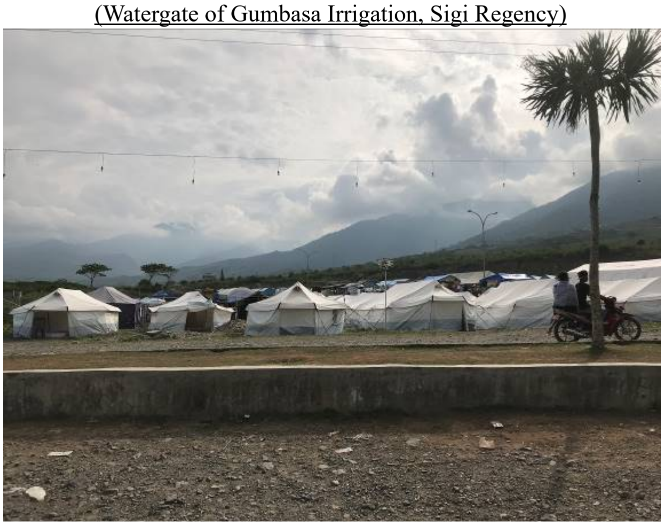
Damaged Caused by Floods and Landslides (Bangga River, Sigi Regency)

Sediment Disaster Caused by Debris Flow (Salua River, Sigi Regency)

Collapsed buildings by the Earthquake (Pal City)

Damaged Irrigation Facilities by Ground Deformation (Watergate of Gumbasa Irrigation, Sigi Regency)

Damaged in Sirenja Area by Inundation (Donggala Regency)



Evacuation Shelter Built in Balaroa District of Palu City After the Disaster

Lead-off Photos (4/7)

Stakeholder Discussions and Field Surveys

The First Joint Coordinating Committee (February 17, 2019)

Discussions with the Ministry of Land and Spatial Planning (ATR) and the National Land Agency (BPN)
(March 21, 2019)

Discussions on Infrastructure Reconstruction Plans with the Ministry of Public Works and National Housing (PUPR)
(February 18, 2019)

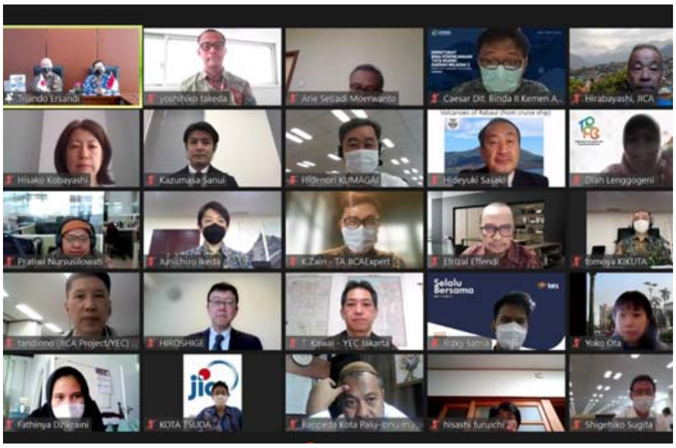
The Second Joint Coordinating Committee (August 6, 2019)

The Third Joint Coordinating Committee（December 11, 2019）

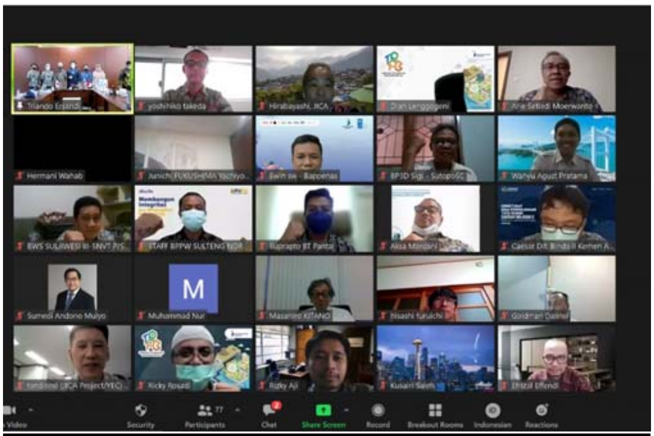
Discussion on the Japanese Support Committee (Nalodo)
(March 25, 2019)

Stakeholder Discussions and Field Surveys

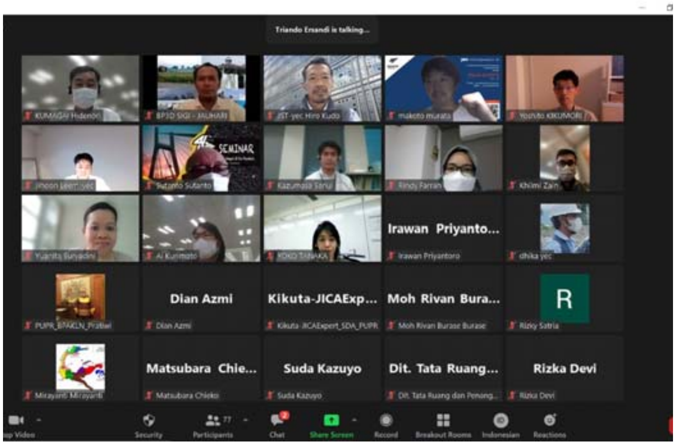
The Final Joint Coordinating Committee (October 6, 2021)
In Bappenas Meeting Room (Onsite participation)



The Final Joint Coordinating Committee (October 6, 2021)
By web communication tool (Online participation-1)



The Final Joint Coordinating Committee (October 6, 2021)
By web communication tool (Online participation-2)



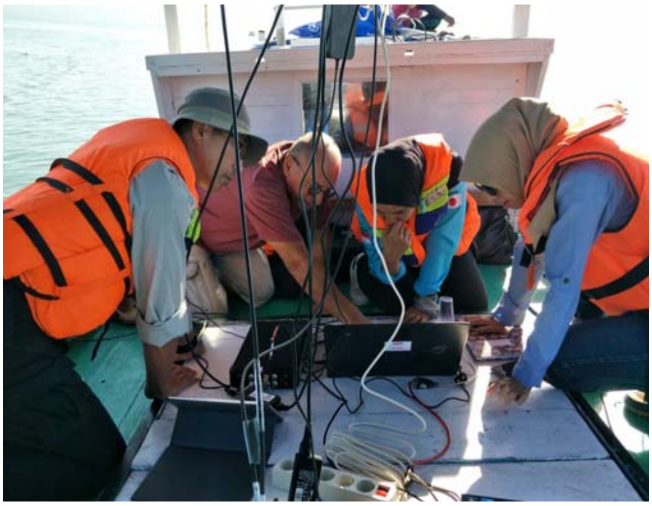
The Final Joint Coordinating Committee (October 6, 2021)
By web communication tool (Online participation-3)

Closing Ceremony – Handover report (October 6, 2021)

Closing Ceremony – Group picture (October 6, 2021)
(left-right); Mr. Ikeda; Mr. Kikuta; Mr. Fukushima; Mr. Tsuda, Mr. Sumedi, Ms. Lenggo

Lead-off Photos (6/7)

Stakeholder Discussions and Field Surveys



Reflection seismic survey of Palu Bay (Output 1 Activity)

A survey conducted to understand the geological composition and structure of the seabed at the southern of the Palu Bay, including the area around the Palu River Estuary (total 29.6 km).

Discussion with the Ministry of Land and Spatial Planning (ATR) (Output 1 and Output 2 Activities, April 11, 2019)

Discussion with Local Government (Central Sulawesi) (Output 2 Activity, March 18, 2019)

Discussion on Anutapura Hospital Design Review (Output 3 Activity- Public Facilities Sector, April 9, 2019)

Palu IV Bridge Field Survey (Output 3-Road and Bridge Sector)

Survey for reconstruction of the collapsed Palu IV Bridge (January-May 2019).

Pilot Project Activities in Balaroa Shelter (Output 4 Activity)

Training was conducted twice to introduce Silar leaves weaving as an activity to obtain income in a short term.

Lead-off Photos (7/7)

Stakeholder Discussions and Field Surveys

Pilot Project Activities in Balaroa Shelter (Output 4)

Small culinary business activities were carried out by the groups of victims of the Balaroa evacuation shelter

Pilot Project Activities in M'panau Village (Output 4)

Training was conducted to improve the construction skills for the victims in the community in collaboration with vocational schools in the Province

Pilot Project Activities in M'panau Village (Output 4)

A MSMEs Centre was built to support the improvement of livelihood through micro business entities

Pilot Project Activities in Lero Tatari Village (Output 4)

20 fishing boats were provided to support the recovery of livelihood activities of a group of 40 fishermen.

Pilot Project Activities in Lero Tatari Village (Output 4)

Training on new processing technology of *Ikan Teri* (White bite) was conducted in cooperation with the department of SMEs in Central Sulawesi Province.

Pilot Project Activities in Lero Tatari Village (Output 4)

DRR education seminar was conducted for the pilot project beneficiaries by BPBD together with inviting BMKG and BASARNAS as lecturers

List of Abbreviation

Abbreviation	Indonesian Language	English
Organization / Institution		
AASHTO	–	American Association of State Highway and Transportation Officials
ACT	Aksi Cepat Tanggap	Quick Response Action
ADB	Bank Pembangunan Asia	Asian Development Bank
ADRA	–	Adventist Development and Relief Agency
AMC	–	Anutapura Hospital Medical Center
ASB	–	Arbiter Samariter Bund
ATR	Kementerian Agraria dan Tata Ruang	Ministry of Land and Spatial Planning
AusAID	–	Australian Agency for International Development
BAPPEDA	Badan Perencanaan Pembangunan Daerah	Regional Development Planning Agency
BAPPENAS	Badan Perencanaaan Pembangunan Nasional	National Development Planning Agency
BG	Badan Geologi	Geological Agency
BIG	Badan Informasi Geospasial	Agency for Geospatial Information
BM	Bina Marga	Directorate General of Highways
BMKG	Badan Meteorologi, Klimatologi dan Geofisika	Agency for Meteorology, Climatology and Geophysics
BNPB	Badan Nasional Penanggulangan Bencana	National Disaster Management Authority
BPBD	Badan Penanggulangan Bencana Daerah	Regional Disaster Management Authority
BPN	Badan Pertanahan Nasional	Provincial land agency
BPPW	Balai Prasarana Permukiman Wilayah	Regional Settlement Infrastructure Center
BSN	Badan Standardisasi Nasional	National Standardization Agency
BWS	Balai Wilayah Sungai	River Basin Development Agency
Cipta Karya	–	Directorate General of Human settlements
CRS	–	Catholic Relief Services
CWS	–	Inanta Church World Service
DGST	Direktorat Jenderal Perhubungan Laut (DirJen Hubla)	Directorate General of Sea Transportation
Dinas	–	Agency
DKP	Dinas Kelautan dan Perikanan	Agency of Marine Affairs and Fisheries (at regional level)[1]
DLH	Dinas Lingkungan Hidup	Environmental Agency (at regional level)
DPMPTSP	Dinas Penanaman Modal dan Perijinan Terpadu Satu Pintu	One-stop office of integrated Investment and Permit Services
DPRP	Dinas Penataan Ruang dan Pertanahan	Local Spatial Planning and Land Service Agency
EA	–	Executing Agency
ESDM	Energi dan Sumber Daya Mineral	Ministry of Energy and Mineral Resources
FAO	Organisasi Pangan dan Pertanian Dunia	Food and Agriculture Organization
GOI	Pemerintah Negara Republik Indonesia	Government of Indonesia
HAKI	Himpunan Ahli Konstruksi Indonesia	Association of Indonesia construction expert
HATTI	Himpunan Ahli Teknik Tanah Indonesia	Indonesian Society For Geotechnical Engineering[2]

[1] Note: DKP at regional level (D = Dinas); KKP at national level (K=Kementerian/Ministry).

[2] Source: https://www.hatti.or.id/

Abbreviation	Indonesian Language	English
IFRC	―	International Federation of Red Cross and Red Crescent
ILO	Organizasi Pekerja Internasional	International Labour Organization
INGO	Lembaga Swadaya Masyarakat Internasional	International Non-Governmental Organization
INKINDO	Ikatan Nasional Konsultan Indonesia	National association of Indonesian Consultant
JCC	Komite Koordinasi	Joint Coordinating Committee
JFPR	―	Japan Fund for Poverty Reduction
JICA	―	Japan International Cooperation Agency
JST	Tim Studi JICA	JICA Study Team
KfW	Lembaga Pendanaan untuk Rekonstruksi - Jerman (Kreditanstalt für Wiederaufbau)	A German State-owned Development Bank
KKP	Kementerian Kelautan dan Perikanan	Ministry of Maritime Affairs and Fisheries
KPKPST	Kelompok Perjuangan Kesetaraan Perempuan Sulawesi Tengah	Central Sulawesi Women's Equality Group
LNGO	Lembaga Swadaya Masyarakat Lokal	Local Non-Governmental Organization
LTF	Satuan Tugas Lokal	Local Task Force
MCI	―	Mercy Corps Indonesia
MDMC	Pusat Manajemen Bencana Muhammadiyah	Muhammadiyah Disaster Management Center
Ministry of Cooperatives and SMEs	Kementerian Koperasi dan Usaha Kecil dan Menengah, Republik Indonesia	Ministry of Cooperatives and Small and Medium Enterprises
MOT	Kementerian Perhubungan	Ministry of Transport
NGO	Lembaga Swadaya Masyarakat (LSM)	Non-Governmental Organization
OGD	Departemen Kebidanan dan Kandungan[3]	Obstetrics and Gynecology Department
PARCIC	―	PARC Interpeoples' Cooperation
PMI	Palang Merah Indonesia	Indonesian Red Cross Societies
PUPR	Kementerian Pekerjaan Umum dan Perumahan Rakyat	Ministry of Public Works and Public Housing
PuSGen	Pusat Studi Gempa National	National Center for Earthquake Studies
PUSKIM	Pusat Kebudayaan Indonesia	Indonesian Cultural Center
SATGAS	Satuan Tugas	Task Force
SDA	Direktorat Jenderal Sumber Daya Air	Directorate General of Water Resources
SKP-HAM	Solidaritas Korban Pelanggaran Hak Asasi Manusia	Solidarity of Victims of Human Rights Violations
TABG	Tim Ahli Bangunan Gedung	Building Construction Expert Team
TKPRD	Tim Koordinasi Penataan Ruang Daerah	Regional Spatial Planning Coordination Team
UN	Persatuan Bangsa-Bangsa (PBB)	United Nations
UNDP	―	United Nations Development Programme
UNFPA	―	United Nations Fund for Population Activities
UNHCR	―	United Nations High Commissioner for Refugees
UNICEF	―	United Nations International Children's Emergency Fund
WB	Bank Dunia	World Bank
WFP	Program Pangan Dunia	United Nations World Food Programme
WHO	―	World Health Organization
WVI	Wahana Visi Indonesia	World Vision Indonesia
YEU	Unit Gawat Darurat Yakkum	*Yakkum* Emergency Unit

[3] In private hospitals as well as universities, commonly they use the term *Obstetri dan Ginekologi*

Abbreviation	Indonesian Language	English
YPAL	Yayasan Panorama Alam Lestari Kabupaten Poso	*Panorama Alam Lestari* Foundation, Poso Regency
YPI	Yayasan Pusaka Indonesia	Indonesian Heritage Foundation
YSTC	Yayasan Sayangi Tunas Cilik	Save The Children Foundation
Regulation / Plan		
EPMA	Undang-Undang Tentang Perlindungan dan Pengelolaan Lingkungan Hidup	Environmental Protection and Management Law
IMB	Izin Mendirikan Bangunan	Building Permit
KDB	Koefisien Dasar Bangunan	Building Coverage Ratio
KLB	Koefisien Lantai Bangunan	Floor Area Ratio
PERDA	Peraturan Daerah	Local regulation
PP	Peraturan Pemerintah	Government Regulation
PRR	Laporan Kemajuan	Progress Report
RAB	Rancangan Anggaran Biaya	Budget Plan
RDTR	Rencana Detail Tata Ruang	Detailed Spatial Plan
RSNI	Rancangan Standar Nasional Indonesia	Draft Indonesian National Standard
RTRW	Rencana Tata Ruang Wilayah	General Spatial Plan
RTRWN	Rencana Tata Ruang Wilayah Nasional	National spatial plan
RW	Rukun Warga	Neighbourhood unit[4]
SEA	Kajian Lingkungan Hidup Strategis (KLHS)	Strategic Environmental Assessment
SNI	Standar Nasional Indonesia	National Standard of Indonesia
UKL-UPL	Upaya Pengelolaan Lingkungan Hidup dan Upaya Pemantauan Lingkungan Hidup	Environmental Management Efforts and Environmental Monitoring Efforts
ZRB	Zona Rawan Bencana	Disaster Prone Zone
Others		
AP	Rencana Aksi	Action Plan
APBN	Anggaran Pendapatan dan Belanja Negara	State budget
ASTER	—	Advanced Space-borne Thermal Emission and Reflection
Banpem	Bantuan Pemerintah	Government Assistance
BARRATAGA	Bangunan Rumah Rakyat Tahan Gempa	Earthquake Resistant Housing
BBB	Membangun Kembali dengan Lebih Baik	Build Back Better
BCP	Rencana Kelanjutan Bisnis	Business Continuity Plan
BLM	Bantuan Langsung Masyarakat	Community Direct Assistance
BMS	Sistem Manajemen Jembatan	Bridge Management System
BoQ	—	Bill of Quantity
BTP	—	Brownian Passage Time
BUMDes	Badan Usaha Milik Desa	Village-Owned Company
BWP	Bagian Wilayah Perencanaan	Part of the Planning Area
C/P	—	Counter Part
CBD	Kawasan Niaga Terpadu	Central Business District
CCT	Pembayaran Tunai Bersyarat	Conditional Cash Payment
CRED	—	Centre for Research on the Epidemiology of Disasters
CSO	Organisasi Masyarakat Sipil (ORMAS)	Civil Society Organization
CSR	Tanggungjawab Sosial Korporat	Corporate Social Responsibility

[4] In urban area (especially Java Island), RW is a neighbourhood unit below Village Level. Smaller unit is RT (Rukun Tetangga). 1 RT consist of 10-50 Households and 1 RW consist up to 10 RT.

Abbreviation	Indonesian Language	English
DED	—	Detail Engineering Design
DEM	—	Digital Elevation Model
DFR	Draf Laporan Akhir	Draft Final Report
DG	Direktur Jenderal (Dirjen)	Director General
DRR	Pengurangan Risiko Bencana (PRB)	Disaster Risk Reduction
DTM	—	Digital Terrain Model
EIA	Analisis Mengenai Dampak Lingkungan (AMDAL)	Environmental Impact Assessment
EMP	Rencana Pengelolaan Lingkungan	Environmental Management Plan
EMoP	Rencana Pemantauan Lingkungan	Environmental Monitoring Plan
ER	Tanggap Darurat (TD)	Emergency Response
ESMF	—	Environmental and Social Management Framework
EWS	Sistem Peringatan Dini	Early Warning System
EXPO	—	Exposition
FGD	—	Focus Group Discussion
FLSH		
FR	Laporan Akhir	Final Report
F/S	Studi Kelayakan	Feasibility Study
G/A	Perjanjian Hibah	Grant Agreement
GBV	—	Gender-Based Violence
GC	Kondisi Umum	General Conditions
GERTASKIN	Program Gerakan Pengentasan Kemiskinan	Poverty Alleviation Program
GIS	Sistem Informasi Geografis (SIG)	Geographic Information System
GL	Panduan	Guide Line
GRP	Produk Regional Bruto	Gross Regional Product
HIV	—	Human Immunodeficiency Virus
Huntap	Hunian Tetap	Permanent Relocation Site
Huntara	Hunian Sementara	Temporary Housing Site
ICR	Laporan Awal	Inception Report
IDR	Rupiah	Indonesian Rupiah
ITR	Laporan Sementara	Interim Report
IKM	Industri Kecil Menengah	Small and Medium Industries
IMB	Ijin Mendirikan Bangunan	Procedures of building permit
IPAL	Instalasi Pengolahan Air Limbah	Wastewater Treatment Plant
IPLT	Intalasi Pengelolaan Limbah Tinja	Faecal sludge treatment plant
ITB	—	Instructions to Bidders
IUMK	Izin Usaha Mikro Kecil	Micro Small Business Permit
JET	—	Japan Exchange and Teaching
KRK	Keterangan Rencana Kota	City Plan Description
L/A	Perjanjian Pinjaman	Loan Agreement
LGBTQ+	—	Lesbian, Gay, Bisexual, Transgender, Questioning, etc.
LLC	—	Level Luffing Crane
Linsek	Lintas Sektor	Inter Sector
LPG gas	—	Liquefied Petroleum gas
MD	Risalah Diskusi	Minutes of Discussion
MEP	Mekanikal, Elektrikal dan Perpipaan	Mechanical, Electrical and Plumbing
M/M	Risalah Rapat	Minutes of Meeting
MKK	Mengawasi Kondisi Konstruksi	Construction supervising works

Abbreviation	Indonesian Language	English
MOU	Nota Kesepahaman	Memorandum of Understanding
M/P	Rencana Induk	Master Plan
MSMEs	UMKM	Micro Small and Medium Enterprises
MTU	Unit Pelatihan *Mobile*	Mobile Training Unit
ODA	—	Official Development Assistance
OP	Keluaran	Output
PASIGALA	Kota Palu, Kabupaten Sigi dan Kabupaten Donggala	Palu city, Sigi Regency and Donggala Regency
PGA	—	Peak Ground Acceleration
PTHA	—	Probabilistic Tsunami Hazard Assessment
PC	Konsultasi Publik	Public Consultation
Persub	Persetujuan Substansi	Substantial Approval (on the Spatial Plan)
POKJA	Kelompok Kerja	Working Team
POKMAS	Kelompok Masyarakat	
PPP	Kebijakan, Rencana dan Program	Policies, Plans and Program
PPs	Proyek Percontohan	Pilot Projects
PQ	Prakualifikasi	Pre-qualification
PRR	Laporan Perkembangan	Progress Report
PSHA	—	Probabilistic Seismic Hazard Assessment
PV	—	Photo Voltaic System
QGC	—	Quay Gantry Crane
RB	Rusak Berat	Severely damaged
RD	Risalah Diskusi	Record of Discussion
R/D	Riset dan Pembangunan	Research and Development
RKPD	Rencana Kerja Perangkat Daerah	Regional Government Work Plans
LARAP	Rencana Aksi Pembebasan Lahan dan Pemindahan Pemukiman	Land Acquisition and Resettlement Action Plan
RRI	—	Rainfall Runoff Inundation
RS	Rusak Sedang	Moderately damaged
RT	Rukun Tetangga	Neighbor Association
SD	Sekolah Dasar	Primary school
SHMs	—	Stakeholder meetings
SLF	Sertifikat Laik Fungsi	Certificate of Building Performance and Function
SMEs	Usaha Kecil dan Menengah (UKM)	Small and medium-sized enterprises
SMP	Sekolah Menengah Pertama	Middle School
SNS	Layanan Jejaring Sosial	Social Networking Service
SOP	Standar Prosedur Operasi	Standard Operational Procedure
SPPL	Pernyataan Kesanggupan Pengelolaan dan Pemantauan Lingkungan Hidup	Statement of Environmental Management and Monitoring Undertaking
TA	Bantuan Teknis (Bantek)	Technical Assistance
ToR	Kerangka Acuan Kerja (KAK)	Terms of Reference
TPA	Tempat pembuangan akhir	Landfill
WASH	Air, Sanitasi, Kebersihan	Water, Sanitation, Hygiene

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Volume II Disaster Hazard Assessment and Hazard Map

Chapter 1 Objective and Content

1-1 Objective and Content

In Japan, hazard map generally refers to a map that display the locations of facilities related to disaster prevention such as disaster prone areas, evacuation sites, and evacuation routes, for the purpose of disasters mitigation and disaster prevention measures caused by natural disasters. However, in the Project, hazard map is defined as a map that evaluate the hazards from various disasters on a four-grade scale evaluation where it can be used as a basic material in formulating spatial plans and land use plans based on the policy in Indonesia. On the other hand, disaster prone zone (hereinafter referred to as "ZRB") map was generated based on this hazard map, by conducting coordination with local governments and residents, considering the local aspects, and the ZRB was evaluated on a four-grade rank evaluation. Formulation of ZRB map was conducted in Output 2.

The target disasters include tsunami, liquefaction landslides (hereinafter referred to as "Nalodo[1]"), earthquake, sediment disaster, and flood, as well as the risk of occurring when the characteristics of the terrain and geology are taken into account. After evaluating these multiple disasters and creating individual hazard maps, the policy was to finally consolidate them into one hazard map.

The JICA first survey team urgently created a rough hazard map for the five disaster types, i.e. tsunami, liquefaction landslide (Nalodo), earthquake, sediment disaster, and flood. By referring to these maps, related organization in Indonesia such as Bappenas prepared the draft ZRB map in December 2018. However, the ZRB map is not appropriate for basic data for spatial plan formulation. In the Output 1 the JICA Study Team created digital topographic maps, analyzed the disasters condition, conducted geological surveys and groundwater monitoring, etc. The main assistance activity is to evaluate five disaster types based on these survey results, refine the hazard maps, and assist on manual creation for the refinement works.

The main activities of Output 1 are as follow:

- Analyze the damage situation
- Conduct geological survey
- Evaluate five types of disasters (tsunami, Nalodo, earthquake, sediment disaster, and flood)
- Technical support for refining hazard maps
- Create a reference manual for the hazard map refinement

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[1] Nalodo is a local Kaili word meaning "buried in mud" or "burrowing into the ground." The local people call a large-scale liquefaction landslide "Nalodo" and since it is a unique phenomenon in the world, the liquefaction landslide will be referred to as "Nalodo" in the Project.

1-2 Outline of the Activities

First, the JICA Study Team conducted field survey to understand the disaster and damage situation. As the basic data for analyzing disaster occurrence mechanism and possible risks in the future along with the creation of digital topographic maps, various surveys such as geological surveys, geological test, survey of tsunami trace, inundation depth survey, fault survey were conducted as shown in Figure 3-1. In addition, the groundwater monitoring which requires long-term data observation and accumulation was continuously observed for 5 months from the end of February 2020 to the end of July 2020. The automatic groundwater measuring device has been taken over by Indonesian related organization and the observation data is still being collected. For field survey and soil test, the JICA Study Team invited the relevant ministries and agencies in Indonesia, local governments, and several related individuals including research institutes and students to participate in the survey. Besides sharing the technical knowledge, the data was smoothly collected and shared.

Based on the results of these various surveys, JICA Study Team evaluated and analyzed the risks of tsunami, Nalodo, earthquake, sediment disaster, and flood, then refined the hazard map. In the hazard map, "before" and "after" risk reduction measures were created, where the "after" reflects the effects of structural measures for infrastructure which is conducted in Output 3. The detailed method of refining the hazard map and the criteria for hazard levels were described and compiled as a reference manual.

In addition, estimation of disaster scale is necessary when creating the hazard map. However, the scale in this project was set as the largest level of earthquake and tsunami in the history. In particular, the scale for Nalodo and tsunami which have special causes in the earthquake, was examined with advice from Japanese Advisory Committee which consist of multiple Japanese academic experts. For tsunami, JICA experts repeatedly explained to Indonesia governments and trainees that the JICA proposal is the best mixed plan which consists of uplifting road, covering with vegetation, land use regulations, building regulations, etc. Such activities was aimed to promote consensus building among stakeholders for the disaster mitigation. JICA Study Team also provided explanatory materials to promote understanding among the stakeholders. In addition, understanding of Indonesia government was obtained through model experiments such as verification of the uplifted road shape and effectiveness on introduction of vegetation. However, since Nalodo is a unique phenomenon in the world, high degree of expertise is required for analysis of factors and mitigation measures. JICA experts and Japanese academic experts conducted several discussions at the Japanese Advisory Committee on the hypothesis of the mechanism. The hypothesis of Nalodo mechanism was created by the JICA experts based on the survey results conducted immediately after the earthquake. As a result of several discussions between JICA experts and Japanese academic experts in the Japanese Advisory Committee, the JICA Study Team received advice as below. This advice was conveyed from JICA Study Team to Indonesia government.

- Liquefaction was possibly caused by strong seismic motion.
- The mechanism that caused the long-distance flow was related to abnormal water pressure from underground, but the cause was not identified yet.
- In addition, disaster reduction measures should be based on the understanding of the groundwater level over a wide area in consideration of land use.

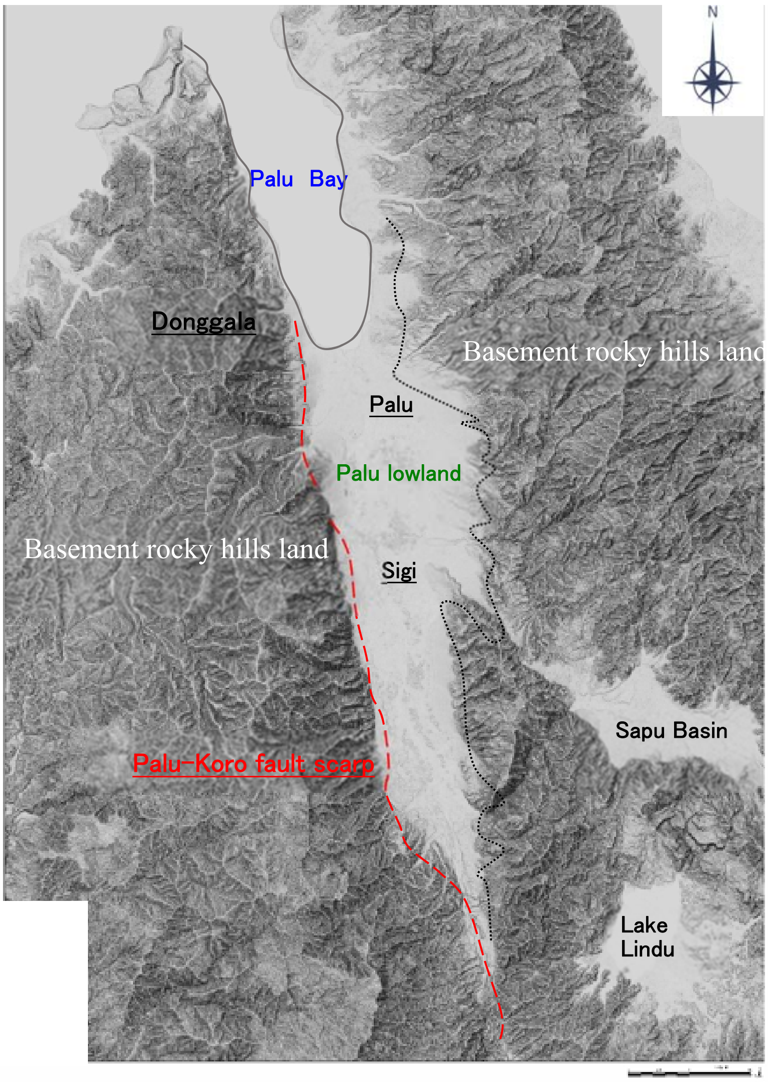
Chapter 2 The Damages Analysis

By considering the topographical and geological overview of the target area, damage to the population, houses, and economic caused by this earthquake, damage analysis is conducted as shown below.

2-1 Topographical Outline

As shown in Figure 2-1, topography around the heavily damaged Palu City, Sigi Regency, and Donggala Regency is divided into Palu lowlands which is bounded by basement rocky steep-hills land and plate-boundary faults (Palu-Koro Fault) extending to the Palu bay. On the western side of the Palu lowland, left lateral fault topography is clearly interpreted by a series of linear cliffs. The eastern side of the lowlands is not as clear as the western side. Terraced alluvial fans are distributed on the boundary with the basement rocky hills land. (Palu-Koro Fault will be described later)

The eastern side is not clear because the fault displacement is covered with alluvial fans. Lowland zone formed by alluvial fan and Palu River is distributed inside the Palu lowland zone. The earthquake faults that appeared on the surface due to the current earthquake is located 2-3 km off to the east compared to the past active fault locations as interpreted by topography.

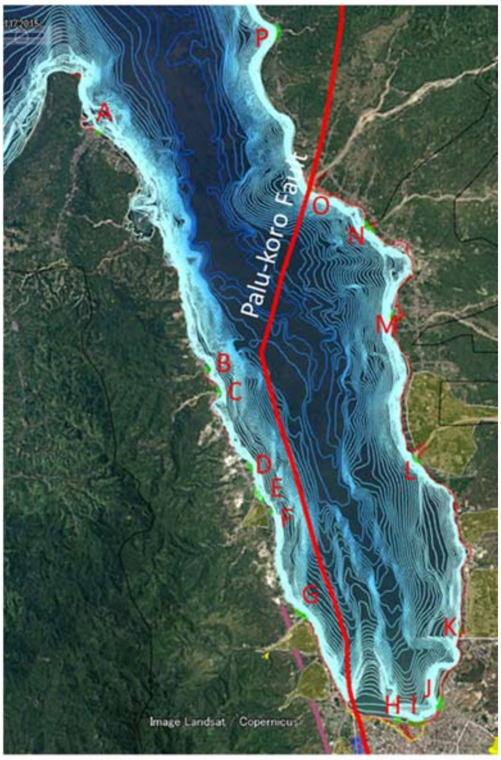


Source: JICA Study Team

Figure 2-1 Topological Condition around Palu City, Sigi Regency, and Donggala Regency

2-1-1 Topographical of Palu Bay

The topography of Palu Bay, where the tsunami occurred, is a steep submarine canyon with a depth of over 500 m. The coastal area consists of offshore alluvial fans with seasonal rivers flowing from west and east, terraced dissected alluvial fans, and basement rocky area terrain. The coastal area is composed of offshore alluvial fans with seasonal rivers flowing from west and east, terraced dissected alluvial fans, and basement rocky hills topography. Among these features, the landslides due to the earthquake occurred in the estuary (state sediment distribution area) of the alluvial fans. Figure II-2 (A to P are places in the coastal area where the ground sank below the sea level) shows the topography of Palu Bay and the coastal areas where the landslide occurred due to liquefaction.

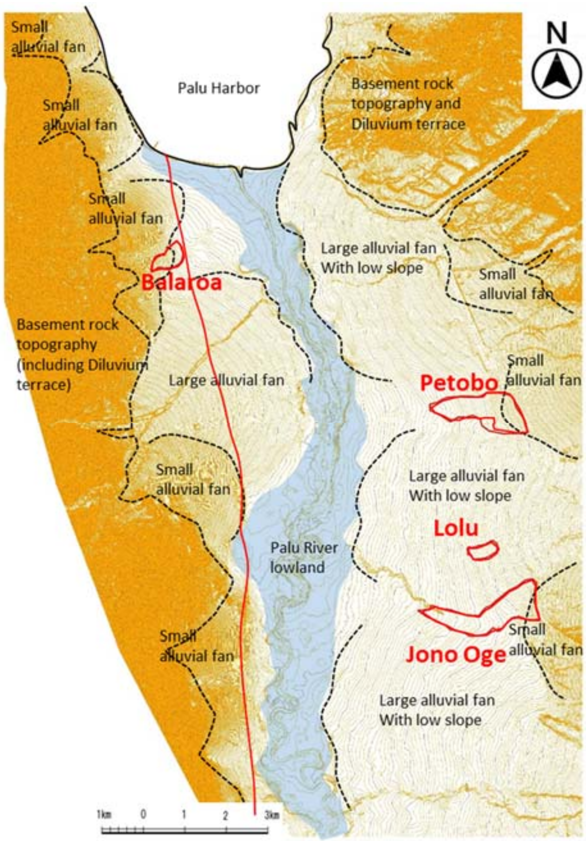


Source: JICA Study Team

Figure 2-2 Topological Condition around Palu City, Sigi Regency, and Donggala Regency

2-1-2 Topographical of Palu Lowlands

As shown in Figure 2-3, Palu lowlands is roughly classified into "small alluvial fans" with slope about 5% or more, "large alluvial fans" with slope of 1-5%, and "Palu River lowland" which are formed by meandering of the Palu River. The small alluvial fans are composed of coarse gravel with the mouth of basement rocky valley as apex of the alluvial fan and seasonal surface river is generated only during heavy rains. In addition, the areas where Nalodo occurred i.e. Balaroa, Petobo, Jono Oge and Sibalaya which located further in the south, have the same characteristics at the toe of small alluvial fans. Petobo and Jono Oge are the largest affected area of Nalodo which located in the lowlands at the boundary of the large alluvial fan. While Lolu is located inside the large alluvial fan between Petobo and Jono Oge.

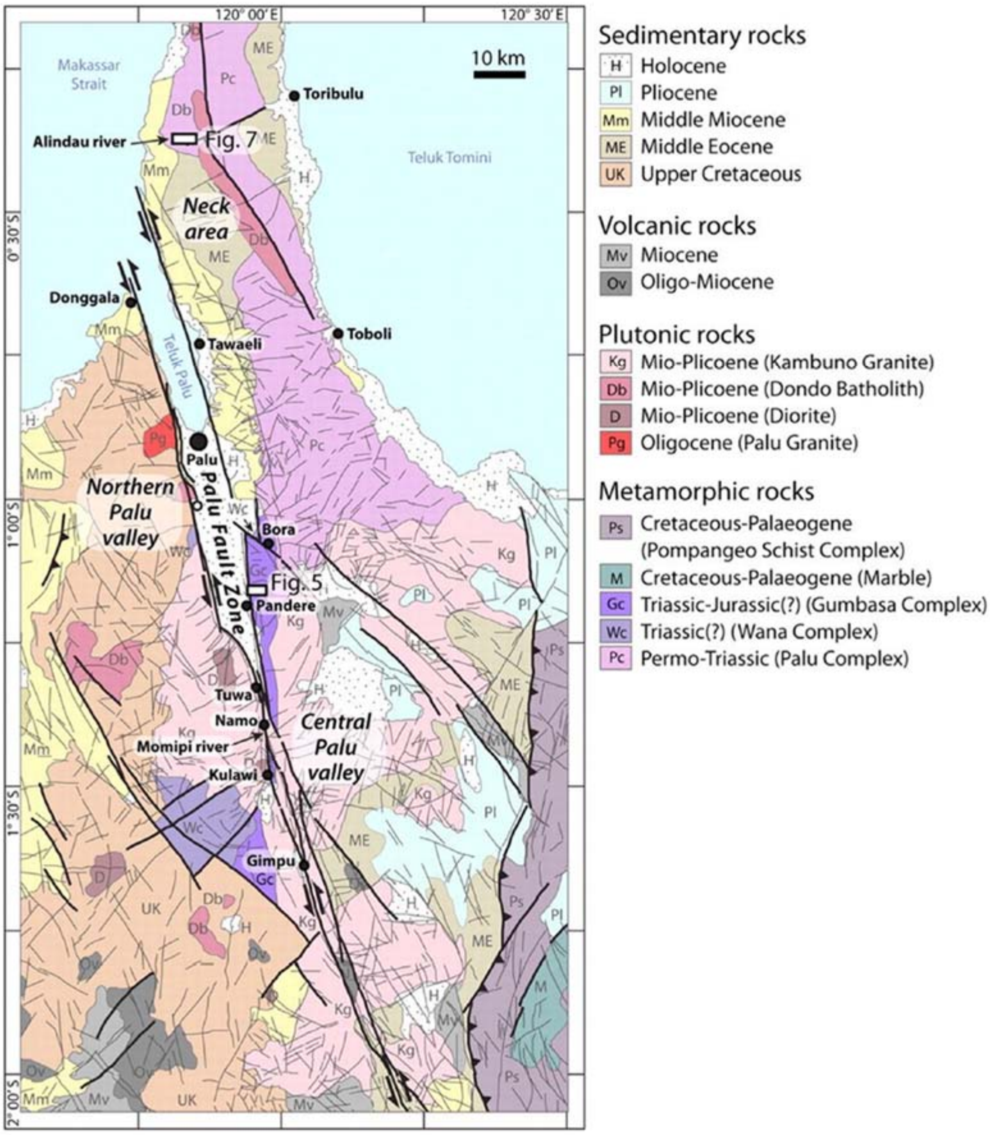


Source: JICA Study Team

Figure 2-3 Topological Condition of Palu Lowlands

2-2 Geological Outline

The geological condition around Palu City, Sigi Regency, and Donggala Regency differs between the west side and east side with Palu-Koro fault as a boundary. In the west side, cretaceous sedimentary rocks are widely distributed with intrusion of plutonic rocks such as granite and diorite. At the east side, metamorphic rocks of older than Jurassic is widely distributed, and Neogene granites widely intrude. In addition, the terrestrial gravel layer about the same period are distributed near the boundary between mountains and lowlands. In Palu lowlands where Palu-Kuro fault is located, alluvial sediments cover the gravel layers. Furthermore, Balaroa, Petobo, Jono Oge, Sibalaya, etc. where Nalodo occurred are characterized by the presence of granite and granitic metamorphic rocks in the catchment area.



Source: WATKINSON et al. 2011, Modified after SULAROX; Sukamto (1973, 1975); Sukido et al. (1993); and van Leeuwen & Muhardjo (2005).

Figure 2-4 Geological Map of Palu Region

2-3 Analysis of the Affected Areas Status

The affected areas will be organized and analyzed (refer to II-4 for the various disaster status) based on the on-site reconnaissance conducted after the earthquake and the materials collected on-site. According to the information published by the Central Sulawesi Province as shown in (1) and (2) below, the earthquake resulted in 4,547 people were dead or missing, approximately 173,000 people were affected, and more than 100,000 houses were damaged. This earthquake was reported to cause 5 trillion IDR (about 37 billion yen) economic loss. The main factors for such huge loss are Nalodo in the inland areas and tsunami in the coastal areas. In contrast, the damages caused by the earthquake and landslide were not significant. Based on the field survey, factors that increased the damage by the earthquake are listed below.

- The construction did not have sufficient strength and structure to deal with the earthquake.
- No structure to withstand the hazard in disaster prevention and mitigation.
- No Early Warning System (EWS) to provide necessary information to the residents.
- The hazardous areas was living areas, even though there is building regulation but it was not functioning.
- The evacuation routes and facilities were considered by the Local Disaster Bureau (hereinafter referred to as BPPD) in 2017, but the master plan was not yet incorporated.
- No system for response (relief, etc.) during the disaster.
- No evacuation drills and the residents' awareness of disaster prevention was low.

2-3-1 The Affected Population and Damaged Houses

Table 2-1 to Table 2-3 show the number of evacuees, damage house, and detailed classification of each municipality (including Parigi Mountong - outside of the target area of the Project).

Table 2-1 Affected Population

Municipal Name	Affected People			Total
	Death	Missing	Unidentified Burial[2]	
1. Palu	2,132	531	1,016	3,679
2. Sigi	434	116	0	550
3. Donggala	249	54	0	303
4. Parigi Mountong	15	0	0	15
Total	2,830	701	1,016	4,547

Source: Presentation material by the Governor of Central Sulawesi Province titled "*Impact of Natural Disaster - Earthquake, Tsunami and Liquefaction in Central Sulawesi Province*", on March 11, 2019.

[2] Number of deaths buried under Islamic law but unidentified

Table 2-2 Number of Evacuees

Municipal Name	Evacuation Status		
	Installation Shelter	Number of Evacuees Household	Number of Evacuees
1. Palu	127	11,165	40,738
2. Sigi	160	29,867	93,187
3. Donggala	98	11,478	36,346
4. Parigi Mountong	15	662	2,728
Total	400	53,172	172,999

Source: Presentation material by the Governor of Central Sulawesi Province titled "*Impact of Natural Disaster - Earthquake, Tsunami and Liquefaction in Central Sulawesi Province*", on March 11, 2019.

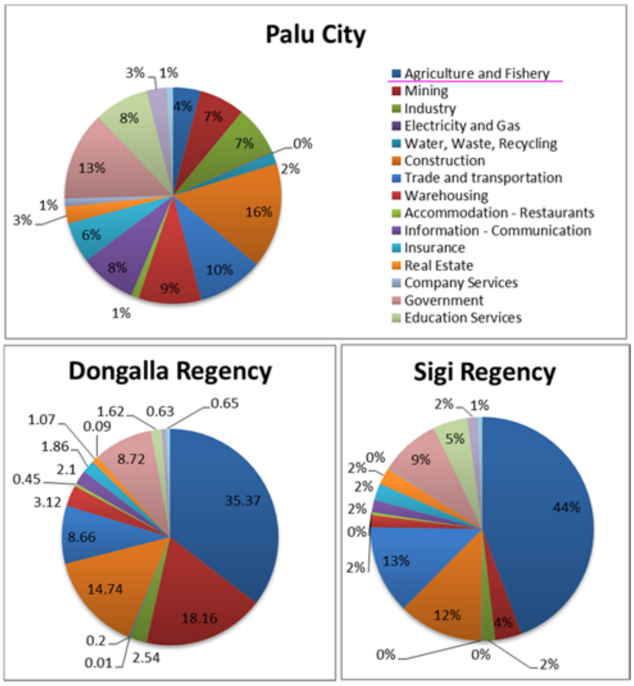
Table 2-3 Number of Damaged Houses

Municipal Name	Damaged House Status				Total
	Minor	Partially Destroyed	Completely Destroyed	Loss	
1. Palu	17,293	12,717	9,181	3,673	42,864
2. Sigi	10,612	6,480	13,144	302	30,538
3. Donggala	7,989	6,099	7,290	75	21,453
4. Parigi Mountong	4,191	826	533	0	5,550
Total	40,085	26,122	30,148	4,050	100,405

Source: Presentation material by the Governor of Central Sulawesi Province titled "*Impact of Natural Disaster - Earthquake, Tsunami and Liquefaction in Central Sulawesi Province*", on March 11, 2019.

2-3-2 Economic Losses

The economic situation in Central Sulawesi before the disaster is dominated by agricultural and fishery sector, followed by construction, processing, mining, and commercial sectors. As shown in Figure 2-5, construction, commercial, and warehousing services relatively have large percentages in Palu City, but there are also other various economic activities. Meanwhile, agriculture and fishery are the main activities in Sigi Regency and Donggala Regency.



Source: Regional Action plan for Rehabilitation and Reconstruction of each local Government

Figure 2-5 Composition Ration of Regional Gross Domestic Product of Palu City, Sigi Regency and Donggala Regency

According to reconstruction action plan formulated by each local government, the main damages in the economic sector include damage to bridges, irrigation channels, and ports.

Table 2-4 Loss and Damage in the Target Areas

Municipal name	Total Damage Loss (IDR)
Palu	2,444,650,366,689
Sigi	2,410,468,322,601
Donggala	170,508,450,000

Source: Compiled by JICA Study Team based on data in "*Rencana Aksi Daerah Rehabilitasi dan Rekonstruksi*" of Palu as of Feb. 7, Sigi as of March 4, and Donggala as of April 5

The total damage in each municipality is shown in Table 2-4, where the damage in both Palu City and Sigi Regency exceed 2 trillion IDR, but damage in Donggala was only around 170 billion IDR. Such large damage loss in Palu City is estimated due to damage of commercial facilities such as hotel, while in Sigi Regency is due to large damage of Gumbasa irrigation canals and various roads caused by Nalodo.

Chapter 3 Implementation of Geological and Other Surveys

3-1 Outline of Surveys

In the Project, JICA Study team created topographic map which will be the basis for refining the hazard map, and conducted hazard risk assessments and geological surveys to obtain basis data for each infrastructure design and plan including the Palu IV Bridge. Floods and landslides occurred in various places due to heavy rains on the places which the ground has loosened due to the earthquake. For this reason, survey for the countermeasure plan is also being conducted. Table 3-1 shows the survey items and outlines, while Figure 3-1 shows the location of each survey. The detail of each survey is organized in the main report and the survey materials are organized at the end of the report as well as disclosed at the JICA library[3].

Table 3-1 Survey Outline in the Project

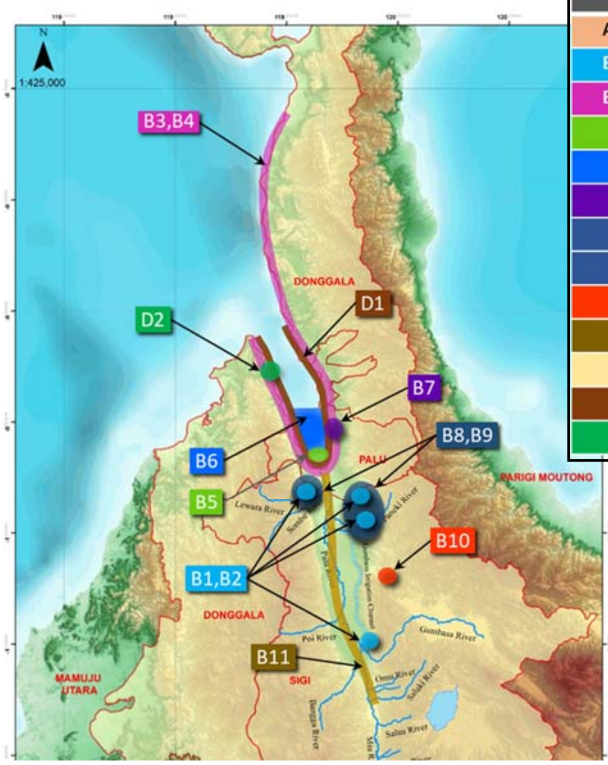
Survey Item	Survey Purpose and Outline
Formulation of digital topographic map <A1, A2, A3, A4>	• Extraction of dangerous areas and refinement of hazard maps for each disaster type in the reconstruction plan • Plane table survey, drone survey
Survey of Nalodo in inland area <B1, B2>	• Nalodo Hazard Risk Assessment • Wide area risk survey, boring survey, SWS (Screw weight penetration test), laboratory soil test, trench survey, etc.
Boring survey in coastal area and sediment disaster area <B3, B4>	• Evaluation of hazard risk of coastal landslide, evaluation of ground for sediment control dam design • Wide area risk survey, boring survey, laboratory soil test, etc.
Boring survey for Palu IV Bridge <B5>	• Evaluation of the ground for Palu IV Bridge design (grant-aid) • Boring survey, laboratory soil test
Seismic reflection survey of Palu Bay <B6>	• Confirmation of sedimentary structures of the seabed • Single channel submarine acoustic survey in shallow water, DGPS positioning (relative positioning method)
Radioactive age determination of sediments <B7>	• Confirmation of geological sediments, estimation of tsunami damage history • C14 radioactive dating test
Water quality analysis for ground water and surface water <B8>	• Evaluation of water quality of rivers, hot spring resorts, resettlement areas, and spring in the landslide areas in Palu areas • Hydrogen oxygen isotope analysis
Monitoring of groundwater level <B9>	• Collecting basic data of groundwater level and formulating irrigation canal management plans • Data collection of self-recording water level gauge installation, rain gauge installation, water level gauge, etc. (Measuring equipment, etc. have already been handed over to Indonesian side because continuous survey is required for groundwater monitoring)
Survey of government facility sites in Sigi Regency (Bora District) <B10>	• Understanding the ground condition of the area where uneven subsidence occurs • Surface wave survey, DCP (Dynamic Cone Penetration), and CPT (electric Cone Penetration Test) survey
Palu-Koro Faults survey <B11>	• Fault risk assessment for resettlement plan • Literature survey, field survey and fault activity survey
Building damage survey <C1>	• Evaluation of building damage status for ZRB map formulation • Detailed investigation of building damage
Tsunami inundation depth survey <D1>	• Hazard map formulation, basic data collection for tsunami countermeasure survey • Tsunami trace survey, hearing survey

[3] https://libportal.jica.go.jp/library/public/index.html

Mangrove and inland tree density survey <D2>	• Basic data collection for mangrove modelling in hydraulic model experiments to confirm vegetation effects as a tsunami countermeasure • Mangrove breeding situation survey (height, trunk diameter, density, etc.)
Sediment disaster situation survey	• Evaluation of hazard risk due to sediment disasters • Satellite photo collection, field reconnaissance

Source: JICA Study Team

< >The number inside the brackets indicates the reference number of the material at the end of the report.



No.	Survey Items
A1-A4	Topographic Survey (Palu, Donggala, Sigi area)
B1/B2	Investigation of liquefaction landslide in inland area
B3/B4	Boring survey for coastal area
B5	Boring survey for Palu IV Bridge
B6	Reflection seismic survey of Palu bay
B7	Radioactive dating test of sediments
B8	Water quality analysis of groundwater and surface water
B9	Monitoring of groundwater level
B10	Survey of government facility Sites in Sigi
B11	Palu-Koro fault Survey
C1	Building Damages Survey (Palu, Donggala, Sigi area)
D1	Survey of Tsunami Inundation Depth
D2	Survey of Mangrove Density, Trunk, and Height

※Numbers A to D correspond to the Appendix II-1-1 at the end of the report

Source: JICA Study Team

Figure 3-1 Field Survey Content and Survey Location (Output 1)

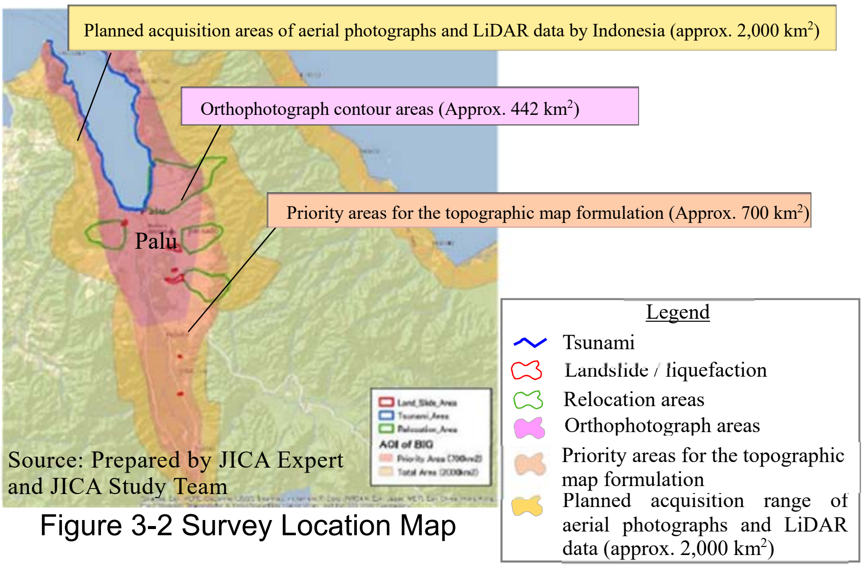
3-2 Survey Details

3-2-1 Digital Topographic Map Formulation

(1) Topographic map for hazard map

- Survey Objective: Extraction of dangerous areas for each disaster type targeted in the reconstruction plan, and refinement of hazard maps. (Formulate a topographic map before and after the disaster)

- Survey Outline: For the range of the topographic map, a high priority area was selected based on the population distribution. The topographic data (Lidar data) provided by BIG was also used.



Source: Prepared by JICA Expert and JICA Study Team

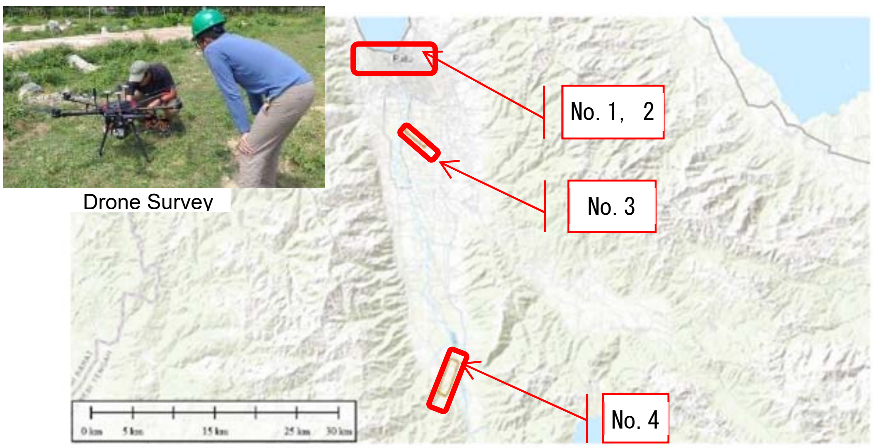
Figure 3-2 Survey Location Map

(2) Topographic map for pilot projects

- Survey Objective: Detailed of current status in the survey area (including the grand project bridge design)

- Survey Outline:

No.	Location	Objective	Area
1	Palu Bay	For road and Palu IV bridge design	A= 0.15 km^2
2	Palu Bay	For road and coastal raised road (drone)	A= 2.00 km^2
3	Sigi Regency	For sediment disaster countermeasures (drone)	A= 2.60 km^2
4	Sigi Regency	For sediment disaster countermeasures (drone)	A= 5.15 km^2



Source: JICA Study Team

Figure 3-3 Survey Status and Survey Location

3-2-2 Geological Survey, Reflection Seismic Survey, Groundwater Monitoring, etc.

- Survey Objective

Evaluation of inland liquefaction landslide, understanding the coastal soil condition, grand design of Palu IV Bridge, understanding the sediment situation in the southern of Palu Bay, radioisotope dating test, confirmation of groundwater quality components, etc.

- Survey Outline

No.	Survey Item	Survey Outline
1	Survey of liquefaction landslide in inland area (1)	Risk survey for liquefaction landslide, 30 borehole, 33 SWS locations, laboratory tests, 19 trench locations.
2	Survey of liquefaction landslide in inland area (2)	Internal investigation of liquefaction landslide, 14 borehole (UDS sample), 13 DCP, laboratory tests (liquefaction strength test), 12 trench locations, PS logging.
3	Boring survey for coastal Area (1)	Risk survey for landslide on costal area. 23 borehole and laboratory tests.
4	Boring survey for coastal Area (2)	Survey of coastal area (subsidence area), 6 borehole, laboratory tests (consolidation test)
5	Boring survey for Palu IV Bridge	Survey for outline design of Palu IV bridge, 7 boreholes, and laboratory tests (consolidation test, etc.)
6	Seismic reflection survey of Palu Bay	29.6 km in total, single channel submarine acoustic survey in shallow water, DGPS positioning.
7	Radioactive dating test of sediments	C14 radioactive dating of test of 14 samples in the liquefaction landslide area, Palu river estuary area and southeast of Palu Bay (tsunami sediments).
8	Water quality analysis of groundwater and surface water	Hydrogen oxygen isotope analysis of 10 samples.
9	Monitoring of groundwater level	5 months data collection of 20 self-registered water level gauges, 1 rain gauge, and water level gauges, etc.

Source: JICA Study Team

Boring Survey

Laboratory

Seismic reflection survey

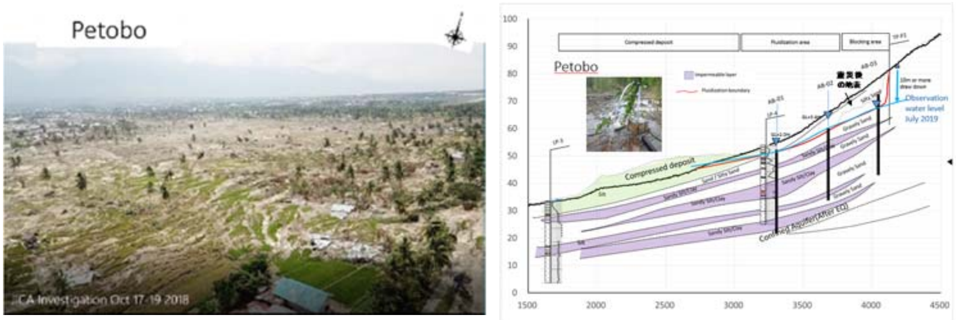
Sediment Dating Survey

Figure 3-4 Survey implementation status

・ Survey Results Summary

■(1)(2)：Survey of liquefaction landslide in inland area

- The four Nalodo sites in the Palu lowlands are characterized by the presence of small fans at the upper slopes, shallow groundwater levels before the earthquake, and the distribution of loose sand and silt with a thickness of 5-10 m.
- The largest affected areas are Jono Oge and Petobo, of about 1 km wide at the head and 2 km long. Tensile fracture zone at the head, a fully fluidized area in the middle, and a compacted sedimentary area at the end were also occurred in some parts.
- The groundwater level (pressure overload) was found to be GL+3.4 m higher than the current ground surface in the fluidized zone in Petobo.
- The area where the liquefaction landslide occurred in the inland area was also the area with shallow groundwater level and a lot of groundwater inflow.

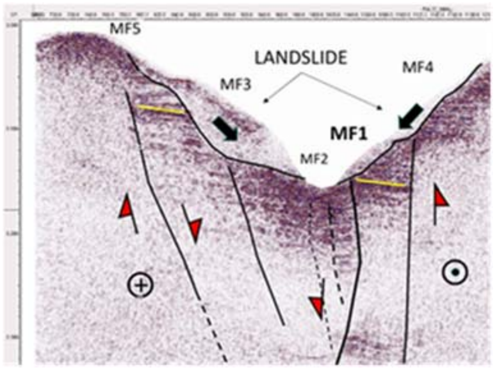


Source: JICA Study Team

Figure 3-5　Nalodo Occurrence Status and geological longitudinal Survey Outline (Petobo)

■(6) : Reflection seismic survey of Palu South Bay

- At the Palu-Koro fault extension in bay area, four to five faults were found where at least one of them was continuous to the uppermost seafloor surface.
- A landslide of about 20 m thick was found over the Palu-Koro fault in the similar manner at a different location.
- The steep Palu bay topography confirms that there is a high risk of future submarine landslides in bay area.



Source:　JICA Study Team

Figure 3-6　Cross-section of Submarine Acoustic Survey of the Seabed in Palu Bay (excerpt)

■(7)：Radioactive dating test of sediments

- Previous sediment surveys results conducted by LIPI (Indonesian Institute of Sciences) determined that the layer located at a depth of 30-40 cm from the ground level were formed by the 2018 tsunami.
- As a result of radiometric dating tests, the age of the layer formulated by the tsunami before the current tsunami was estimated to be around 1910 to 1927 (it is estimated that similar tsunami occurs every 100 years). Based on this result, JICA Study team set target tsunami for the tsunami countermeasures.

Layer	Depth	Maximum Thickness	Possible Tsunami Event
1	8cm	8cm	28 Sep 2018
2	30 - 40cm	3cm	After 1950
3	50 - 60cm	10cm	1927 (from dating test)
4	160cm	2cm	----
5	250cm	1.5cm	----

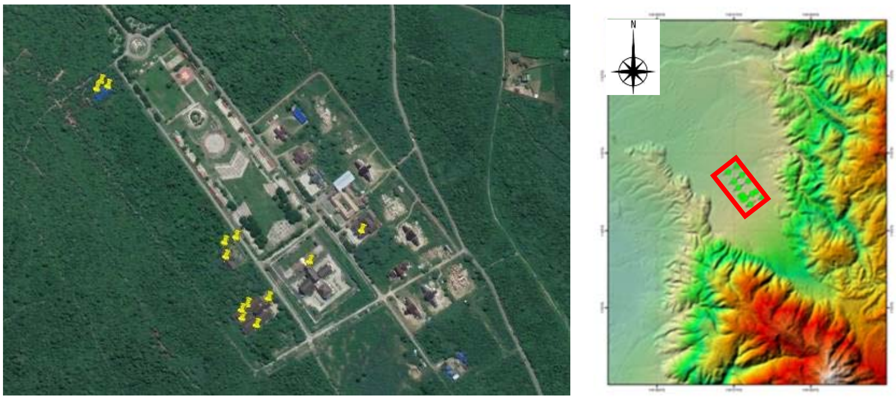
Approximately 100-year cycle

Source: JICA Study Team

Figure 3-7 Geologic time survey results

3-2-3 Government Facility Sites Survey in Sigi Regency (Bora District)

- Survey Objective: Unequal subsidence was occurred at the government facility buildings in Bora District. The survey was conducted to confirm the site condition including its surrounding areas.
- Survey Outline: Surface wave survey 1 set (13 survey lines with total 4,346 m) and portable penetration test (DCP: 50 points and CPT: points).



Source: JICA Study Team

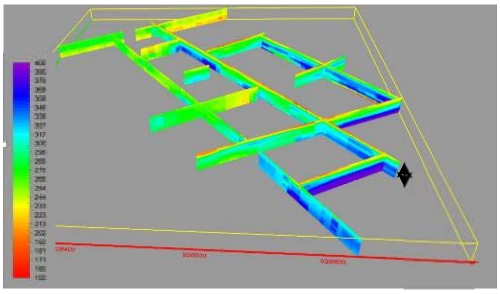
Figure 3-8 Government Facility Location Map in Sigi Regency

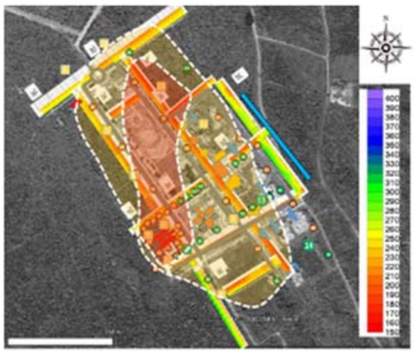
Source: JICA Study Team

Figure 3-9 Damage on Government Facilities in Sigi Regency

- Survey Results Summary

- Based on the surface wave survey (MASW), JICA Study Team confirmed the region with low velocity (the area where the ground layer was loose). This area is confirmed to be thick on the northwest side and thin on the southeast side, and the deep part on the southeast side had a good layer).
- The results of the portable penetration test and the surface wave survey showed almost the same tendency. The ground conditions were different between the northwest side and the southeast side. JICA Study Team identified that the underground cavities and the distribution of hard and soft regions are complicated.





Source:JICA Study Team

Figure 3-10 Surface Wave Survey Results (Left), Ground Property Evaluation Results (Right)

3-2-4 Palu-Koro Fault Survey

- Survey Objective

Palu City has a plan to develop a resettlement on the eastern hilly area, but a literature identified an active fault on the east side of Palu Lowland. This survey was aimed to evaluate the risk of this fault.

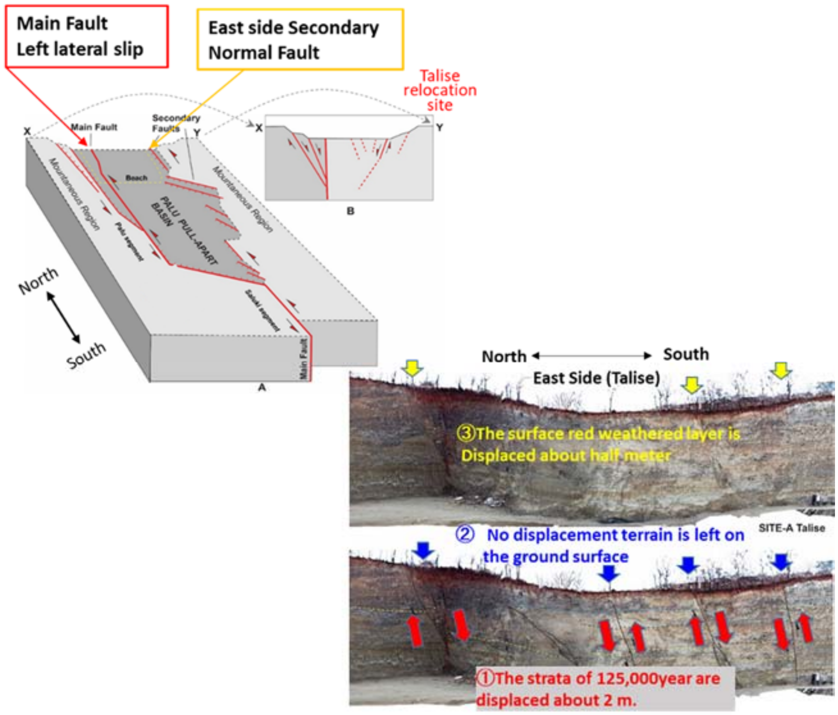
- Survey Outline

Literature survey, fault topography, active fault trench survey, open-cut outcrop survey

Figure 3-11 Fault Topography Survey (Left), Trench Survey (Right)

- Survey Results Summary

- The results of the survey revealed a displaced topography which shows a normal fault near the boundary between Palu lowlands and eastern mountains.
- Several fault outcrops that displace strata were also identified in Palu City resettlement area (Talise) but almost no tectonic landform was left on the terrain.
- The activity of the Palu-Koro fault is predicted to be every 100 years, and the activity of the east margin normal fault is about 1/100th of that of the west margin Palu-Koro fault, suggesting that the Talise area is safe against the displacement of active faults in Palu lowland area.

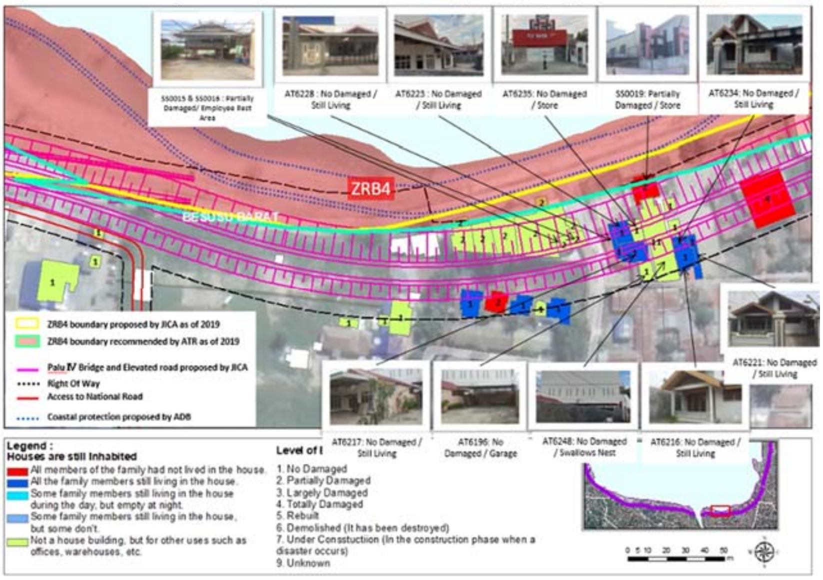


Source: JICA Study Team

Figure 3-12 Summary of Active Fault Survey (Open-cut Outcrop in the Talise Region)

3-2-5 Building Damages Survey

- Survey Objective: Collecting information on the damage buildings caused by the disaster (earthquake, liquefaction, tsunami) for the ZRB map refinement.
- Survey Outline: JICA Study Team conducted survey on the building damages (wall cracks, roof collapse, floor slope, etc.) in Palu City, Sigi Regency, and Donggala Regency.

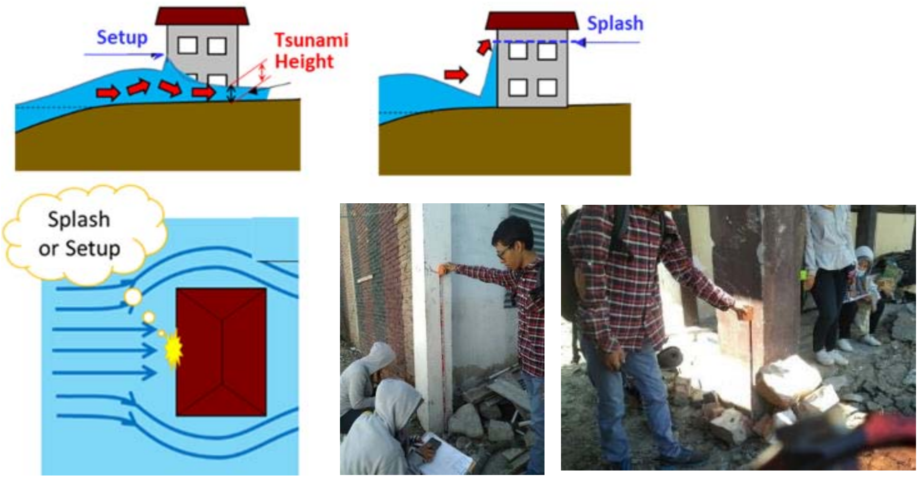


Source: JICA Study Team

Figure 3-13 Damage Survey Example (South Coast of Palu Bay)

3-2-6 Tsunami Inundation Depth Survey

- Survey Objective: Collecting basic data for tsunami countermeasure study and hazard map formulation
- Survey Outline: A survey was conducted in Indonesia immediately after the earthquake. This survey showed a mixture of splash and set-up (as shown below). JICA Study Team conducted on site survey for the inundation depth by excluding these (tracing and hearing).

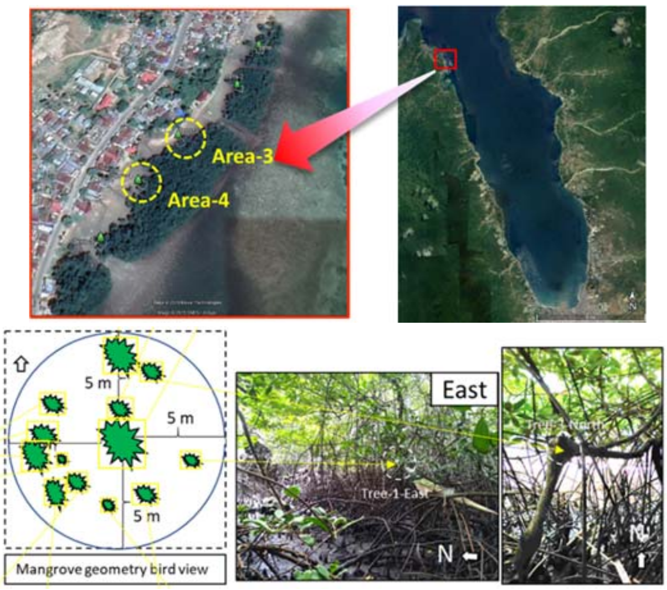


Source: JICA Study Team

Figure 3-14 Splash Setup Explanation (Left), Tsunami Inundation Depth Survey (Right)

3-2-7 Mangrove Vegetation Survey

- Survey Objective: Collecting a basic data for mangrove modelling in hydraulic model experiments to confirm vegetation effects as tsunami countermeasures.
- Survey Outline: The JICA Study Team investigated the mangroves density, trunk diameter, height, etc. in Palu Bay.

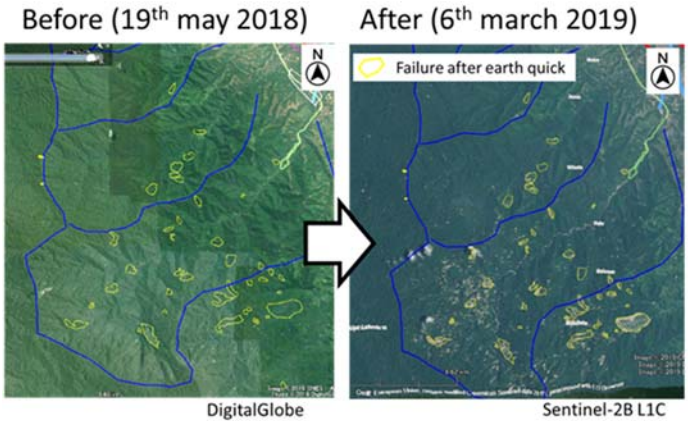


Source: JICA Study Team

Figure 3-15 Mangrove Vegetation Survey Outline

3-2-8 Sediment Disaster Survey

- Survey Objective: Collecting basic data on sediment disaster from combination of ground loosening and heavy rain caused by the 2018 earthquake and presenting it on the hazard map.
- Survey Outline:
  - In addition to the field survey, topographic investigations and old and new satellite images were used to confirm the deterioration of mountain slopes in mountainous areas where field surveys are difficult to carry out.
  - The results were used as the basis for the planning of sediment control dam facilities for landslide disasters.



Source: JICA Study Team

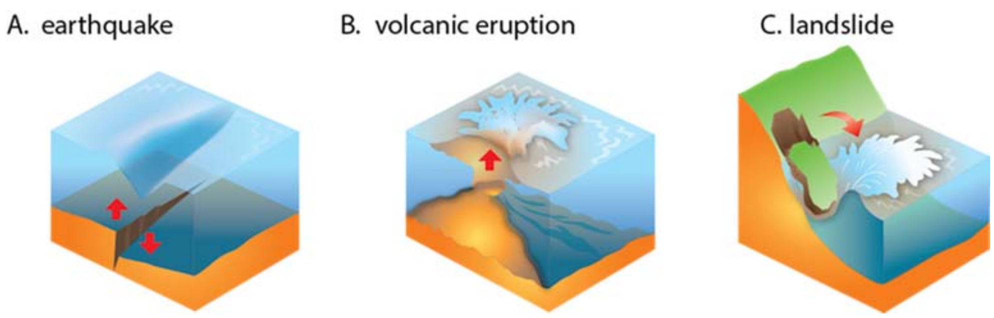
Figure 3-16 Pre- and post-disaster comparisons of satellite images (devastation of mountain slopes)

Chapter 4 Risk Assessment for Tsunami, Nalodo, Earthquake, Landslide, and Flood

Five target disasters are set for the hazard map formulation in this activity, i.e. tsunami, Nalodo, earthquake, sediment disaster, and flood. The following is overview of the causes, risk assessments, etc. for each of the disaster. The specific risk assessment for each disaster is shown in II-6-1.

4-1 Evaluation and Analysis of Tsunami

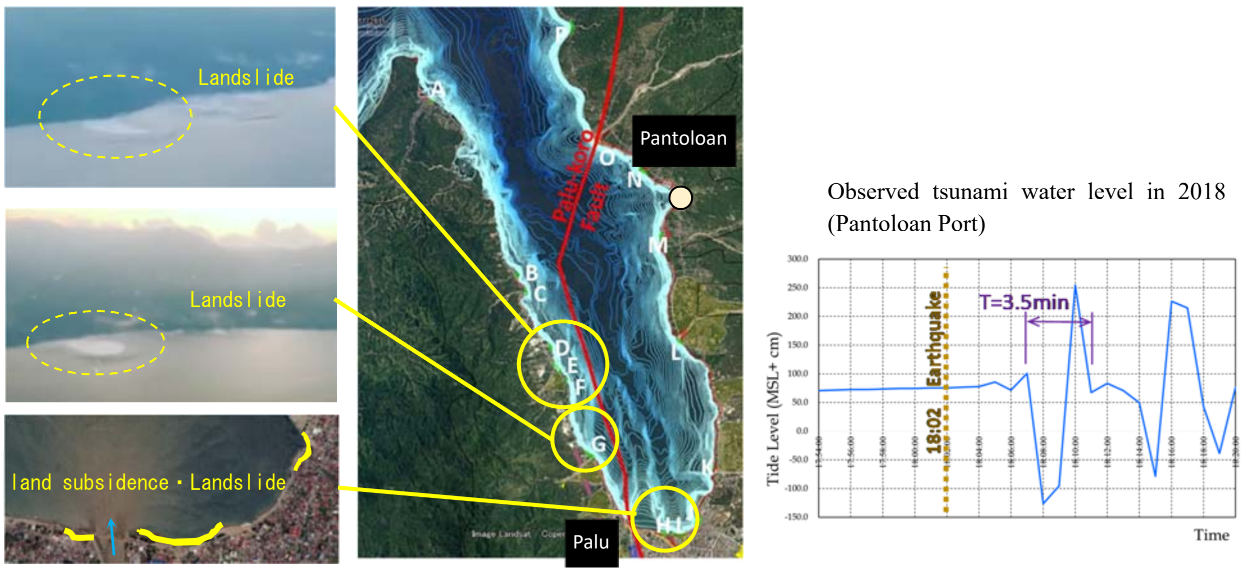
Tsunamis are generally defined as a series of large-scale waves caused by A. earthquakes, B. submarine volcanic eruptions, and C. landslides (refer to Figure 4-1).



Source: University of Hawaii website

Figure 4-1 Cause of Tsunami

The tsunami occurrence was observed throughout the Palu Bay, and from photos and videos the main factor was found to be submarine landslides at multiple locations in Palu Bay which were triggered by the occurrence of the earthquake. Another characteristic of the Palu tsunami is the time from the occurrence of the earthquake to reaching the coast was very short, about 3 to 5 minutes (refer to Figure 4-2). The tsunami cycle is about 3.5 minutes, which was shorter than the general tsunami.



Source: JICA Study Team

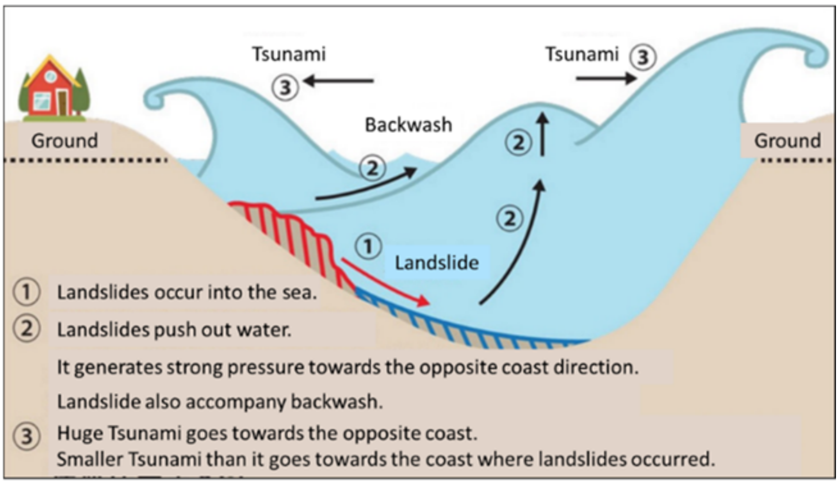
Figure 4-2 Coastal Landslide Occurrence Status (left) Tsunami Waveform Observation (right)

As for the submarine landslides, liquefaction of sediments at the mouth of estuaries was found to cause land subsidence and landslides in many coastal land areas (refer to Figure 4-3). The location and scale of the major tsunami-generating submarine landslides were investigated by tsunami simulations, but the lack of detailed information on the time of occurrence of the submarine landslides and the lack of accurate seabed topography prior to the current disaster in terms of location and scale make it difficult to elucidate the details.

Ssource: JICA Study Team

Figure 4-3 Tsunami Damage Situation
(Left: Collapse of Palu IV Bridge, Right: Landslide Subsidence along the Coast of Palu Bay)

Figure 4-4 shows the mechanism of tsunami generation caused by submarine landslide in Palu Bay. The figure shows that the first tsunami reaches the opposite coast where the landslide occurred, then a smaller tsunami returns toward the coast. The Palu Bay submarine topography is very steep with submarine canyons of deeper than 500 m extending from north to south. Submarine landslide will continue to occur in the future due to a large amount of clastic supplies to Palu Bay from major rivers such as Palu River. If an earthquake with the same magnitude occurs on the Palu-Koro fault which has extremely high activity, the risk of tsunami is considered to be high.

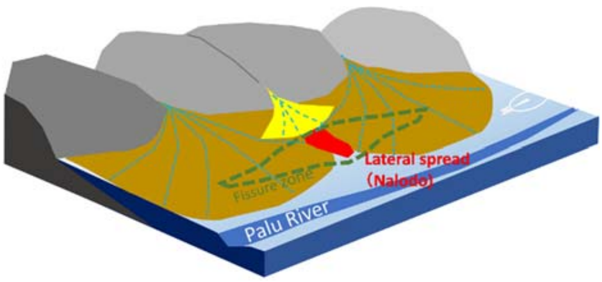


Source: Jakarta Shinbun

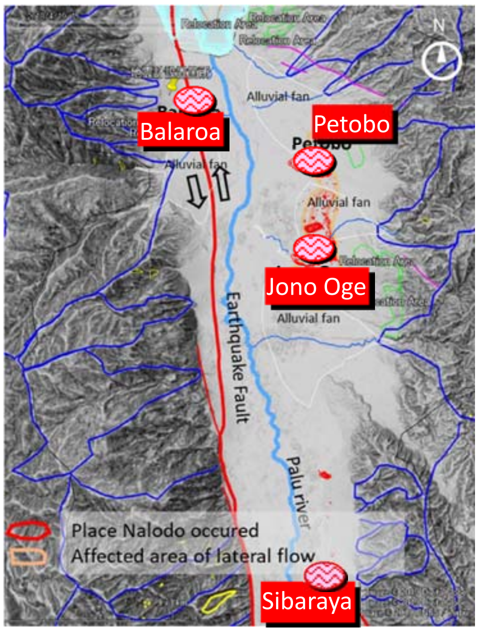
Figure 4-4 Outline of Tsunami Mechanism due to a Landslide

4-2 Evaluation and Analysis of Nalodo

As shown in Figure 4-5, the four Nalodo sites in the Palu Lowlands (Balaroa, Petobo, Jono Oge, Sibalaya,) are surrounded by an old (large) alluvial fans. These sites are characterized by being accompanied by a small new alluvial fan (clastic flow cone) at the upper slope, shallow groundwater level before the earthquake, and distribution of loose sand and silt with 5-10 m thickness.



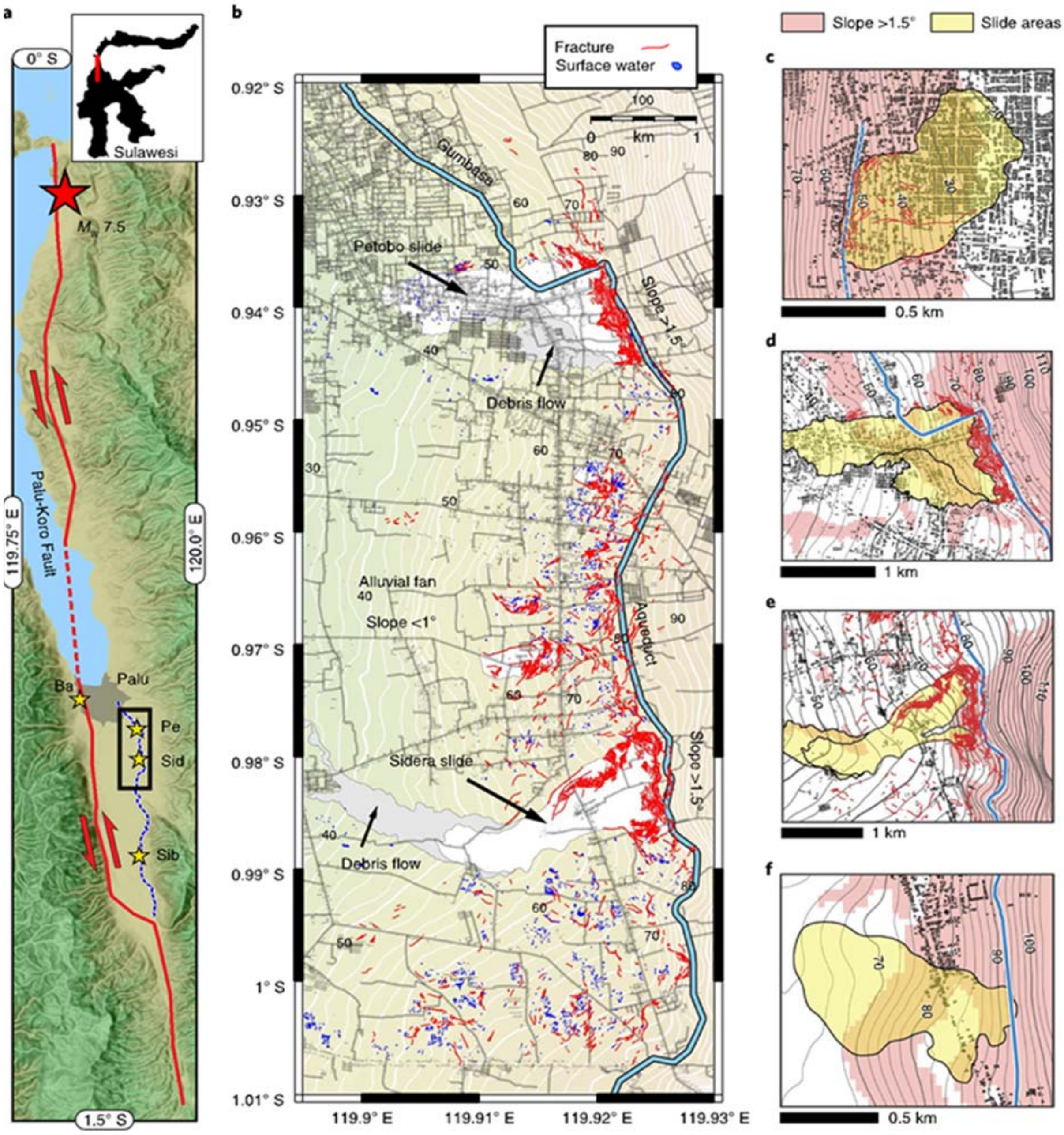
[Nalodo Damaged Area]
Balaroa（0.39km^2), Petobo（1.63km^2）,
Jono Oge（1.75km^2）, Sibalaya（0.5km^2）



Source: JICA Study Team

Figure 4-5 Topographical Characteristic where the Nalodo Occurred

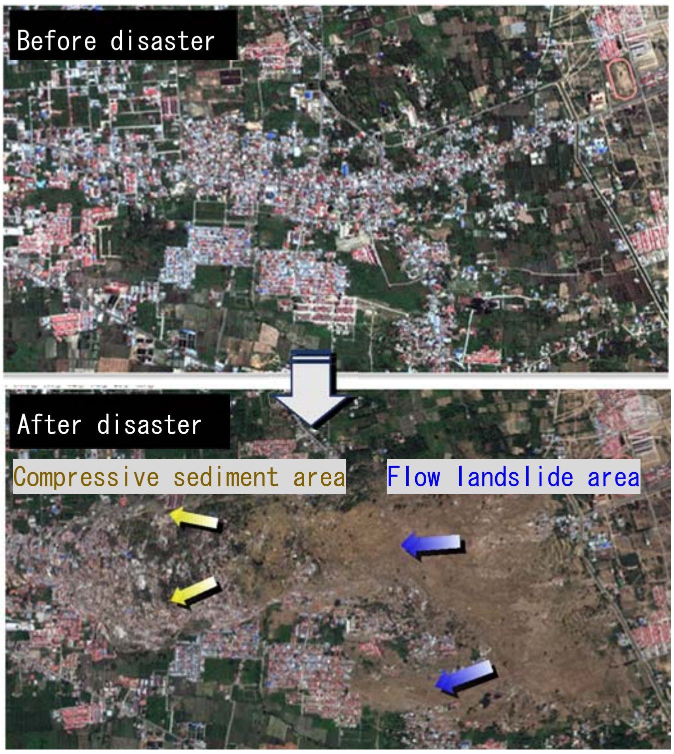
The Nalodo as a large-scale liquefaction disaster that occurred in the inland area is attracting attention from researchers all over the world. According to Bradley et al. (2019), a wide range flow occurred in the eastern areas particularly around Petobo and Jono Oge (refer to Figure 4-6 to Figure 4-8), and many crack topography was reported. In the detailed field survey under the Project, building movement with a maximum of about 380 m in Balaroa area and 800 m in Petobo area were confirmed.



(a) Surface rupture of 2018 Palu earthquake. Stars denote locations of four long-runout landslides (Ba: Balaroa, Pe: Petobo, Sid: Sidera & Jono Oge, Sib: Sibalaya). Mw: moment magnitude. (b) Map of landslides, debris flows, distributed surface fracturing and surface water beneath the Gumbasa aqueduct in the eastern Palu Valley (black-bordered rectangle in a). Elevation contours are labelled in metres. (c–f) Long-runout landslides were sourced from lateral spreads in irrigated areas with surface slopes >1.5°: Balaroa landslide (c), Petobo landslide (d), Jono Oge/Sidera landslide (e) and Sibalaya landslide (f). GMT34 was used to produce this and other figures. Credit: (b–f) from OpenStreetMap

Source: Bradley, K., Mallick, R., Andikagumi, H. *et al.* Earthquake-triggered 2018 Palu Valley landslides enabled by wet rice cultivation. *Nat. Geosci.* 12, 935–939 (2019).

Figure 4-6 Location and Deformed Terrain of Nalodo in the Palu Lowlands



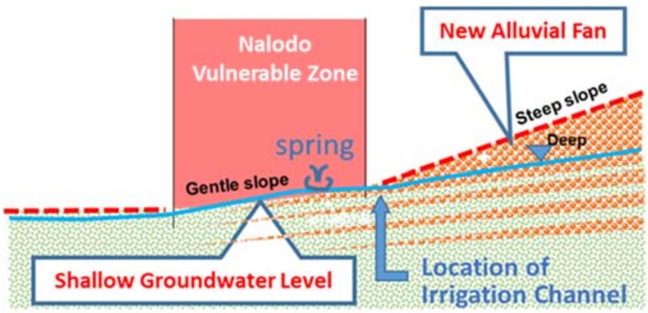
Source: JICA Study Team

Figure 4-7 Nalodo Occurrence Status in Petobo   Figure 4-8 Damage Situation of the Nalodo

Nalodo occurred at the boundary of micro-lowlands of a large fan. Such condition can be a source of the necessary slip power by making a liquefaction environment (loose sandy soils and shallow groundwater table) and cap layers parallel to the ground surface (a fine-grained impermeable layer). Since Nalodo is a rare natural disaster, there were various theories about the mechanism of its occurrence even in the discussions at the committee consisting of academic experts in the Project. As a common understanding, the Nalodo is assumed to occur due to the earthquake in the groundwater and geological conditions as shown in Figure 4-9.

<Ground conditions for the Nalodo occurrence>

① The groundwater level (natural groundwater level) is shallow
② The terrain is sloping
③ Loose sandy layer is deposited
④ Existence of confined groundwater
⑤ Existence of aquiclude layer

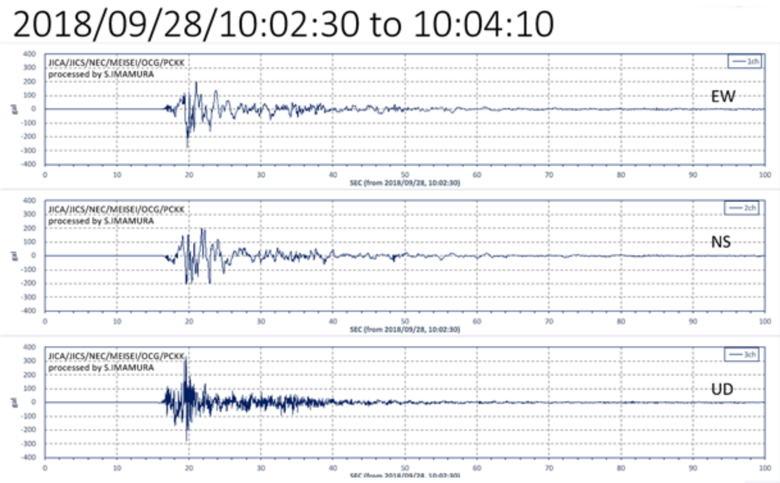


Source: Prepared by JICA Experts

Figure 4-9 Conditions for Nalodo Occurrence

4-3 Evaluation and Analysis of Earthquake (Active Fault)

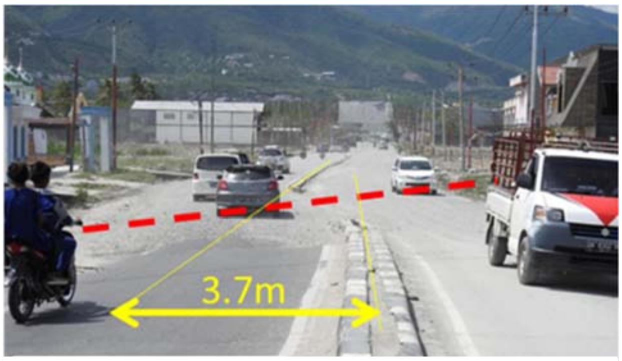
Many seismic records in Palu were lost due to a large-scale power outage occurred immediately after the earthquake. The only obtained seismograph records are limited to seismic data installed at the previous JICA projects i.e. the Meteorology, Climatology, and Geophysical Agency of Palu (hereinafter referred to as "BMKG"). Figure 4-10 shows an excerpt from the seismic acceleration waveform observed by the seismograph. Based on this observation data, the maximum horizontal acceleration component was EW 281 gal, NS203 gal, and the vertical component was 335 gal.



Source: JICA Study Team

Figure 4-10 Waveform Record (BMKG Palu)

In the earthquake, about 4 m strike-slip was observed along the Palu-Kuro fault at the southern coast of Palu Bay. This strike-slip caused damage to houses on the fault and in mid-rise floors above the fourth floor.



Lateral fault JL.Diponegoro

Building damage by seismic motion

Source: JICA Study Team

Figure 4-11 Damage Situation due to the Fault Damage

However, damage was limited on very narrow faults as there was no ground rupture in locations far from the fault. The risk from earthquake vibration depends on the distance from the hypocenter and the ground conditions. Since the maximum acceleration was about 300 gals according to the seismometer records of BMKG, the risk associated with seismic motions was not significant. However, the main reason for the damage caused by this disaster can be considered to be the quality of the construction work which did not comply with the local building standards. Additionally, the characteristics of the ground shaking varies depending on the ground condition.

4-4 Evaluation and Analysis of Flood

No damage due to flood has been confirmed in the disaster. Palu Main River and its tributary rivers flow through the Palu city center. At a crossing point of rivers that connect east and west areas, Palu I Bridge – Palu V Bridge (Palu V Bridge is currently under construction) are built. In October 2016, a nearly 100 mm rainfall was recorded in a day. If sediment supply from the mountainous areas continues, the riverbed elevation of the Palu River will rise. Damage to the river crossing bridge which is an important access for a logistic road and damage to houses that are connected to the river bank are expected.

Source: JICA Study Team

Figure 4-12 Situation of Palu Main River and the Tributary Rivers

4-5 Evaluation and Analysis of Sediment Disaster

Due to heavy rainfall under the condition that the surface ground was loosened by the recent earthquake, surface or deep failure occurred and sediment disasters such as debris, sand, and mud flows have been occurring continuously. In particular, slope failures in the southern mountainous areas particularly in Sigi Regency, are frequently occurs. These slope failures resulting in high risk of other disasters such as flooding due to filling of river beds with sediment, blockage of current roads, and runoff of river crossing structures.

Surface failure on mountain slope

Sediment disaster in mountain streams during heavy rains

Source: JICA Study Team

Figure 4-13 Damage Caused by Sediment Disasters (Sigi Regency)

Chapter 5 Assistance to the Local Government and ATR on the Hazard Map Formulation

5-1 Assistance on the Hazard Map Formulation

In the Project, JICA Study Team assessed the risks for each disaster type such as liquefied landslides, tsunami, sediment disaster, and floods from a viewpoint of complex disasters, and compiled an integrated information to assist the refinement of risk assessment and formulation of hazard maps. For the risk assessment and creation of hazard maps, JICA Study Team conducted field surveys and assessments of current situation through meetings and joint field surveys with the government of Indonesia to reach a common understanding. Specifically, TF1 meetings were held several times in Bandung, Palu, and Jakarta to explain the situation. The JICA experts led and cooperated with JICA Study Team to explain the hazard map, risk map, and the concept of countermeasures for several times until the ATR, local government, and other relevant agencies in Indonesia gained an understanding. In particular, when the matters above are explained to Bantek, which is a local consultant for ATR's spatial planning process, assistance were implemented both for contents of the survey proposal and for verifying their own hazard map. Several meetings were conducted in coordination with JICA Study Team proposal. As a result, the hazard assessments created by JICA using the latest topographical data, geological survey, analysis results, etc. were combined with the hazard assessments created by utilizing field survey result which was conducted by the Indonesian side immediately after the disaster. Such combination improved the accuracy of the hazard map and the Indonesian government side (ATR related organizations) was also convinced. Further, JICA Study Team was successfully formulated the hazard map that can be used for spatial plan (land use plan).

Furthermore, for a smooth technical verification of the proposal and consensus building with the counterpart government agency in considering tsunami and Nalodo hazard analysis and countermeasures, expert panels were held and led by JICA experts in coordination with the JICA Study Team. The expert panels involve the National Expert Panel which composed of Japanese Advisory Committees in Japan including Japan’s and Indonesia’s academics. Table 5-1 shows the outline of the main activities in the Project. Outline of the Domestic Advisory Committee (Tsunami, Nalodo) activities are summarized in Volume IV, and the activities such as tsunami model experiments are summarized in the Appendix.

Table 5-1 Outline of the Main National Expert Panels in Indonesia

Date	Place	Theme	Main experts
26/06/2019	Hotel Gran Melia	Integration of coastal protection and elevated road designs Discussion of coastal protection and elevated road designs Discussion of joint mission plans	Prof. Arikawa (Japanese Tsunami Expert), Dr. Tada (JICA Expert) Gegar S Prasetya, M. Sc, Ph.D, Dr. Widjo Kongko, Semeidi Husrin, Dr. Andojo Wurjanto (Indonesian Tsunami Expert)
07-09/08/ 2019	Bappeda Province office and field survey	Discussion of planning tsunami protection in Palu coast and its surroundings Field observation Experimental plan for Tsunami	Prof. Arikawa (Japanese Tsunami Expert), Dr. Tada (JICA Expert) Dr. Dinar Catur Isyanto, Dr. Andojo Wurjanto, Dr. Rahman Hidayat, Dr. Widjo Kongko (Indonesian Tsunami Expert), Danny Hilman,

Date	Place	Theme	Main experts
			Wilham G. Louhenapessy (Indonesian Geological Expert)
09/10/2019	Indonesia University	National Workshop on Assessment and Mitigation on Liquefaction Hazard	Prof. Ishihara, Prof. Yasuda (Japanese Geotechnical Expert), Dr. Tada (JICA Expert) Mr. Mashyur, Mr. Widjojo, Mr. Mudrik, Mr. Faisal, Mr. Surkiman (Indonesian Geotechnical Expert)
09/02/2021	Web Meeting	Tsunami Countermeasures in Central Sulawesi Rehabilitation and Reconstruction after the Natural Disaster of Central Sulawesi	Prof. Arikawa (Japanese Tsunami Expert) Mr. Abdul; Mr. Ewin (Bappenas), Mr. Arie, Mr. Leo & Team (PUPR), Mr. Gegar; Mr. Danny Hilman (Indonesian Tsunami Expert)

Source: JICA Study Team

5-2 Recommendation on Other Donors Support Projects

In the process of hazard assessment and countermeasure works for Nalodo, JICA Study Team provided recommendation on rehabilitation of agricultural irrigation canal damaged by the earthquake. M/P and F/S of this irrigation canal is being carried out with the support of another donor (ADB), and JICA is providing support for the basic design of a section of the canal (near Petobo) as an activity of OP (3). Since the water supply from this irrigation canal may be one of the reasons for the occurrence of Nalodo, the necessity of groundwater monitoring and the groundwater level observation plan is proposed.

5-2-1 Recommendation on the Need for Groundwater Monitoring

The earthquake caused a significant damage to agricultural irrigation canal (the Gumbasa irrigation canal) that runs in north-south direction on the east (mountain side) of Petobo and Jono Oge Districts where the Nalodo disaster occurred. Since agriculture is the main business activity in these regions, reconstruction of the damaged irrigation canal is important. In addition, considering the measures to reduce the risk of disasters based on the BBB concept is also important.

To reduce the Nalodo disaster risk, controlling the rise of groundwater level and keeping the groundwater level at a certain level are effective. During the reconstruction of the irrigation canal, water gates and drainage network were rebuilt by covering previously dug canal with concrete to prevent water leakage. In addition, when the free surface groundwater level is above a certain level, the water supply to the area should be restricted by closing the sluice gates. Moreover, a proper management of groundwater together with the observation of the groundwater in the entire Nalodo disaster areas is important.

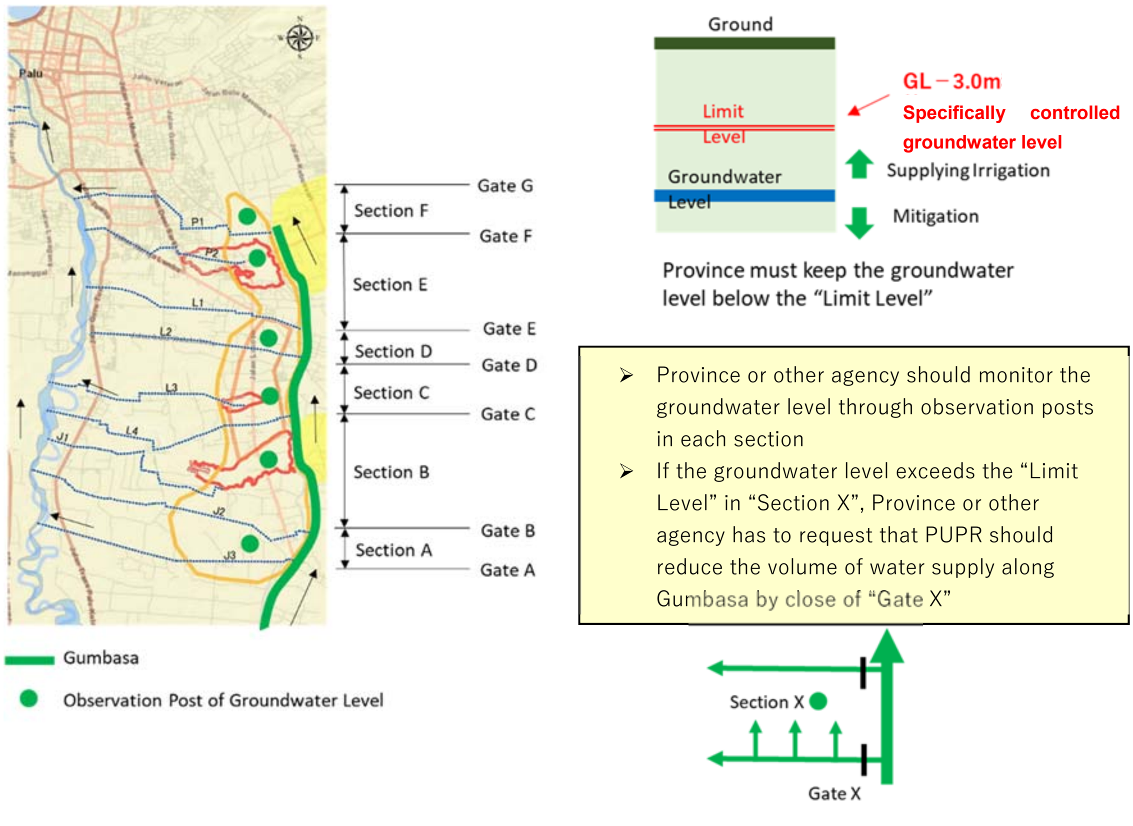
Hourly monitoring of groundwater levels began in March 2020 using 20 boreholes installed by JICA Study Team. Since the groundwater level fluctuates depending on external conditions such as rainfall, the objective of this monitoring is to understand the water level environment (groundwater level) after the disaster (before the restoration of irrigation channels and without any measures). The activities were carried out in cooperation with Tadulako University in Palu City.

5-2-2 Recommendation on the Need for Groundwater Level Observation Plan

The groundwater monitoring plan, such as number and frequency of observation and specifically controlling groundwater level, should be planned based on the results of previous surveys (topography, geology, disaster area, groundwater level monitoring data, groundwater analysis, etc.). The current monitoring plan of the Nalodo countermeasure works (groundwater level) is as follows. The number of observation points was decided to be minimized based on the interpretation of the topography in the catchment area. The controlled groundwater level (proposed) was set to -3 m below the ground level. This is intended to maintain the current surface groundwater level, which had a high hydraulic head before the earthquake, but is now stable at a depth of about 3 m below the ground surface due to the significant changes in the topography and damage to the irrigation channels caused by the earthquake.

- Observing points : 6 points (along the Gumbasa irrigation channel)
- Observing agency : PUPR or local government
- Observation frequency : Daily
- Observation target : Groundwater level
- Specifically controlled groundwater level (proposed): -3 m below ground level

Figure 5-1 below shows outline of the monitoring plan.



Source: JICA Experts and JICA Study Team

Figure 5-1 Outline of Groundwater Monitoring Plan

5-2-3 Data sharing with Indonesia Government Agencies

Future monitoring of groundwater levels should be conducted in collaboration with the PUPR, the management and operating agency of the Gumbasa irrigation channel, and the PUSAIR research institute. Local government agencies (BALAI, Provincial Government, and Sigi government) should also be involved in discussing future monitoring system.

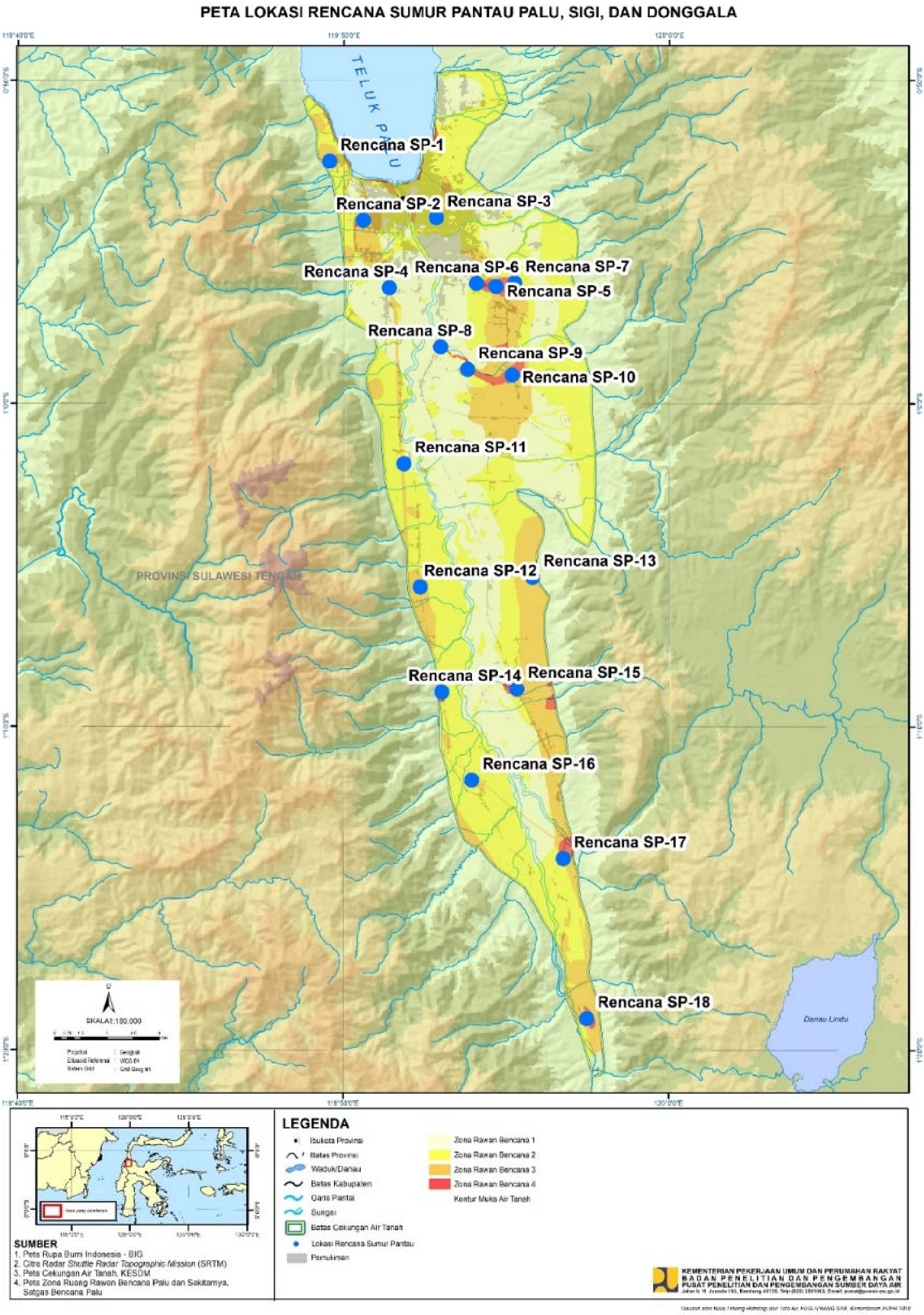
In addition, the observation equipment and data acquired by the JICA mission are planned to be handed over to the local government agencies.

At this stage, the 6 wells in the area between Petobo and Jono Oge are proposed to be used for continuous monitoring. As for the entire irrigation channel, continuous observation of groundwater level should be carried out based on the 18 observation wells recommended by PUSAIR, in addition to the 6 wells around the irrigation channel mentioned above.

Table 5-2 Observation well proposed by PUSAIR

No	Nama	X	Y	Desa	Kecamatan	Kota/Kab
1	Rencana SP-1	119,82594	-0,87504	Silae	Ulujadi	Kota Palu
2	Rencana SP-2	119,84325	-0,90551	Balaroa	Palu Barat	Kota Palu
3	Rencana SP-3	119,88056	-0,90414	Lolu Selatan	Palu Selatan	Kota Palu
4	Rencana SP-4	119,85651	-0,94032	Baliase	Marawola	Kab. Sigi
5	Rencana SP-5	119,91118	-0,93964	Petobo	Palu Selatan	Kota Palu
6	Rencana SP-6	119,90119	-0,93805	Petobo	Palu Selatan	Kota Palu
7	Rencana SP-7	119,92065	-0,93778	Petobo	Palu Selatan	Kota Palu
8	Rencana SP-8	119,88285	-0,97082	Kabobona	Dolo	Kab. Sigi
9	Rencana SP-9	119,89668	-0,98237	Langaleso	Dolo	Kab. Sigi
10	Rencana SP-10	119,91939	-0,98532	Jono Oge	Sigi Biromaru	Kab. Sigi
11	Rencana SP-11	119,86413	-1,03105	Pewunu	Dolo Barat	Kab. Sigi
12	Rencana SP-12	119,87246	-1,09464	Bobo	Dolo Barat	Kab. Sigi
13	Rencana SP-13	119,93001	-1,08956	Sidondo I	SIgi Biromaru	Kab. Sigi
14	Rencana SP-14	119,88358	-1,14895	Poi	Dolo Selatan	Kab. Sigi
15	Rencana SP-15	119,92205	-1,14735	Sibalaya Selatan	Tanambulava	Kab. Sigi
16	Rencana SP-16	119,89891	-1,19435	Baluase	Dolo Selatan	Kab. Sigi
17	Rencana SP-17	119,94580	-1,23468	Pakuli	Gumbasa	Kab. Sigi
18	Rencana SP-18	119,95802	-1,31707	Tuwa	Gumbasa	Kab. Sigi

*Nama = Name, Desa = Village, Kecamatan = districts, Kota/Kab = City
*The planned depth of the wells is 30 meters below from ground level
Source: PUSAIR



Source: PUSAIR

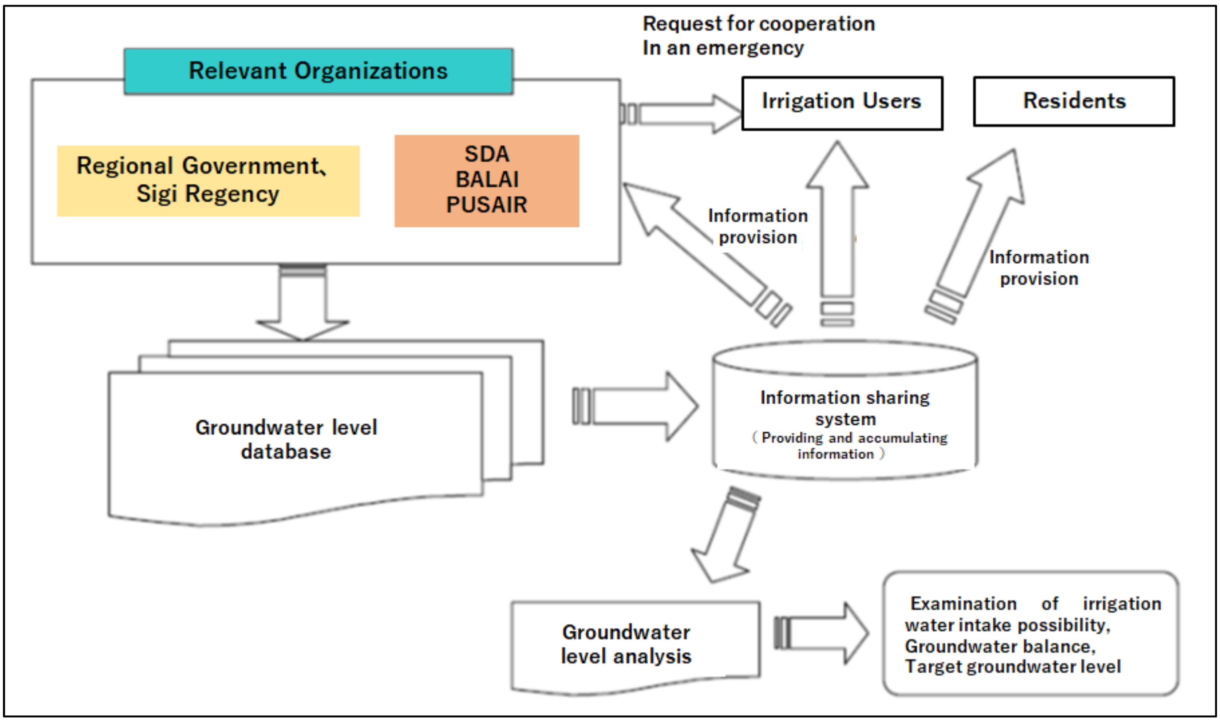
Figure 5-2 Observation well proposed by PUSAIR

5-2-4 Coordination of Irrigation Channel Management Counterpart

For a proper management of irrigation water in the Gumbasa irrigation channel, the relevant agencies should work together to collect and organize data regarding groundwater level, irrigation water volume, rainfall, etc.

If the groundwater level is higher than the specifically controlled groundwater level, the irrigation water needs to be drained appropriately (i.e., the gate should be closed to control the irrigation water).

In such cases, irrigation water users (farmers) and the general public should be provided with information on how to manage the gates and the status of groundwater levels to help in their management.



Source: JICA Study Team

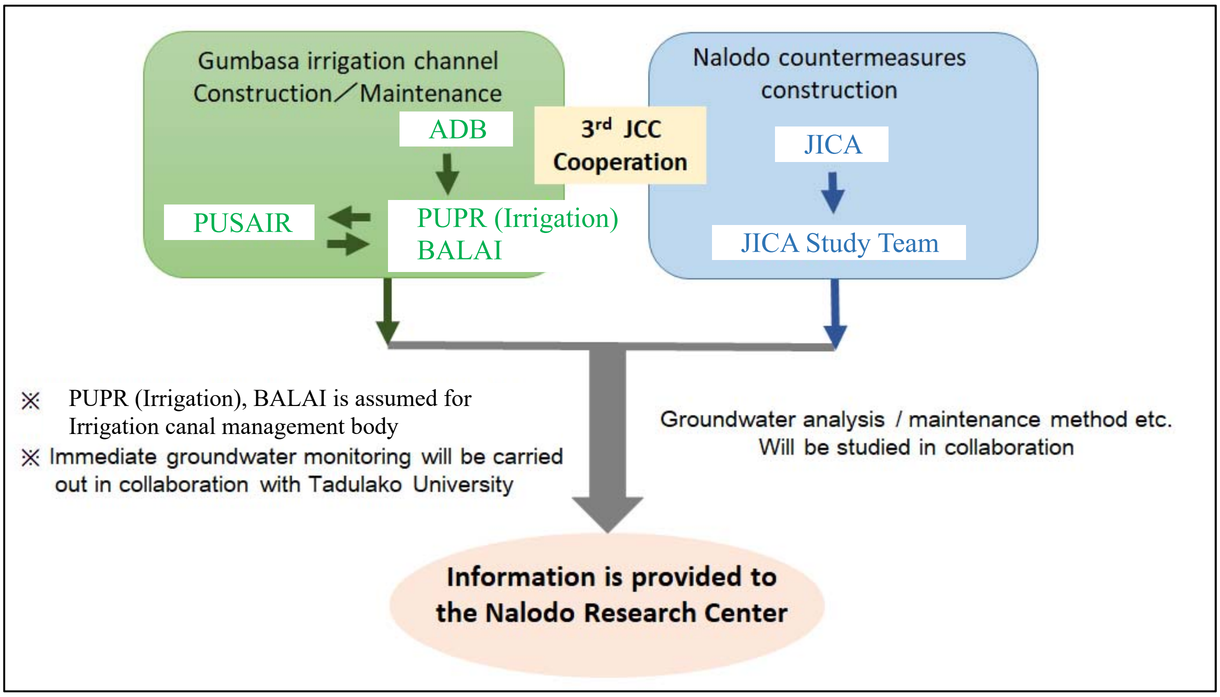
Figure 5-3 Image of Irrigation Channel Management System

5-2-5 Coordination with Other Donor Support Project

For the Gumbasa irrigation channel-related project, the M/P and F/S are being implemented with ADB support, and JICA's support was planned to cover the detailed design and construction supervision of the loan project for only a section of the project (near Petobo).

However, at the 3rd JCC held in December 2019, as a technical guidance (TA) based on the BBB's approach, the PUPR requested support for advice on how to manage the groundwater levels in the irrigation channel along with a groundwater monitoring plan for the Nalodo area. And this was decided to be implemented.

The following is an overview of the distinction between the JICA Study Team and other donors regarding the irrigation channel reconstruction project.



* BALAI = PUPR local (field) office
Source: JICA Study Team

Figure 5-4 Relationship between Gumbasa irrigation channel & Nalodo countermeasures

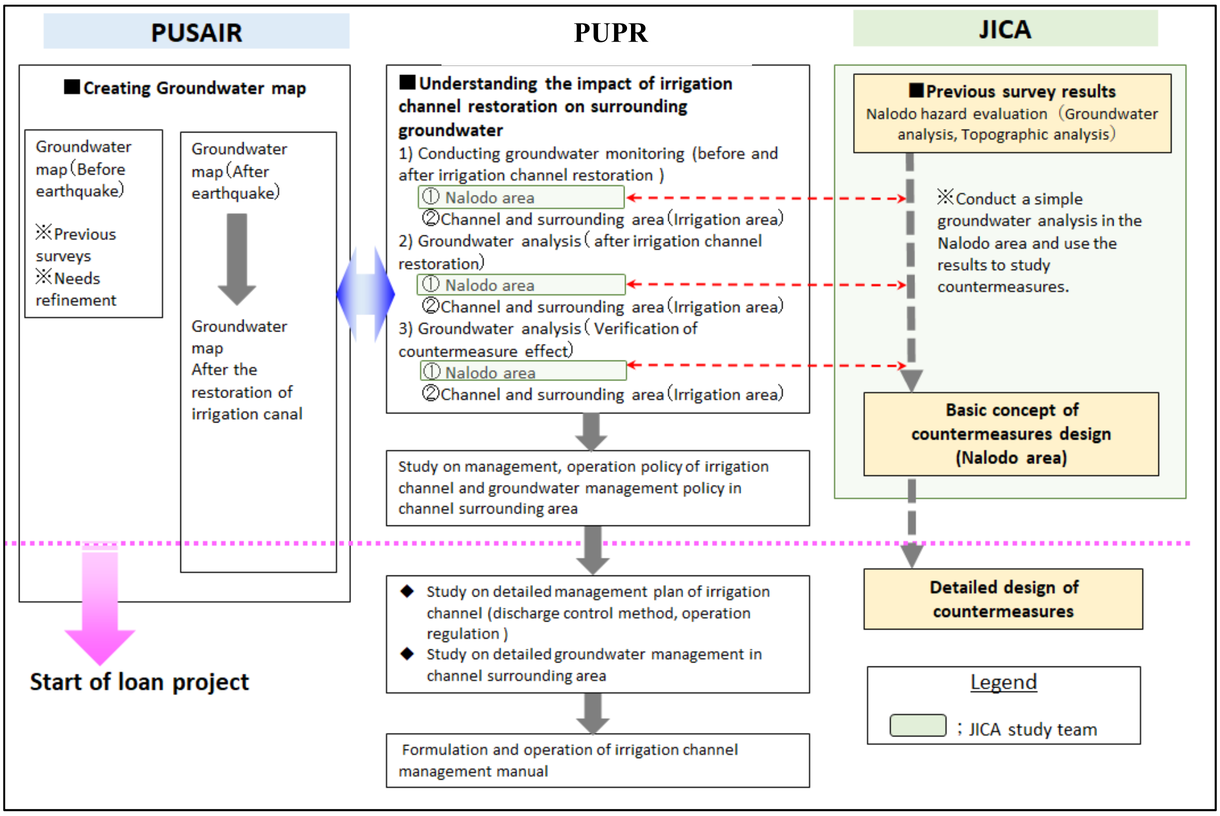
5-2-6 Considerations required for the Gumbasa Irrigation Channel Management Plan

Based on the BBB concept, proper maintenance of irrigation channels is important to achieve both the restoration of agricultural land use and disaster risk reduction in the Nalodo affected area. In addition to the proposed management system mentioned above, a number of issues need to be considered for the maintenance and management of irrigation channels, such as data accumulation through continuous groundwater monitoring, data evaluation and analysis, setting of groundwater management standards, and learning the methods and operations of flow control.

A list of the items to be considered and the proposed implementing entities are described below.

In this study, based on the existing survey results (Nalodo hazard assessment), JICA mission will conduct monitoring of groundwater level in Nalodo area (Petobo - Jono Oge area), which is a part of the irrigation canal related project, and carry out a simple groundwater analysis.

Based on these analyses, the management and operation policy of the irrigation channel and the groundwater monitoring policy around the irrigation channel will be discussed and the basic concept of Nalodo countermeasures will be established.



	Items	ADB	JICA	Noted
1	Creating groundwater map (Before earthquake); Palu alluvial fan	○	—	PUSAIR: map creation、JICA study team: information provision
2	Creating groundwater map (After earthquake, after irrigation channel restoration); Palu alluvial fan	○	—	PUSAIR: map creation、JICA study team: information provision
3	Understanding the impact of irrigation channel restoration on surrounding groundwater	○	Support	PUSAIR: map creation
	1) Groundwater monitoring (before and after irrigation channel restoration)	—	—	
	①Groundwater monitoring and analysis in Nalodo area	—	○	Conducted pilot monitoring in Nalodo area
	②Groundwater monitoring in irrigation channel and surrounding area	○	—	SDA，BALAI implement
	2) Groundwater analysis（after irrigation channel restoration）	—	—	
	①Nalodo area（Understanding groundwater level rise）	○	Support	Simple analysis（Consideration of simple farmland management）
	②Irrigation channel and surrounding area（Understanding groundwater level rise）	○	—	ADB,SDA,BALAI,PUSAIR implement
	3) Groundwater analysis（Verification of countermeasure effect）	○	Support	Considered monitoring results
4	Management, operation policy of irrigation channel and groundwater management policy in channel surrounding area	○	Support	Suggested thinking
5	Basic concept of countermeasures design and channel	○	Support	Suggested thinking
6	Study on detailed management plan of irrigation channel (discharge control method, operation regulation)	○	—	ADB,SDA,BALAI Implement、Consultant in Loan project supports
7	Study on detailed groundwater management in channel surrounding area	○	—	ADB,SDA,BALAI Implement、Consultant in Loan project supports
8	Formulation of irrigation channel management manual (including groundwater monitoring)	○	—	ADB,SDA,BALAI implement
9	Detailed design in channel and surrounding facilities	○	—	ADB,SDA,BALAI Implement、Consultant in Loan project supports
10	Multi-stakeholder cooperation, coordination（ADB,SDA,BALAI,PUSAIR,JICA）	○	—	ADB,SDA,BALAI,PUSAIR,JICA

Source: JICA Study Team

Figure 5-5 Roles of ADB & JICA in supporting Gumbasa irrigation channel
（Proposal of JICA study team）

5-2-7 Future academic research activities

Research activities on the mechanism of occurrence of Nalodo, which is a rare disaster in the world, and its countermeasures will be continued mainly by the Nalodo Research Center supported by the World Bank (WB). Members have already been selected from academics and government research institutes, etc. For the progress of academic research on Nalodo, it is recommended that the center carries out the following activities.

- Topographic and geological surveys, land use surveys, surface ground surveys, and groundwater surveys in the areas of Palu City and Sigi Regency (Balaroa, Petobo, Lolu, Jono Oge, Sibalaya) damaged by the earthquake are conducted and analyzed. The topography / geology, land use, and groundwater characteristics are grasped in detail, and the risk of future Nalodo outbreaks will be clarified.
- It is necessary to carry out pilot projects, geological surveys, monitoring surveys (groundwater level, etc.), etc. in each damaged area and its surroundings in order to clarify the effects of the countermeasures to be implemented. After that, it is desirable to verify the effect of the countermeasure work.
- Areas with risks of Nalodo and liquefaction will be extracted from all over Indonesia, risk assessment methods will be set, and research will be promoted on risk assessment and effective countermeasures in those areas.

Chapter 6 Formulating Manual for Hazard Map Formulation

JICA Study Team created a manual on how to formulate various hazard maps for tsunami, Nalodo, earthquakes, floods, and sediment disasters. In the process of manual formulation, JICA Study Team closely exchanged opinions with Indonesian related organizations to make the manual more practical and can be used continuously by the Indonesia side. Outline on the hazard map formulation method for each type of disaster as described in the hazard map's manual is described below.

6-1 Hazard Map Formulation

JICA Study Team analysed each disaster factor and specified high hazardous areas of tsunami, Nalodo, earthquakes (faults), flood, and sediment disasters based on the collected data and the results of various field surveys. Regarding hazard assessment and hazard map creation, the scale of earthquake and tsunami was set as the largest tsunami in the history. In particular, for tsunami and Nalodo which had special causes in this disaster, the study was conducted not only by members of the JICA Study Team, but also university professors and specialists through domestic Advisory Committee. The study is aimed to examine the mechanism of occurrence, the method of setting hazard levels, and the outline plan of countermeasures.

Hazard map reference manual was created to summarize the creation method of hazard maps. Basic conditions of creating hazard maps are presented below. The target area of hazard map is same as the ZRB map that was prepared in December 2018. Hazard criteria was classified in four levels which is similar to the criteria of ZRB.

- Scale: 1/25,000
- Target area: Same range as ZRB map published in December 2018
- Hazard criteria: four levels, similar to the criteria of ZRB
- The use of hazard maps: reflect in the spatial planning of the local government (state, province and city).
- Two types of hazard maps: one without and one with countermeasures are prepared.
- Technology transfer of risk assessment methods should be promoted

Table 6-1 Classification of Hazard criteria

Criteria of ZRB			Hazard Criteria
ZRB-1	**Developed Zone** ➢ No Additional Regulation	⇒	Hazard level-1
ZRB-2	**Controlled Zone** ➢ Middle Density Development	⇒	Hazard level-2
ZRB-3	**Limited Zone** ➢ Low Density Development ➢ To Prohibit New Construction ➢ To Allow Reconstruction with ➢ "Additional Requirement of Buildings Structure"	⇒	Hazard level-3
ZRB-4	**Prohibited Zone** ➢ To Prohibit New Construction and Reconstruction ➢ Relocation of Existing Buildings	⇒	Hazard level-4

Source: JICA Study Team

Reference manuals (tsunami, Nalodo, earthquake, flood, sediment disaster) on how to create a hazard map was prepared for the above detailed hazard maps. A summary of hazard assessment methods for each disaster type is presented in Table 6-2 below.

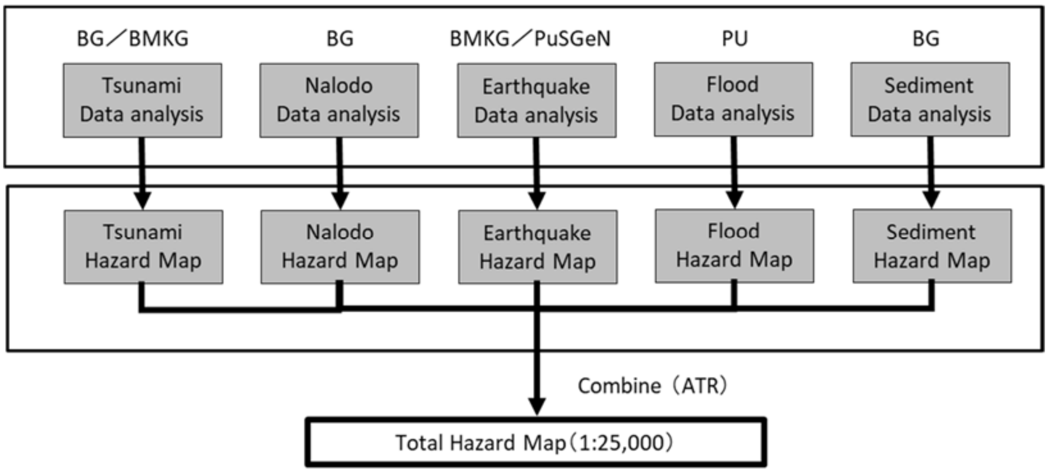
Table 6-2 Classification of Hazard criteria

Disaster Type	Hazard Assessment Method
Tsunami	Completing the analysis in a short period of time is difficult due to the lack of existing data and the complicated generation mechanism. The investigation was also determined would be large-scale, including sounding surveys of the seafloor topography. Therefore, we conducted a field survey of the damage caused by the current disaster (inundation status, inundation depth, etc.) and conducted a hazard assessment based on the results.
Nalodo	Nalodo is liquefaction accompanied by landslides that is assumed caused by mainly following five factors: shallow groundwater level, existence of slope, existence of liquefiable layers, confined aquifer, and cap layer. The hazard assessment of future disaster was carried out by considering the existence of shallow groundwater levels and liquefiable layers that can be evaluated in a short period and many data are available.
Earthquake (Active fault)	Earthquake hazard evaluation based on the damage of the surface earthquake active fault that appeared in this earthquake.
Flood	A model for rainfall runoff inundation analysis was created by RRI model[1] (Rainfall-Runoff-Inundation Model) for small and medium rivers flowing into Palu River Basin and Palu Bay. The digital topographic map created after the disaster was used for as topographical conditions in the floodplain that greatly affect the inundation characteristics and inundation depth.
Sediment	The steep slope failure and debris flow were evaluated from the topographic gradient and the devastation situation of the basin. Field surveys were conducted in areas where disasters occurred to determine the risk of disasters that could not be known with satellite images.

Source: JICA Study Team

The JICA Study Team formulated the hazard map based on the above hazard assessment method and the result of adjusting hazard criteria with Indonesian relevant organizations. Its reference manual was created to summarize the creation method of hazard maps. The hazard maps formulation method is as shown in Figure 6-1 (Listed based on each related organization).

[1] A model that predicts the phenomena of rainfall collecting in a river, floods flowing down a river, and water flowing down a river overflowing into a floodplain in a basin.



Source: Prepared by JICA Experts

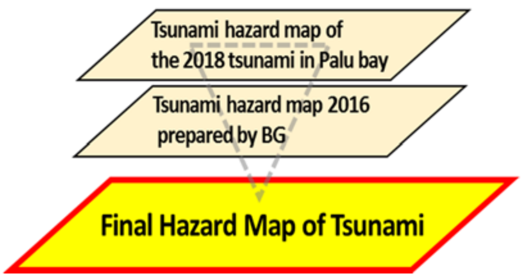
Figure 6-1 Flow of Hazard Map Formulation (Tsunami, Nalodo, Earthquake, Flood, Sediment Disaster)

The method for creating hazard map of each disaster is explained below.

6-1-1 Tsunami

(1) Basic concept of hazard map preparation

The target hazard is commonly set based on statistical data such as past inundation history, and set scale and probability of target tsunami to predict the hazard area by simulation. However, the existing data of target area are insufficient and have reliability issues, while the only reliable historical data are the records of the 2018 tsunami in Palu. Therefore, the JICA hazard map was created by using the inundation depth data of this tsunami based on the results of the field survey as basic data. We do not consider all conditions and a basic map for formulating land use plan in this hazard map. Regarding the tsunami inundation depth data, Dr. Arikawa (Professor of Chuo University and a member of the Japanese Advisory Committee) advised that the inundation depth of the first survey include splash and setup effect. Inundation depth survey was re-conducted to confirm and its results was reflected in the hazard map.



Source: JICA Experts and JICA Study Team

Figure 6-2 Image of Tsunami Hazard Map Formulation

Further, since another main source of tsunami is earthquake, the Geological Agency (BG) prepared a hazard map in 2016 by simulating tsunami caused by an earthquake in the Makassar Strait. The tsunami hazard map prepared by JICA was overlaid on the map prepared by BG in 2016 after determining hazard criteria by discussion with BG, as the figure below describes. The hazard map of BG in 2016 was created by AusAID using the Probabilistic Tsunami Hazard Assessment (PTHA) model in 2013 and 2014, and the analysis result is reliable. Combination of hazard maps by JICA and BG produced a final hazard map covering tsunami hazards caused by landslides and earthquakes.

(2) Criteria of hazard level

For tsunami caused by landslide such as this disaster, the evacuation time from the occurrence of the earthquake is only about 3 to 5 minutes. This fact should be taken into the hazard level criteria consideration. Therefore, 3 m or more inundation depth was set as hazard level 4 due to a possibility that people will be attacked by tsunami even if they evacuate to the second floor of the building. Further, 1-3 m inundation depth was set as hazard level 3 where people can evacuate to first floor, 0.3-1 m inundation depth was set as hazard level 2 where people can evacuate with difficulty. While inundation depth of 0.3 m or less was set as hazard level 1 where people are easy to evacuate.

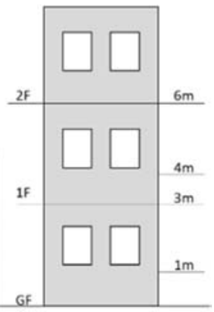
On the other hand, the tsunami hazard map prepared by BG (BG 2016 Hazard map) assumed that the source is in Makassar Strait, thus the evacuation time is considered to be more than 10 minutes. This consideration was based on the average water depth, wave velocity, and distance to a certain point. Hence, the standard depth of inundation for BG hazard map was set and the combined hazard level to a rank down. Further, the area where inundation depth more than 4 m was set as hazard level 4 (Figure 6-3).

For Tsunami induced by Fault (Hazard map 2016 by BG) --> Evacuation Time (20min)

Hazard Level		Inundation depth	Comments
4	Extremely High	> 4m	Not Good for Residence
3	High	> 3m	Evacuate to 2F
2	Medium	1-3m	Evacuate to 1F
1	Low	0-1m	Evacuate with difficulty

For Tsunami induced by Landslide (Hazard map 2018 by JICA) --> Evacuation Time (3-5min)

Hazard Level		Inundation depth	Comments
4	Extremely High	> 3m	Not Good for Residence
3	High	1-3m	Evacuate to 1F
2	Medium	0.3-1m	Evacuate with difficulty
1	Low	0-0.3m	Easy to evacuate

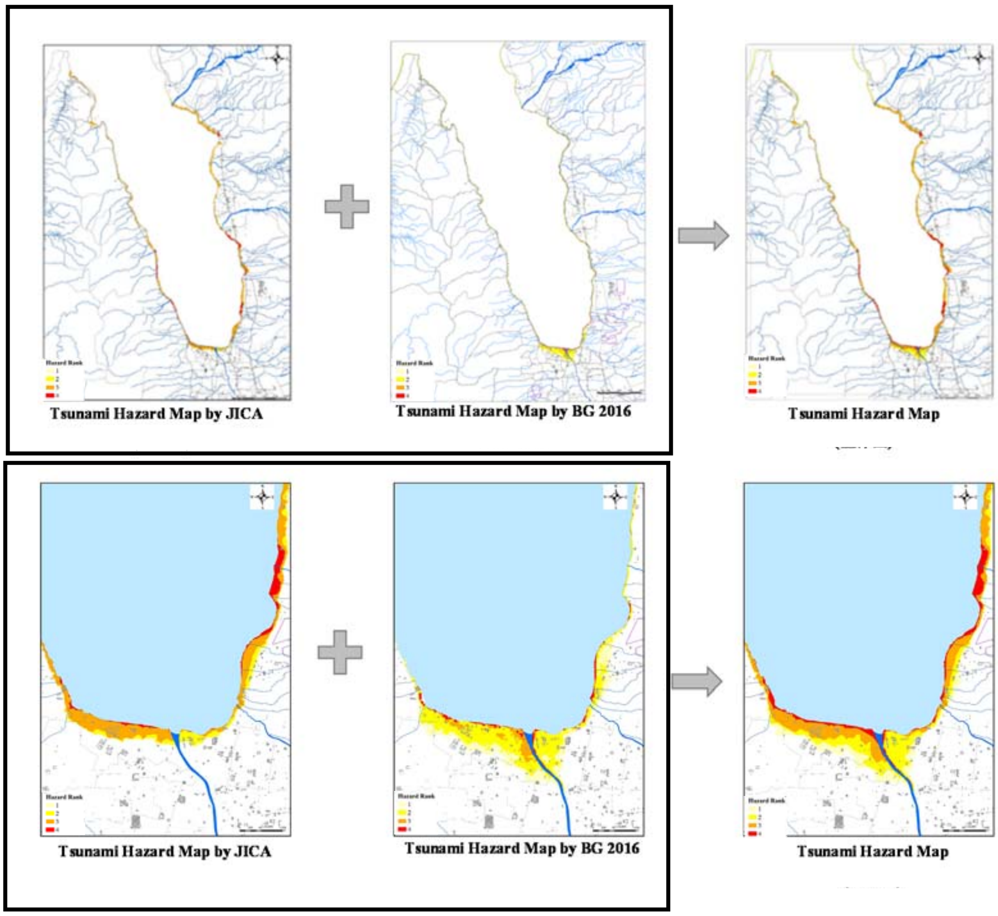


Source: JICA Experts and JICA Study Team

Figure 6-3 Hazard Level Criteria of JICA Hazard Map and BG Hazard Map 2016

(3) Tsunami hazard map after the refinement

The final tsunami hazard map was created by overlaying JICA's tsunami hazard map with BG's 2016 tsunami hazard map as presented in Figure 6-4.



Source: JICA Experts and JICA Study Team

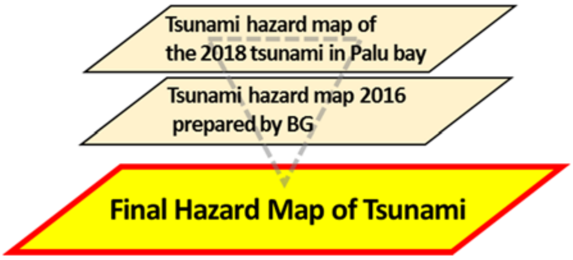
Figure 6-4 Tsunami Hazard Map

(4) Methodology of Hazard Map

When preparing a tsunami hazard map, it is necessary to set the scale and return period of the target hazard. It is common to set the target hazard based on statistical data, such as past inundation history, and to predict the hazard area by simulation. However, the existing data of the target area are not enough and have reliability issues; the only reliable historical data are the records of the 2018 tsunami in Palu. Therefore, the JICA hazard map refinement is based on the 2018 tsunami, which was mainly caused by landslide.

Besides, another main source of tsunami is earthquake, and the Geological Agency (BG) prepared a hazard map in 2016 by simulating tsunami caused by an earthquake in the Makassar Strait. It is hardly necessary to take into consideration volcanic eruptions for the area.

The reviewed tsunami hazard map prepared by JICA is overlaid on that prepared by BG in 2016, as the Figure 6-5 describes. The combination produced a final hazard map covering tsunami hazards caused by landslides and earthquakes.



■ Tsunami hazard map

- When preparing a tsunami hazard map, it is necessary to set the scale and return period of the target hazard.
- It is common to set the target hazard based on statistical data, such as past inundation history, and to predict the hazard area by simulation

→However, the existing data of the target area are not enough and have reliability issues; the only reliable historical data are the records of the 2018 tsunami in Palu.

■ Sources for tsunami hazard map

1. Hazard Map based on the 2018 Tsunami by JICA
   : the JICA hazard map refinement is based on the 2018 tsunami, which was mainly caused by landslide.
2. Hazard Map in 2016 by BG
   : the Geological Agency (BG) prepared a hazard map in 2016 by simulating tsunami due to an earthquake in the Makassar Strait

→The reviewed tsunami hazard map prepared by JICA should be combined with the hazard map by BG in 2016 for refinement of the final tsunami hazard map.

Source: JICA Expert and JICA Study Team

Figure 6-5 Sources of Tsunami

1) Flow of the reviewing tsunami hazard map

Based on the Indonesia government's request, JICA Study Team refined the existing one tsunami hazard map formulated by Badan Geolosi (BG, Geological Agency) until December 2018, especially for Palu case. The methodology of formulating tsunami hazard map is shown in Figure 6-6. The first step is collecting the necessary data for assessing tsunami hazard. The second step is conducting a field survey for supplementing the existing data. The third step is identifying the inundation area using the data collected in steps 1 and 2 of tsunami damage records, and assessing and formulating tsunami hazard map for the target area with criteria developed based on damage level by inundation depth. The detail explanation of each step is provided below.

i) Data Collection

↓

ii) Identification of Inundation Area

↓

iii) Assessment and Formulation of Tsunami Hazard Map

Source: JICA Expert and JICA Study Team

Figure 6-6 Flowchart of Formulating Tsunami Hazard Map

a) Data collection

The fundamental data for formulating tsunami hazard map have been collected. The referred data are listed in below.

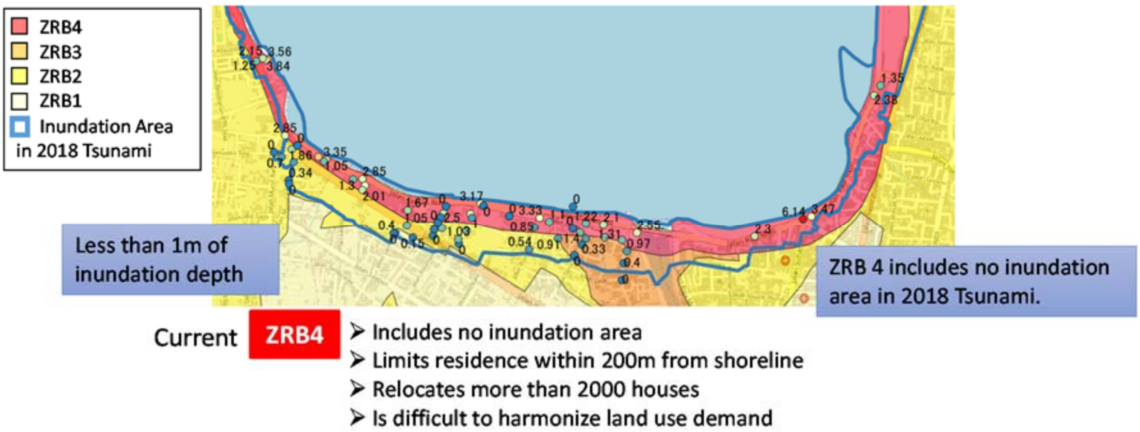
Table 6-3　List of the Referred Data for reviewing the hazard map

	Title of the data	Source
1	Water mark survey results	BG,BMKG, KKP, Tohoku/Chuo Univ. PCKK
2	Inundation area of 2018 tsunami	ATR, Tohoku Univ., PASCO
3	Topography Data	BIG, PASCO

Source: JICA Expert and JICA Study Team

For the analysis of tsunami hazards, inundation depth data are the most important, because the depth indicates the potential of damage to people, buildings and so on. When tsunami hits something, such as building, it leaves water marks higher than inundation level with splash and setup. Although some of the heights of the Palu tsunami have been collected, their accuracy (whether they include splash and/or setup heights) could not be confirmed. The measurements have to be made in a uniform way with the same standard, but it was unclear whether the indicated heights are those of the inundation, splash or setup.

Although about 200 m wide sections along the coastline are uniformly designated as red in the ZRB of December 2018 issued by ATR, there are many areas which have not affected by the 2018 tsunami and even not inundated as shown in Figure 6-7. The inundation area of the 2018 tsunami has been jointly studied by ATR, Tohoku University and PASCO. Since the ZRB 4 area is set to be a living-prohibited area, even residents who have not suffered must be forced to relocate.

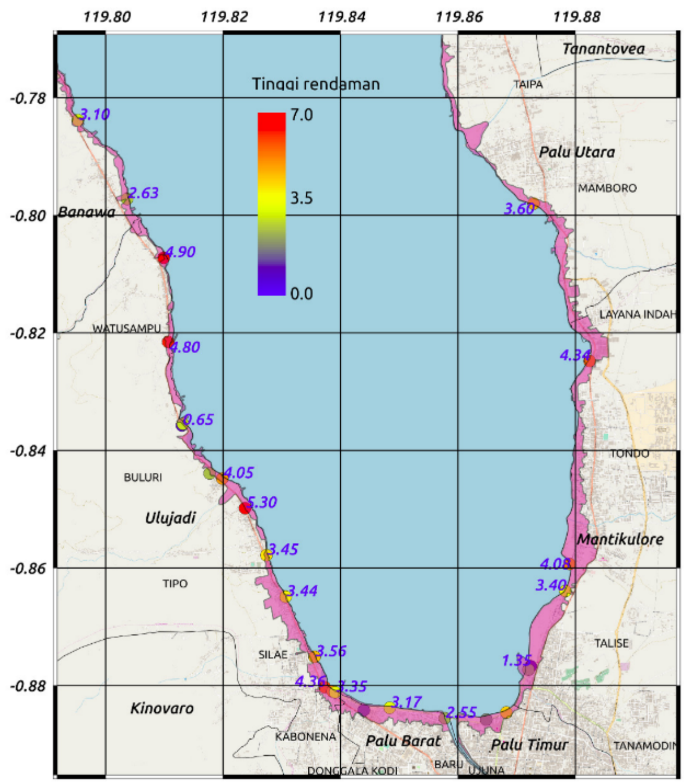


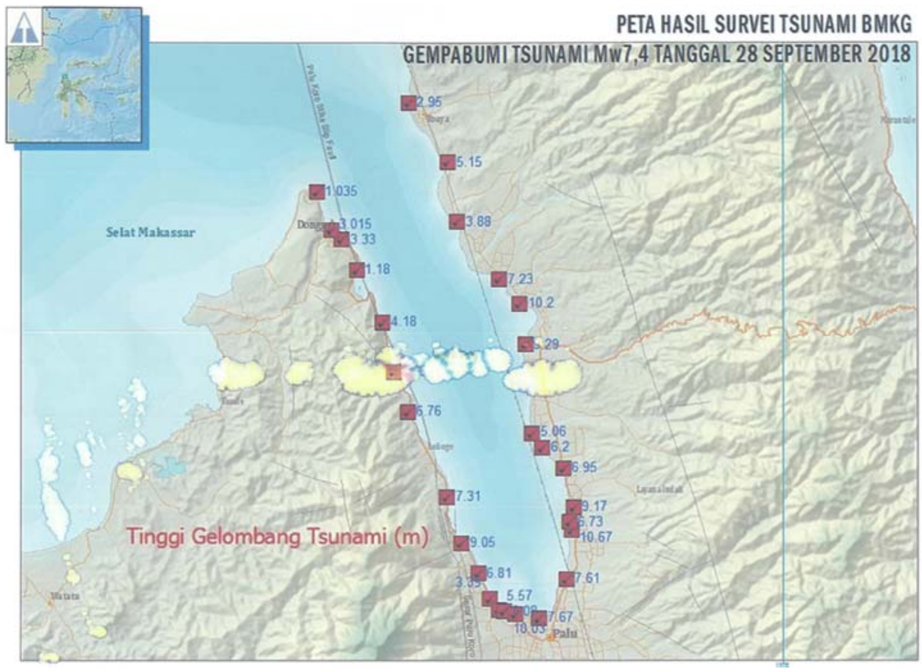
Source: JICA Expert and JICA Study Team

Figure 6-7　ZRB and Inundation Area in 2018 Tsunami

Therefore, in order to reflect the actual damage caused by the tsunami, it is decided to review this hazard map after checking accurate inundation depth.

Thus, only the inundation data collected after the 2018 tsunami in the target area are adopted for reviewing the tsunami hazard map. The Indonesian government (BG, BMKG) had investigated the inundation depth after the disaster; the results are shown in the following figure.

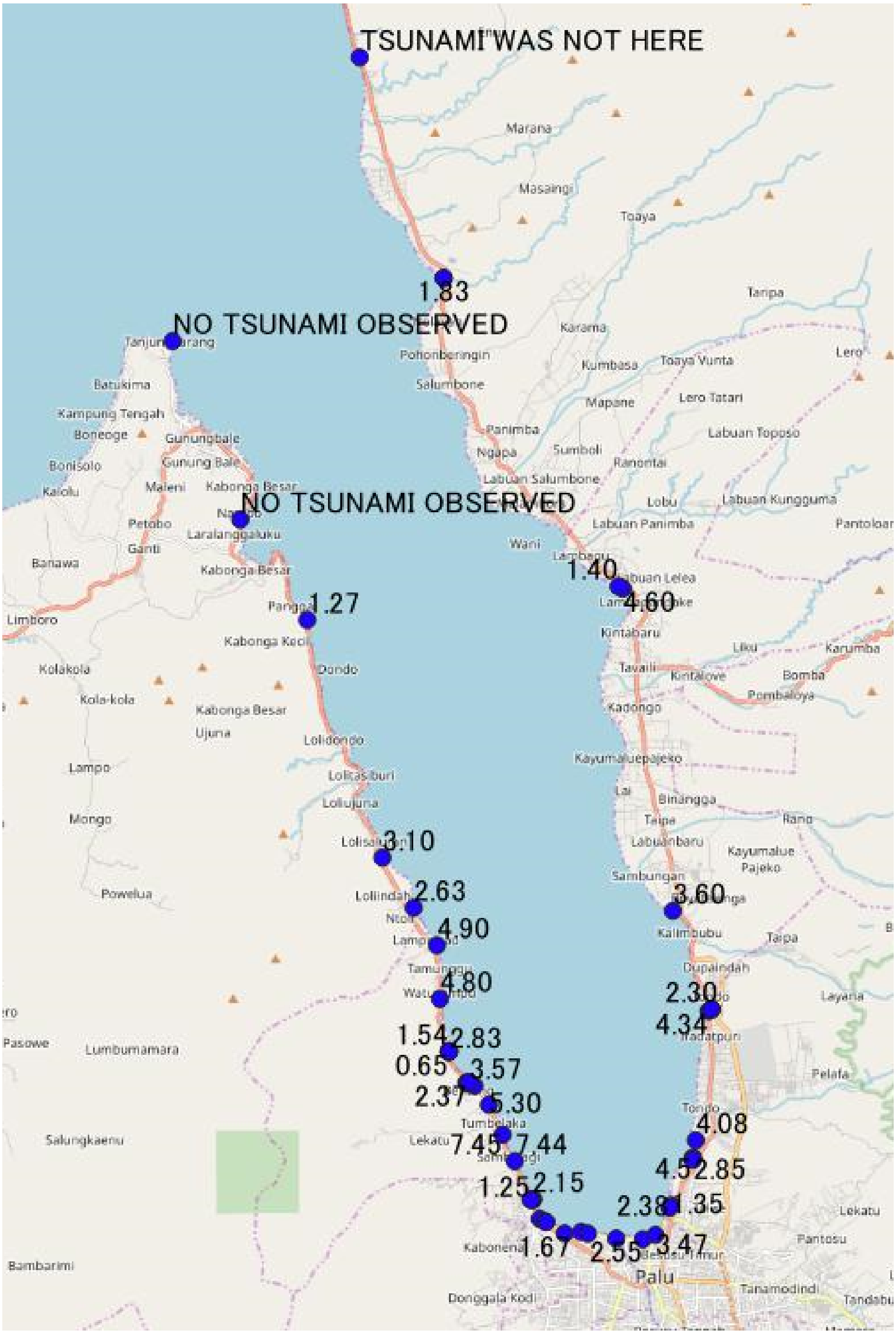




Source: water mark survey results (BG, BMKG)

Figure 6-8 Survey Points and Water Mark Survey Results (Top: BG, Bottom: BMKG)

JICA Survey Team has gathered all official results of the water mark surveys conducted by the Indonesian government and Japanese researchers. The referred inundation depths and survey points of the water mark survey (BG, BMKG, KKP, Tohoku/Chuo Univ. PCKK) are shown as follows.



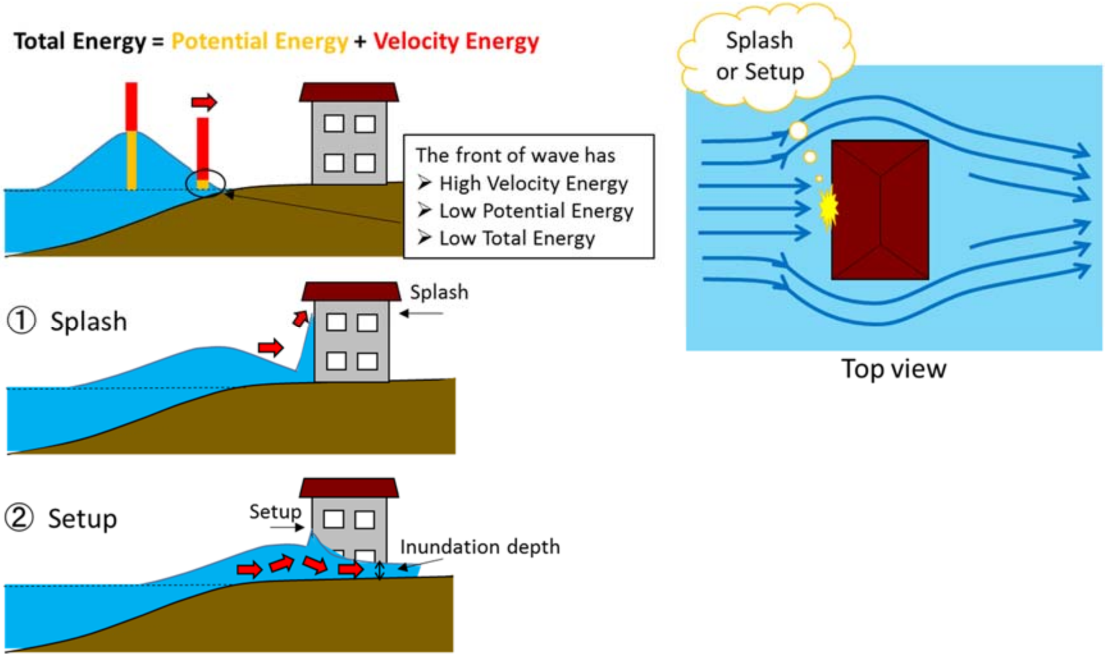
Source: water mark survey results (BG, BMKG, KKP, Tohoku/Chuo Univ., PCKK)

Figure 6-9 All Survey Points and Water Mark Survey Results b） Identification of inundation area

After the tsunami disaster, several post-event surveys have been conducted in order to grasp the tsunami heights, inundation areas and depths as well as damage characteristics. Additionally, inundation depths have been surveyed by JICA Study Team based on the water marks by excluding splash and setup heights, to supplement existing data.

Tsunami energy consists of potential energy and velocity energy. When a tsunami wave passes through a building (or some artificial structures), velocity energy forms as splash or setup at the front side (seaside) of the building. Therefore, in order to measure the real potential energy of a tsunami, the inundation depth should be measured by avoiding the front side. In other words, the inundation depth of the interior part or two sides or backside of the building should be measured.

The method of making accurate inundation depth measurement is described below. The information collected from local residence through interviews is also taken into consideration in identifying the inundation depth.



Source: JICA Expert and JICA Study Team

Figure 6-10 Method for Accurate Inundation Depth Measurement

JICA survey team has conducted several additional surveys for Palu bay. The results are shown in the following figures.

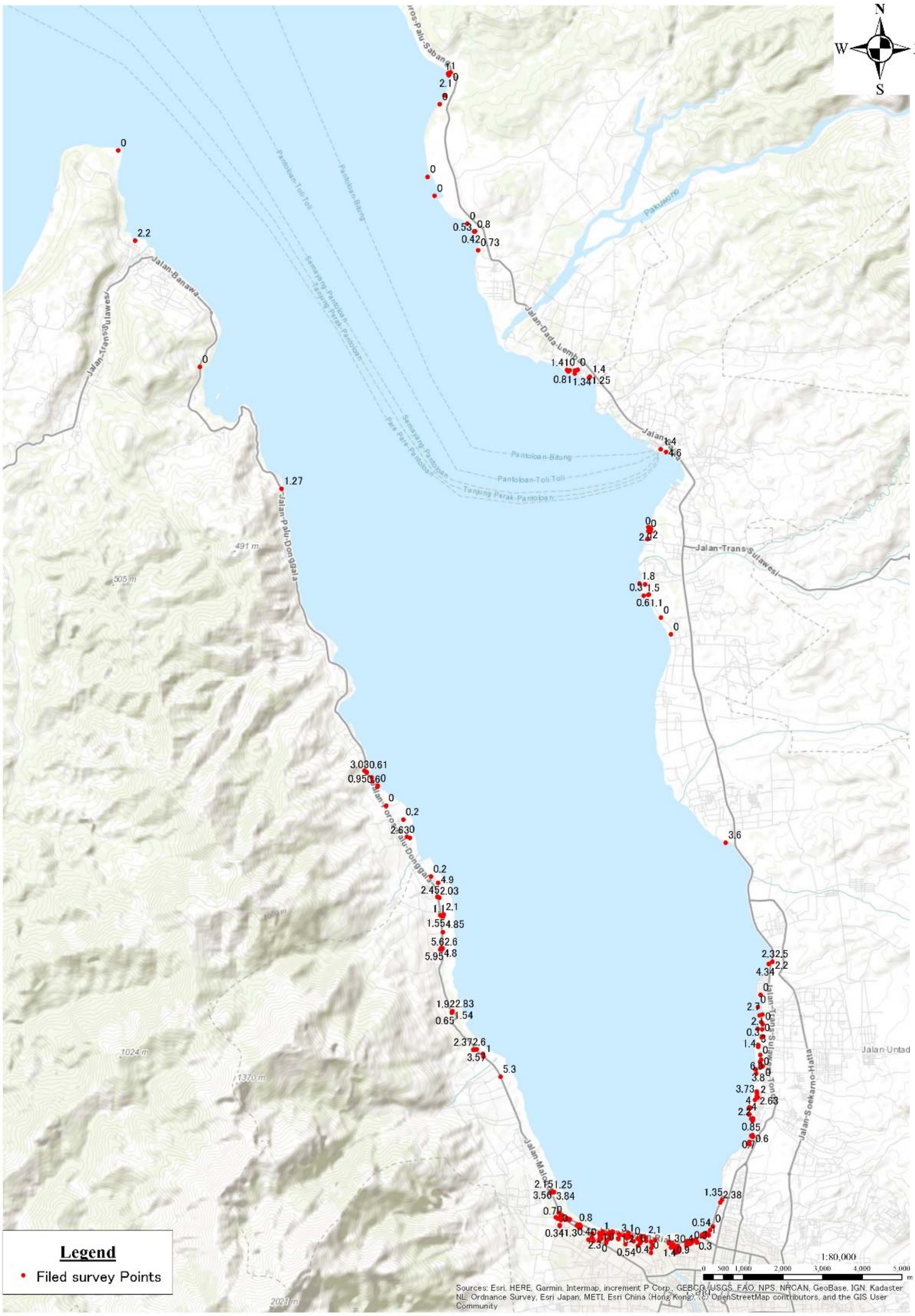
Source: JICA Expert and JICA Study Team

Figure 6-11　Additional survey results in Palu Bay East

Source: JICA Expert and JICA Study Team

Figure 6-12　 Additional survey results in Palu Bay West

The JICA Study Team summarized the results of the post-tsunami survey conducted in Palu after the 2018 tsunami as shown below.



Source: JICA Expert and JICA Study Team

Figure 6-13 Field Survey Points by JICA Study Team

c) Assessment and formulation of tsunami hazard map

Tsunami hazard map is a map showing the vulnerability or hazard level of an area, which is determined by using certain criteria, such as classification of the area by inundation depth.

The JICA Study Team has summarized the damage level (casualties and damaged buildings) according to the Japanese guideline shown in Table 6-4. For the tsunami caused by landslides, this guideline proposes the development of tsunami hazard map based on the criteria shown in Table 6-5 for the following reasons:

The proposed classification criteria should be the same as those used by BG (i.e., inundation depth).

An inundation depth exceeding 1 m makes the evacuation on foot hard and leads to the collapse of some of the buildings with weak structure. An inundation depth exceeding 3 m means the submergence of upper floors and the collapse of most the buildings with weak structure. An inundation depth less than 0.3 m causes minor damage to buildings and evacuation is easier under this condition.

People may survive a "3 m" deep inundation if only they could evacuate to the second floor in a short time. Thus, the standard value dividing hazard level 3, 4 is set as 3 m.

Table 6-4 Summary of Damage Status during Tsunami

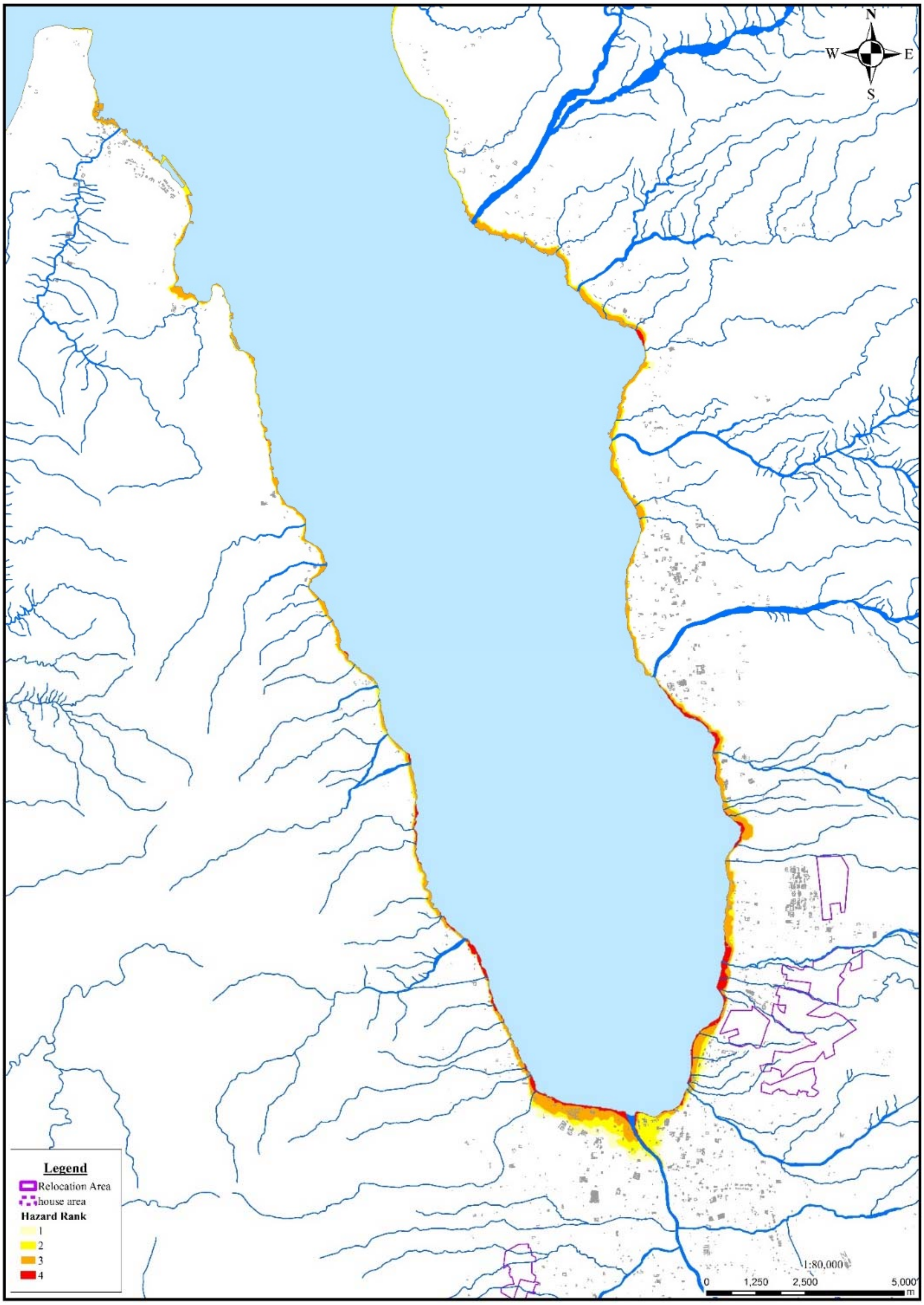
Inundation depth	Damage Status	
	People	Buildings
	➢ Only People on the upper floor can survive	➢ Almost all Buildings with weak structure like wooden houses would collapse ➢ Upper floors would submerge even if buildings remain
—3.0m—		➢ More than half of buildings with weak structure would collapse ➢ Ground floor would submerge
—2.0m—	➢ People cannot evacuate on foot ➢ Some people cannot survive on the ground floor or outside	➢ Some of buildings with weak structure would collapse
1.0m	➢ People can evacuate on foot, but with difficulty	➢ Buildings would have miner damage
—0.3m—	➢ People can evacuate on foot with ease	

Source: Japanese guideline and data from the 2011 tsunami

Table 6-5 Classification of Tsunami Hazard Map Proposed by JICA Study Team

Hazard Level		Inundation depth
4	Extremely High	> 3m
3	High	1-3m
2	Medium	0.3-1m
1	Low	0-0.3m

Source: JICA Expert and JICA Study Team



Source: JICA Expert and JICA Study Team

Figure 6-14 Tsunami Hazard Map without Mitigation Measures

2) Tsunami hazard map prepared by BG

The BG formulated a tsunami hazard map for Palu Bay in 2016 considering an earthquake in Makassar Strait. The tsunami height in Palu Bay was taken from the results of Probabilistic Tsunami Hazard Assessment (PTHA).

Since a hazard map becomes more reliable when multiple sources of tsunami are taken into consideration, the refined hazard map has taken into account the 2018 tsunami caused by landslide and the 2016 hazard map prepared by BG considering an earthquake caused in Makassar Strait. When the 2016 hazard map prepared by BG is overlaid on that of 2018 by JICA, the hazard level criteria should be developed as suitable by converting the classification. It is estimated that the hazard level criteria of the 2016 hazard map has more than 10 minutes evacuation time based on the average water depth, wave velocity and distance to a certain point, thus the standard depth of inundation is set to be higher than that of the 2018 hazard map.

For Tsunami induced by Fault
(Hazard map 2016 by BG)

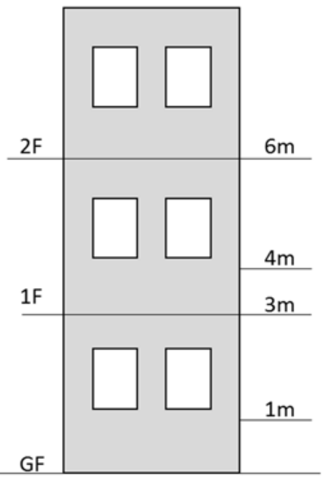
--> Evacuation Time (20min)

Hazard Level		Inundation depth	Comments
4	Extremely High	> 4m	Not Good for Residence
3	High	> 3m	Evacuate to 2F
2	Medium	1-3m	Evacuate to 1F
1	Low	0-1m	Evacuate with difficulty

For Tsunami induced by Landslide
(Hazard map 2018 by JICA)

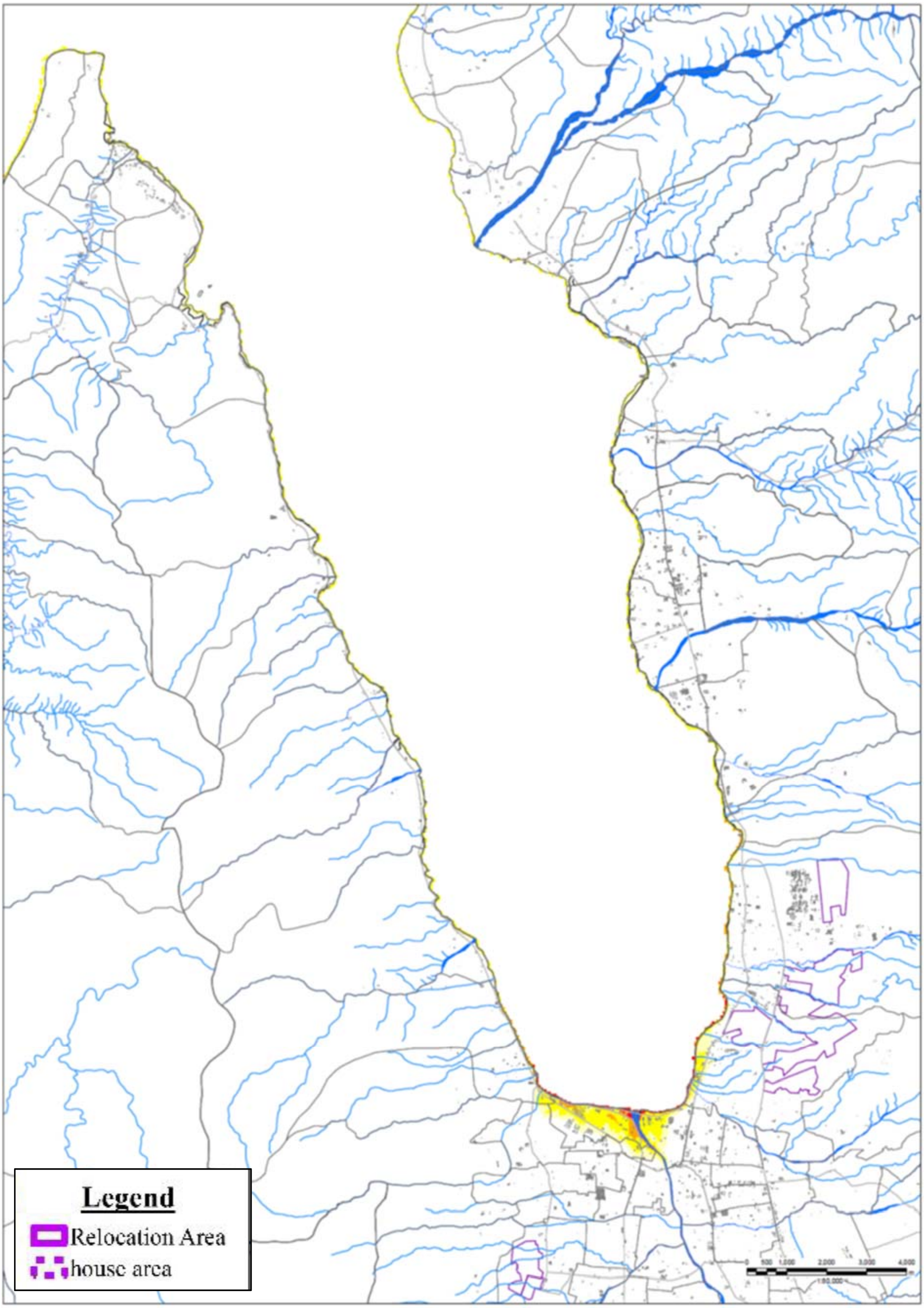
--> Evacuation Time (3-5min)

Hazard Level		Inundation depth	Comments
4	Extremely High	> 3m	Not Good for Residence
3	High	1-3m	Evacuate to 1F
2	Medium	0.3-1m	Evacuate with difficulty
1	Low	0-0.3m	Easy to evacuate



Source: JICA Expert and JICA Study Team

Figure 6-15 Converting Hazard Level Criteria of the 2016 Hazard Map to those of 2018

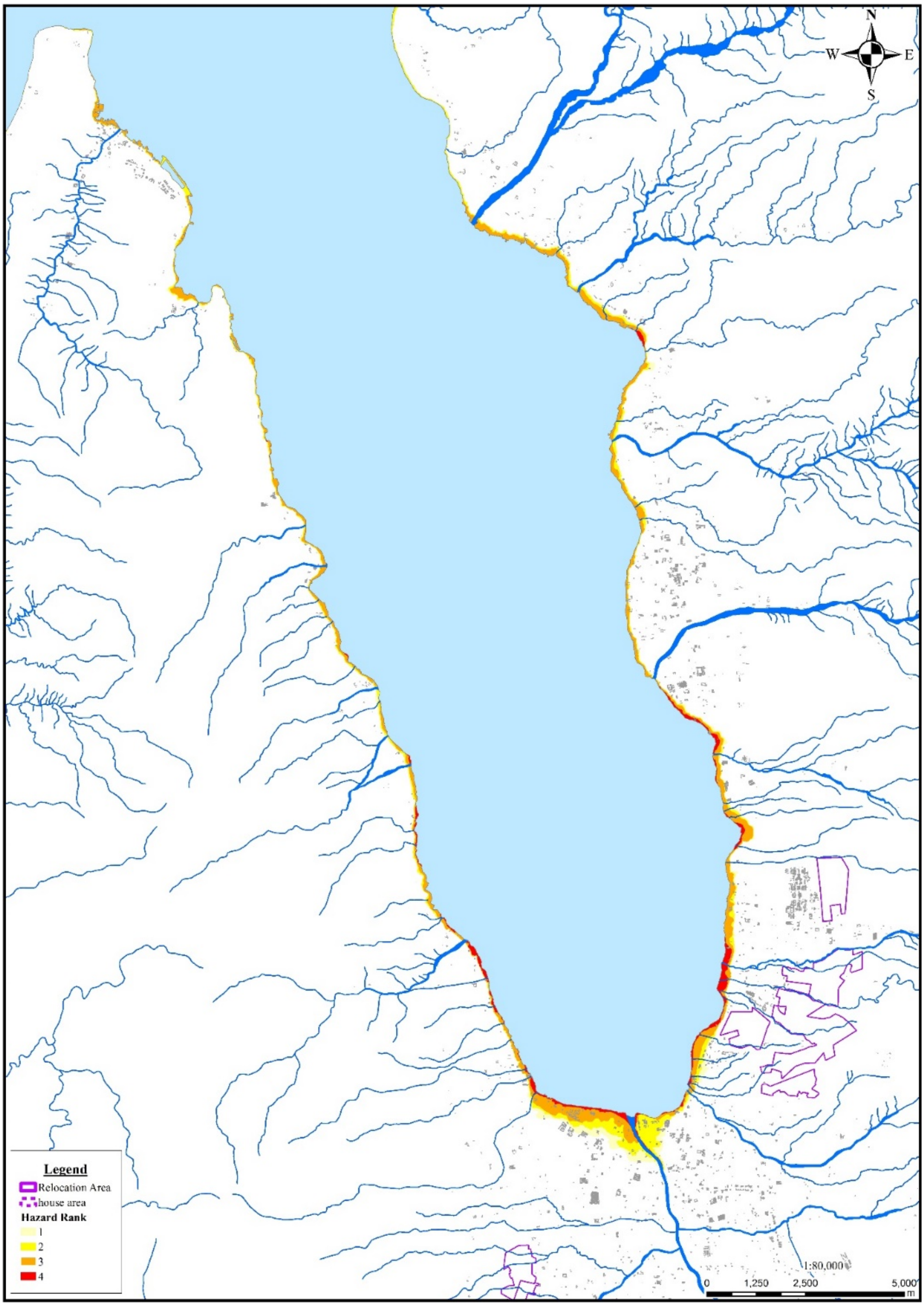


Source: BG

Figure 6-16 Tsunami Hazard Map by BG 2016

3） Tsunami hazard map combined with BG and JICA's hazard map

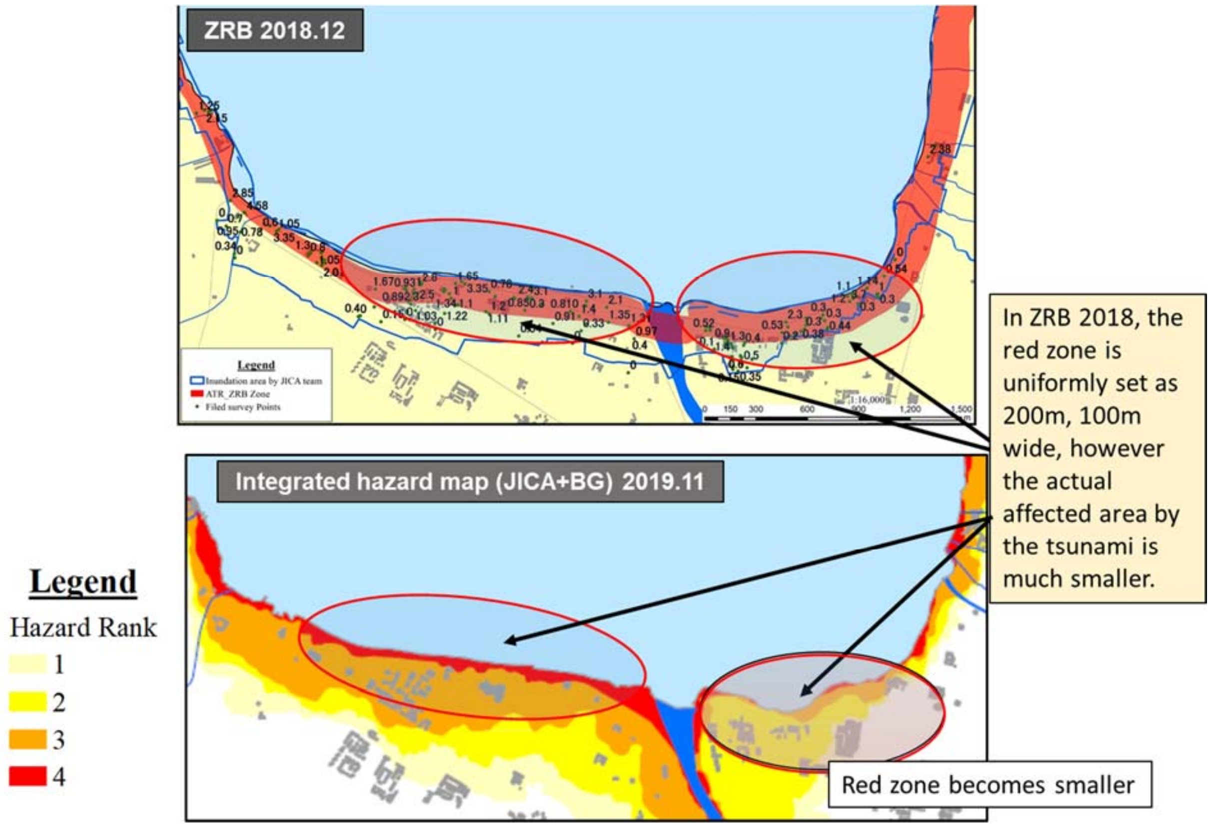
The final overlaid hazard map of the tsunami hazard map without mitigation measures prepared by JICA and tsunami hazard map prepared by BG in 2016 is shown below.



Source: JICA Expert and JICA Study Team

Figure 6-17 Final Refined Tsunami Hazard Map (whole area)

The following figure compares the ZRB4 (red) zone in the Palu bay between the ZRB by ATR Dec 2018 and tsunami hazard map by BG and JICA. In the ATR's ZRB 2018, the red zone is uniformly set as 200m or 100m wide from the coastal line. However the actual affected area (inundated area) by the tsunami 2018 is much smaller. In the BG and JICA's hazard map, the red zone becomes smaller than that of the ATR's ZRB.



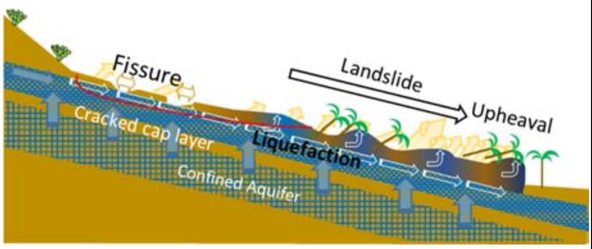
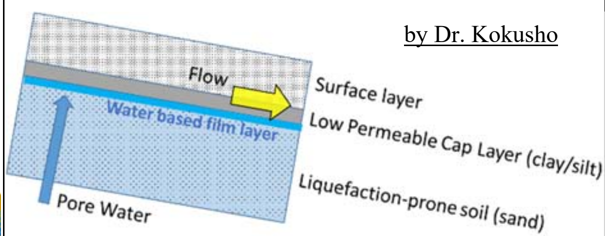
Source: JICA Expert and JICA Study Team

Figure 6-18 Comparison of ZRB4 zone in the Palu Bay

6-1-2 Nalodo

(1) Basic concept of hazard map preparation

Nalodo is a rare natural disaster where continuous academic research is required to understand its occurrence mechanism. Several hypotheses of the mechanism have been analysed by the Japanese Advisory Committee. In general, there are two possible mechanism of Nalodo, namely 1) the water film theory and 2) the water ejection from earth crust theory. For the first hypothesis, Emeritus Professor Kokusho (Chuo University) advocates the water film theory, where the water drained by liquefaction accumulates on the lower surface of a shallower impermeable layer. In this hypothesis, ground flow is generated by a formation of a thin layer with extremely low strength water film. For the second hypothesis, since there have been no cases of single liquefaction which generates a flow of several hundred meters or more in the inland area, a large amount of water was released from the deep underground, causing strong pressure and large amount of rising water. In this hypothesis, the formation of a water film was promoted and a long-distance flow of the ground was generated. As for the strong pressure of groundwater and large amount of rising water in the second hypothesis, the mechanism can be considered as: 1) the shallow layer was strongly liquefied and groundwater spouted out; 2) the shallow layer of pressured groundwater spouted out from the mountains and irrigation water behind the east and west; and 3) a strong pressure was generated and groundwater spouted out due to seismic motion and ground displacement on the submerged fault. However, although various ground surveys and analyses have been conducted, no conclusion has been reached due to the complexity of the phenomenon.

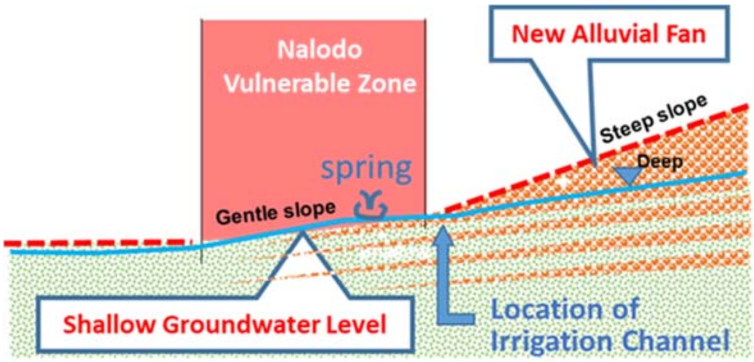
Water Ejection From Earth Crust Theory	Water Film Theory
	
1. Liquefaction near the surface occurred by seismic move and it reduced friction of lateral movement drastically, then major landslide along the slope occurred by gravity. 2. A prospective factor for sustaining the fluidized layer after the occurrence of ground flow. Simple calculations show that flood scale water generated on site during the landslide flow time (5-10 minutes) drained from the liquefied layer and continued to supply water to the fluidized layer or surface.	1. A low water permeable cap layer exists under the surface layer, consisting of clay and silt materials 2. In liquefaction, pore water could not go up across clay/silt, and the water would remain just below this low permeable cap layer and forms a “water film”. 3. As friction reduced drastically beneath the “water film”, the surface layer could move downward along slope freely by gravity.

Source: Prepared by JICA Experts, cited from Professor Kokusho’s Water Film Theory

Both the above theories commonly attribute the following five factors to the occurrence of Nalodo.

a) Shallow ground water level
b) Slope
c) Existence of a loose sandy soil layer
d) Existence of confined aquifer
e) Existence of law permeable cap layer

Note: a), c) are occurrence conditions and d), c) and b), e) are highly relevant



Source: Prepared by JICA Experts

Figure 6-19 Occurrence Conditions of Nalodo

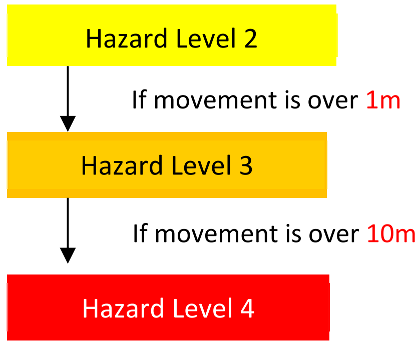
For the risk of liquefaction, recurrence at the same location is highly possible. While for the risk of Nalodo, if the surface cap layer is restored in about 100 years (recovery of paddy fields), Nalodo is likely to reoccur when all factors such as groundwater level condition, liquefied soil layer, slope, artesian water, etc., (① to ⑤ above) exist. In addition, liquefaction has high possibility to occur in the same area on the same scale because the route is the submerged fault where the deep sea water is ejected.

(2) Criteria of hazard level

1) Procedure on setting the hazard level

In the first step of the procedure for evaluating the hazard level of the area for reconstruction, hazard level 2 areas were estimated over a wide area based on the hypothesis of the generation mechanism described in section 1. Then, based on the actual damage caused by the current disaster, the areas with a higher hazard level of 3 and 4 were narrowed down.

Hazard Level	Phenomena
Hazard Level 2	If it meets both conditions below ; ・Shallow & pressured groundwater ・Easy-liquefied soil layer
Hazard Level 3	Nalodo is very rare disaster Original conditions of soil and ground water just before Nalodo have dismissed
Hazard Level 4	It will take more time to identify quantitative threshold from physical aspects on soil and ground water

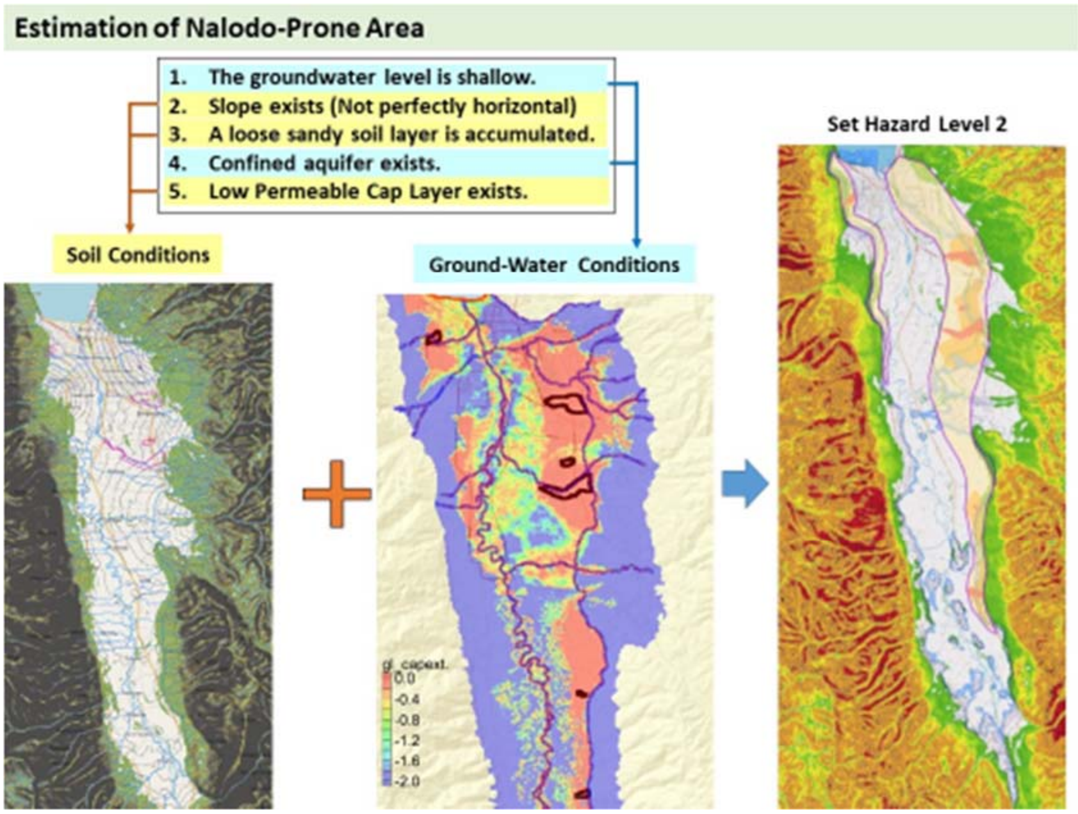


Source: JICA Experts and JICA Study Team

Figure 6-20 Method of Setting Hazard Level 3 and 4

2) Method on setting hazard level 2

The regions of hazard level 2 were set up over a wide area based on the hypothesis of Nalodo generation mechanism as summarized in (1). Regardless the hypothesis, the above mentioned items ① to ⑤ are common factors of the Nalodo occurrence.



Source: JICA Experts and JICA Study Team

Figure 6-21 Method of Setting Hazard Level 2

3) Method on setting hazard level 3 and 4

The ZRB map formulated by ATR in 2018 has set criteria focused on 1) density of liquefaction occurrences, 2) width of soil crack, 3) land subsidence, 4) horizontal displacement, and 5) distribution of undulating (wavy) land. On the other hand, the JICA Study Team conducted an on-site survey of geology, groundwater and analysis of existing data, and the committee discussed the hypotheses on the Nalodo mechanism. Scientific proof requires the continuation of academic research. Based on this situation, hazard level 4 and level 3 were set based on the actual large ground displacement occurrence with actual damages in the target area by field survey results. Hazard level 4 area was considered for relocation because there were many victims in the area where Nalodo occurred, many people were still missing, and the safety of the area where Nalodo occurred has not yet been confirmed. Hazard level 4 area is where Nalodo actually occurred in the disaster where lateral movement is more than 10m. Hazard level 3 was set for the area where the flow could be visually confirmed.

Table 6-6 Hazard Level Criteria of Nalodo (JICA)

Hazard Level	Phenomena	Outline of the zone
Hazard Level 4	If it meets all conditions High-speed fluid landslide Mudflow Lateral movement over 10 m or vertical movement over 1 m The area where human disaster occurred In addition, sliding prone area	Lateral movement occurrence area this time Sliding prone area
Hazard Level 3	If it meets all conditions in the actual disaster Lateral movement 1-10 m The area which did not reach human damage, but great damage occurred to farmland.	Creep deformation occurrence area this time
Hazard Level 2	If it meets both conditions below; ・Easy-liquefied soil layer ・Shallow & pressured groundwater	--
Hazard Level 1	Except for hazard level 4, 3, 2	--

Source: JICA Experts and JICA Study Team

Moreover, sliding occurred and steep cliffs formed in the uppermost stream of the Nalodo. Newly formed steep cliffs are often unstable and easily cause slides due to the influence of rainfall and/or earthquake. Therefore, this unstable cliff area in the uppermost stream of Nalodo was included in hazard level 4 based on survey result.

After consultation with the BG staff who prepared the 2018 Nalodo Hazard Map, we decided to adjust the levels and overlay the hazard level rating criteria of the BG-produced hazard map to align with the JICA-produced Nalodo Hazard Map criteria as follows.

BG's Nalodo hazard level 4 was set for the area where lateral movement can be visually confirmed that equivalent to hazard level 3 of JICA's evaluation. Hazard level 3 of BG was set for the area where small scale of liquefaction occurred that equivalent to hazard level 2 of JICA's evaluation. Hazard level 2 of BG was set for the area where small scale of liquefaction did not occurred that equivalent to hazard level 1 of JICA's evaluation.

Table 6-7 Integration of criteria between BG hazard level with JICA hazard map

BG's Criteria **JICA's criteria**

BG Original Colour	Criteria		JICA Adjusted colour
Hazard level 4 RED	High density of liquefaction occurrences (more than 25% per liquefaction location) Soil crack > 5 cm Land subsidence > 10 cm Horizontal displacement > 5 cm Widespread of undulating (wavy) land	Movement can be confirmed visually	Hazard level 3 Orange
Hazard level 3 Orange	Localized liquefaction (spot per spot) Soil crack < 5 cm Land subsidence < 10 cm Horizontal displacement < 5 cm Undulating (wavy) land could be occurred	Small scale of movement can be confirmed	Hazard level 2 Yellow
Hazard level 2 Yellow	No liquefaction Soil crack < 1 cm No Land subsidence No Horizontal displacement No Undulating (wavy) land		Hazard level 1 No colour

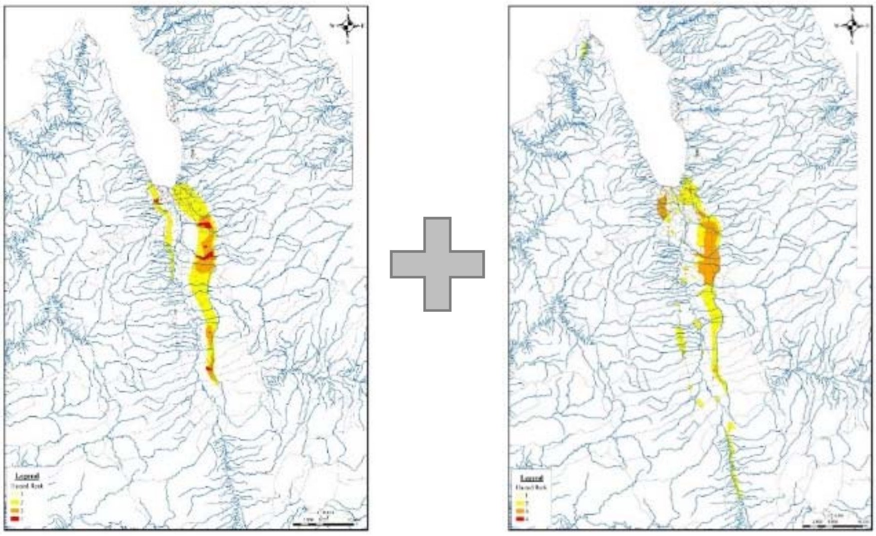
Source: Prepared by JICA Experts based on BG's data

When overlaying the final hazard level (the BG's map after adjusting criteria and JICA's map), the higher hazard level would be used.

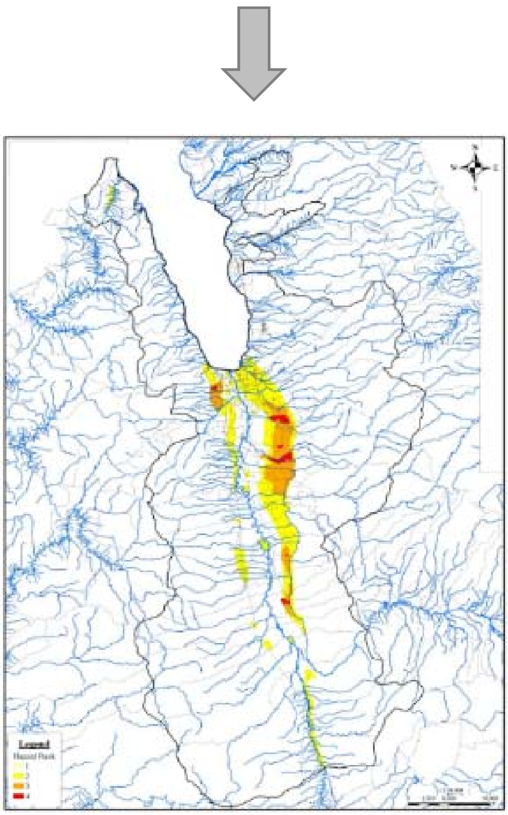
(3) Nalodo hazard map after the refinement

The final Nalodo hazard map was obtained by overlaying the JICA's Nalodo hazard map and the BG's 2018 Nalodo hazard map. This final map is presented below.

JICA hazard map **JICA criteria applied BG hazard map**



Integration of BG hazard map and JICA hazard map



Source: Prepared by JICA Experts and JICA Study Team

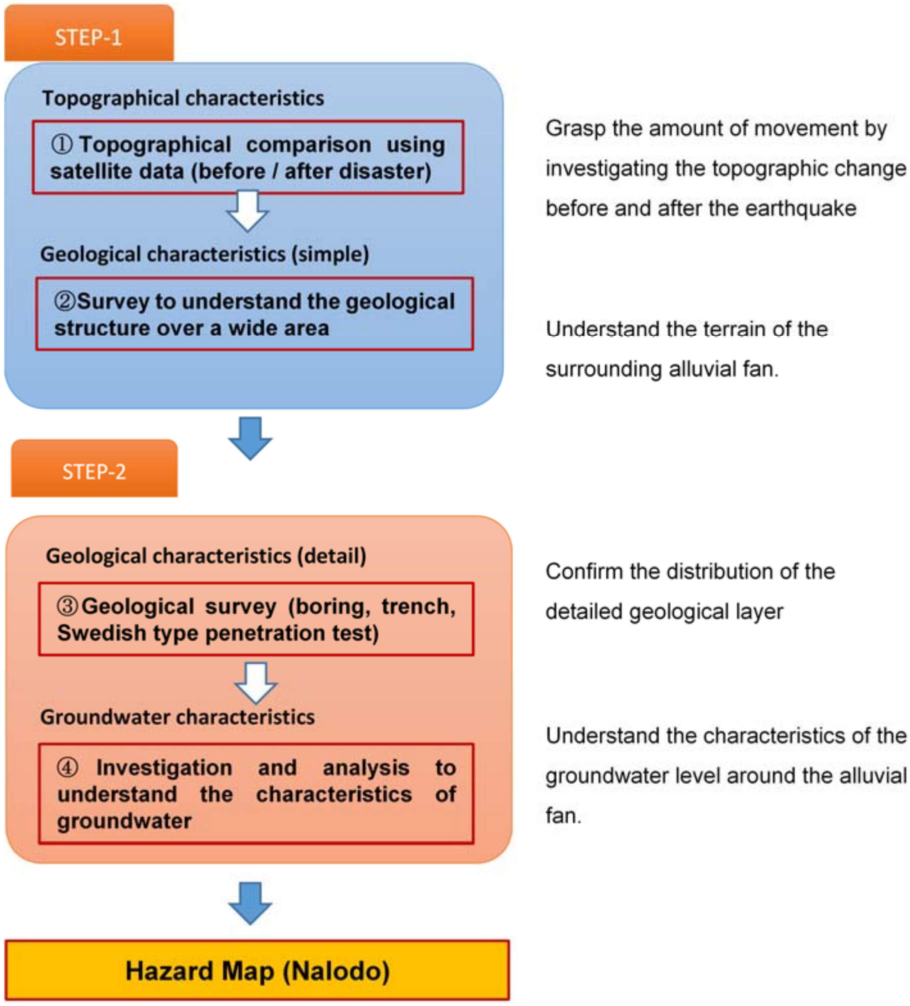
Figure 6-22 Nalodo Hazard Map

The refinement of Nalodo hazard map under the time constraint of the project was completed and submitted to the Indonesian authorities. However, the mechanism and factors of Nalodo occurrence remained unclear. Further scientific studies on the distribution of liquefied layers and the location of excess pore pressure should be carried out to establish more accurate hazard areas in the future.

(4) Methodology of Nalodo Hazard Map

The earthquake that occurred in September 2018 had caused Nalodo (large-scale liquefied landslide) disaster. It is highly necessary to investigate the mechanism of Nalodo in order to create the Nalodo hazard map, however it takes a long time to complete the necessary research to understand the mechanism. While there is only limited time for assessment, it was decided to set the hazard level according to the actual damages directly affected by the disaster occurred in September 2018 to produce the hazard map refined from the ATR's hazard map issued in December, 2018. Therefore, this Nalodo hazard map should be treated as a reference.

According to the survey results accumulated so far, the characteristics of the affected area (geographical, geological, ground water condition (overpressure), land use, etc.) have been clarified to some extent after the Nalodo occurrence. In order to effectively conduct the preparation of hazard map, first of all extraction of "hazard level-2" areas based on the geographical and geological data including underground water condition has been implemented to set up the basis of Nalodo hazard map. Secondary identifying "hazard level-3 and 4" areas has been made based on the actual disaster based ground movement, since there is no sufficient time to conduct more scientific mechanism analysis. The hazard map preparation flow is shown as follows.



Source: JICA Expert and JICA Study Team

Figure 6-23 Workflow for Preparation of Nalodo Hazard Map

In the end JICA Study Team and Badan Geologi (BG) have discussed and agreed to submit the refined hazard map to ATR together. In this regard, two hazard maps prepared by both JICA Study Team and BG are superimposed to make a final map.

1) Setting up Nalodo Hazard Level

The Nalodo hazard level has been set in level-1 through level-4. Level-1 and level-2 areas are set based on the existing geographical and geological data of the target area, however the boundary between level-1 and level-2 is not clearly defined. Level-3 and velel-4 areas are set based on the actual ground movement identified by the image comparison between before and after of disaster occurrence and this should be judged by satellite photo analysis, actual field survey, etc.

The level-1 and level-2 areas (mainly level-2 area) are set first, then the level-3 and level-4 areas are identified to complete the hazard map.

a） Identifying Hazard Level- 2 Areas

The area of hazard level 2 was set in consideration of the following two conditions by utilizing existing data.

- Groundwater conditions (spring water area and groundwater level)
- Topographical conditions (ground slope less than 2°)

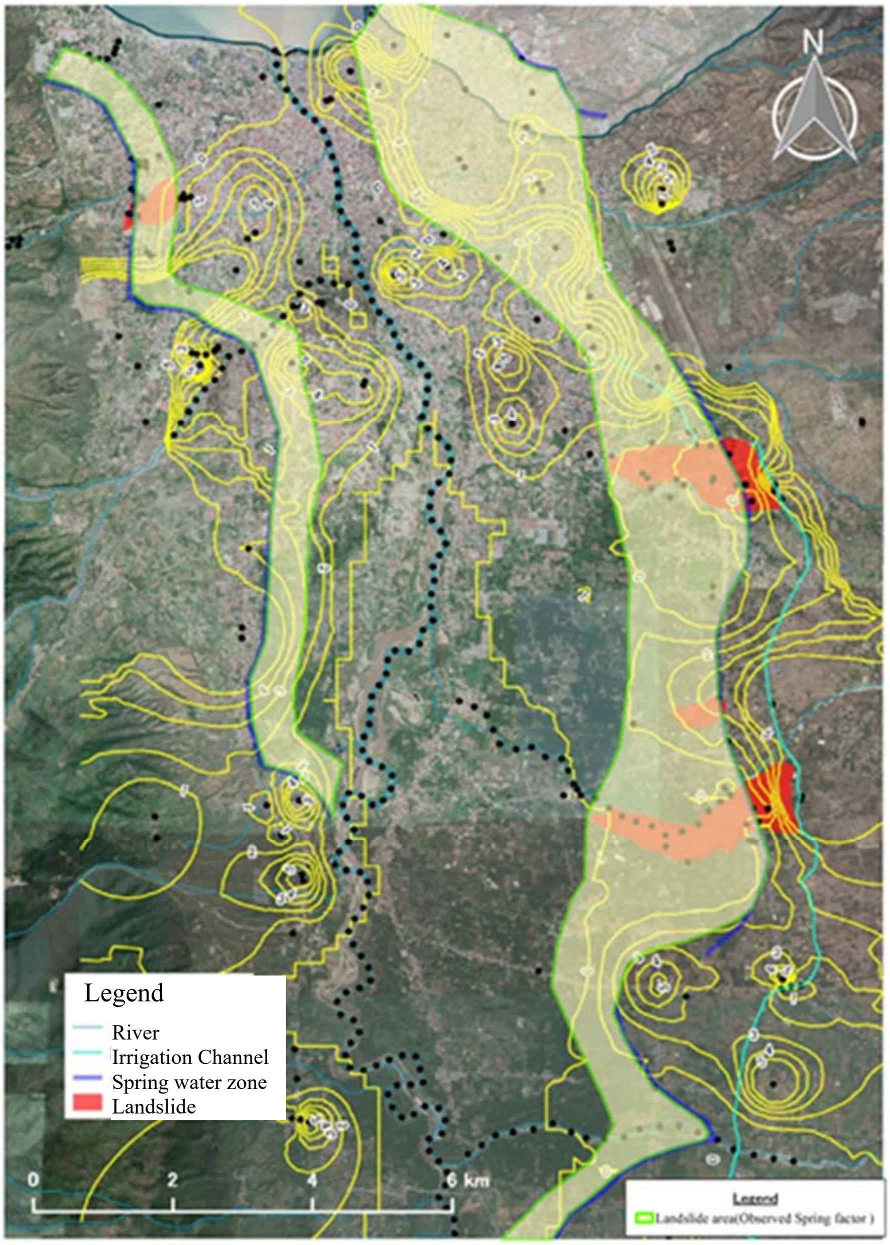
In order to clarify the boundary (between hazard level-2 and level-1) as much as possible, a spring water zones, etc. are located by the present groundwater investigation (borehole testing and spring water investigation), and simulation is carried out based on the information to set boundaries.

Note: Land use conditions (presence of water non-permeable layer) is not considered in setting the area of hazard level-2 because a wide range of borehole testing data is required. Distribution of liquefiable layer is not considered in setting the range of hazard level-2, because it also requires a wide range of borehole testing data.

✓ **Groundwater condition analysis (spring water area and groundwater level)**

<u>Groundwater investigation</u>

Groundwater data was obtained by borehole soil investigation data from the past and by related organizations.



Source: JICA Expert and JICA Study Team

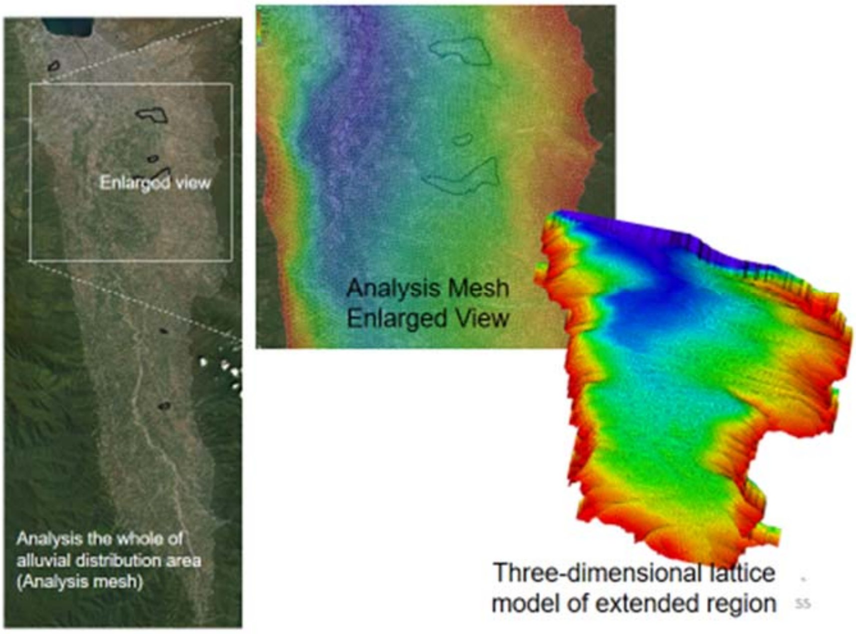
Figure 6-24 Estimation of Area Groundwater Distribution by Groundwater Analysis (MODOFLOW)

<u>Groundwater Analysis of Target Area</u>

By analysing groundwater under the alluvial fan, the distribution of groundwater of the fan and the location of water spring zone are confirmed.

In this study, MODFLOW-USG / MODFLOW-NWT is used for groundwater analysis, which is one of the most popular analysis programs developed and released by the US Geological Survey authority.

In addition, groundwater system and structure is examined by using a modeling system namely GMS (Groundwater Modelling System, Aquaveo) that can quickly and effectively reflect various measures to modeling.



Source: JICA Expert and JICA Study Team

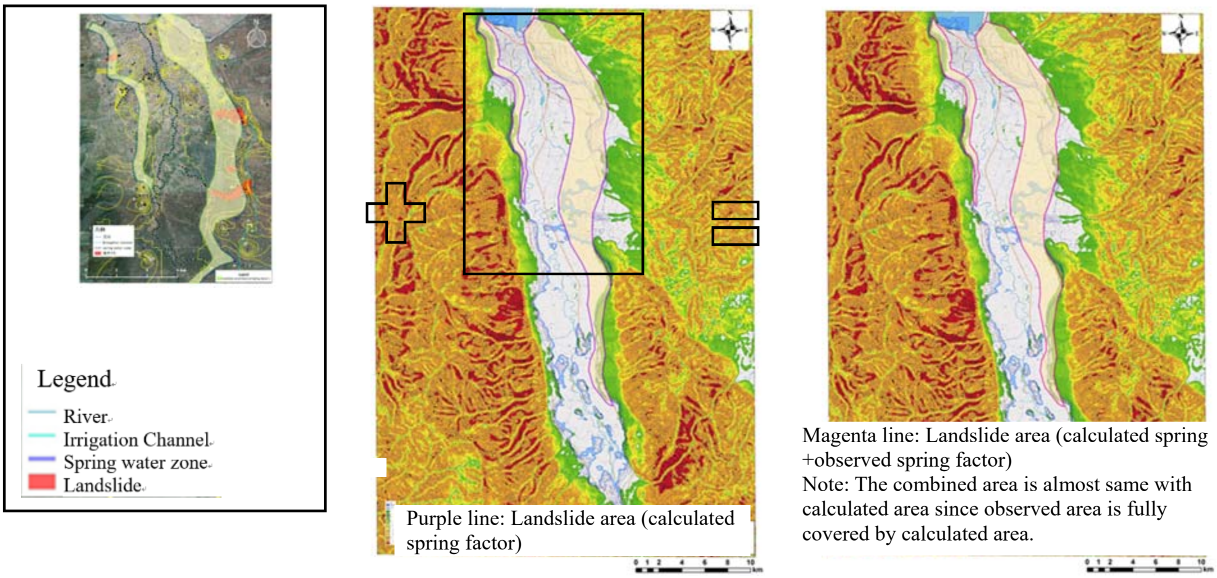
Figure 6-25 Analysis of Whole Alluvial Distribution Area and Three-dimensional Lattice Model

The water spring area results obtained from the groundwater analysis is shown below.

Source: JICA Expert and JICA Study Team

Figure 6-26 Distribution of Water Spring Areas

The groundwater level condition should be analysed based on the results of water spring zone survey conducted in the field and the result of simplified groundwater analysis including model. According to this procedure, the areas, where the groundwater level is near the ground surface and the groundwater may be pressurized is located on the area map.



① Hazard area (Observed Spring factor)

② Hazard area (Calculated Spring factor)

③ Hazard area (Observed + Calculated Spring factor)

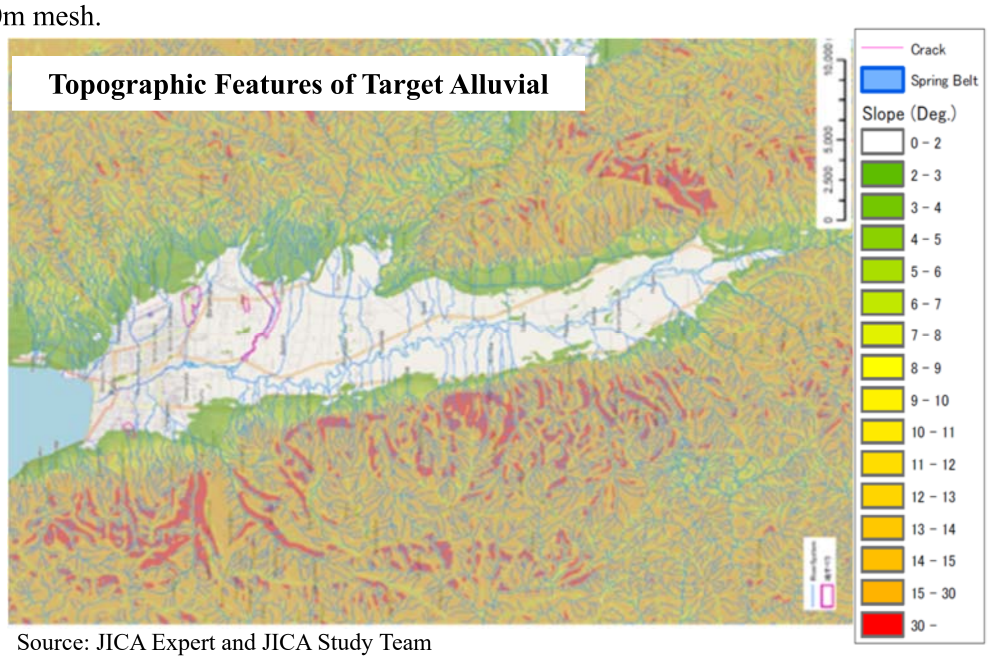
Source: JICA Expert and JICA Study Team

Figure 6-27 Area Map of Pressured Groundwater near the Ground Surface

✓ **Topographical condition analysis**

Topographical Characteristics of Target Area

The topographical characteristics of the whole alluvial fan is grasped using the satellite imagery data at 30m mesh.



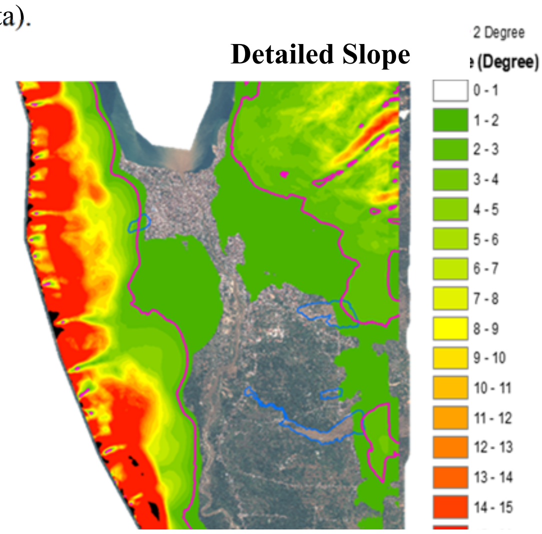
Source: JICA Expert and JICA Study Team

Figure 6-28 Satellite Topography DEM Data (2m mesh DEM data used)

In particular, for areas where the damage was severe, detailed topography characteristics were grasped using 2m mesh DEM data (satellite topography DEM data).

In case of Sulawesi, it was confirmed that the occurrence point of Nalodo (trigger point) is a slope of about 1° to 2 ° (Refer to the right figure).

Nalodo is likely to be triggered where there is a spring of groundwater, a liquefiable layer (sandy soil, for instance) and a cap layer.



Source: JICA Expert and JICA Study Team

Geological Characteristics of Target Area (presence of liquefiable layers)

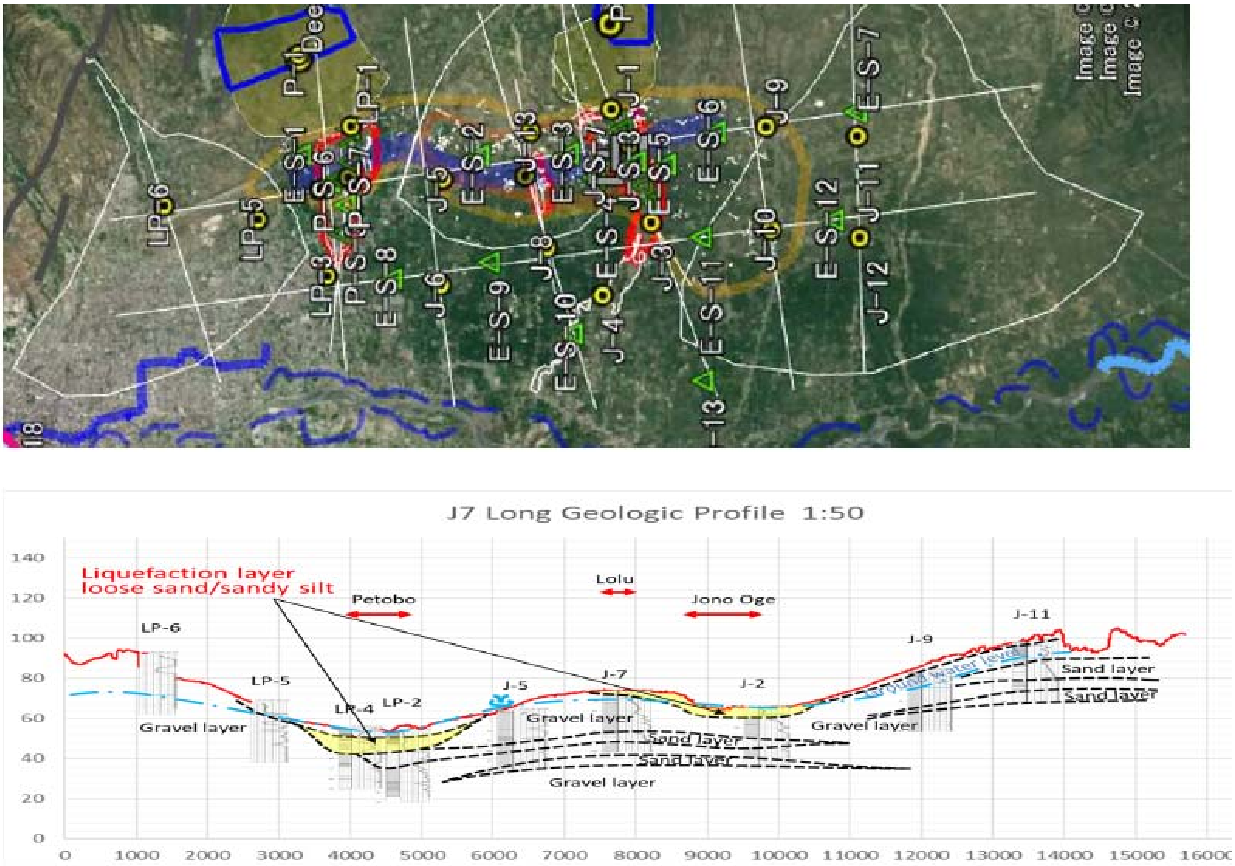
- Conduct of borehole soil investigation

- Collection of borehole testing data of the past and related organizations

Geological survey (i.e.: borehole testing, trench inspection, Swedish type penetration testing) should be conducted in order to confirm the distribution of the detailed geological layer such as distribution of liquefiable layers (soft layers), conditions of surface layer and distribution of spring zones.

By conducting these surveys, topographical and geological characteristics of the area could be analyzed to identify where a Nalodo could possibly occurs (distribution of liquefiable layers) and where the impounding of groundwater (high pressured groundwater) exists.

In areas other than the geological survey this time, since the presence or absence of the liquefaction layer is not clear, it is set here that the liquefaction layer is present at the tip of the fan.



Source: JICA Expert and JICA Study Team

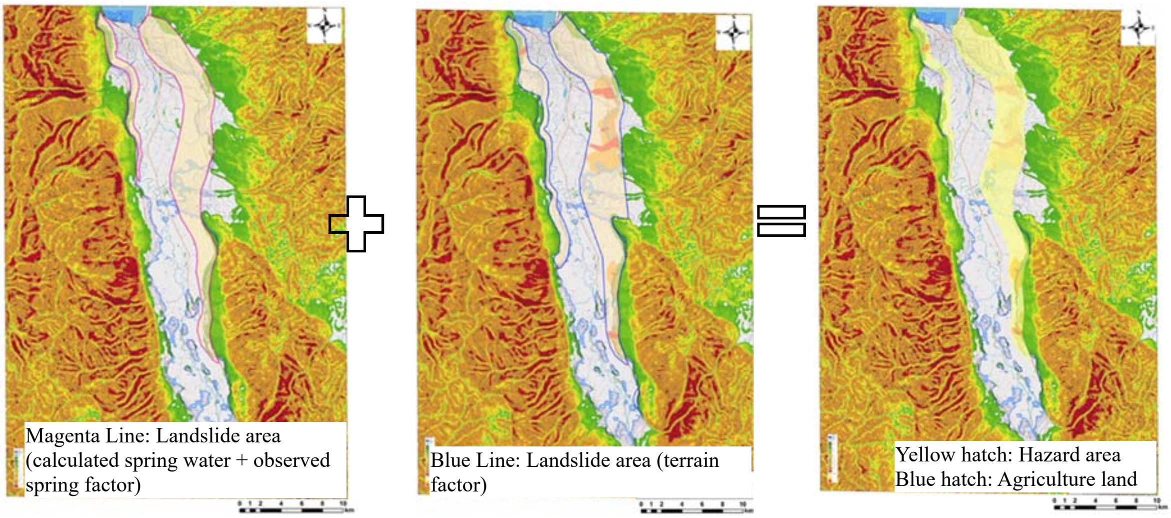
Figure 6-29 Geological Survey Points and Sample of Result

Source: JICA Expert and JICA Study Team

Figure 6-30 Distribution of Liquefiable Layers

✓ **Setting of hazard level-2 area based on groundwater level and topography conditions (Examination based on groundwater level and topography conditions)**

Based on the above ground water level and topographic conditions, the area, in which higher groundwater level and ground slope around 2° are both identified, should be set as the hazard level-2 areas. As a result, hazard level-2 map is made as per shown in Figure 6-32.



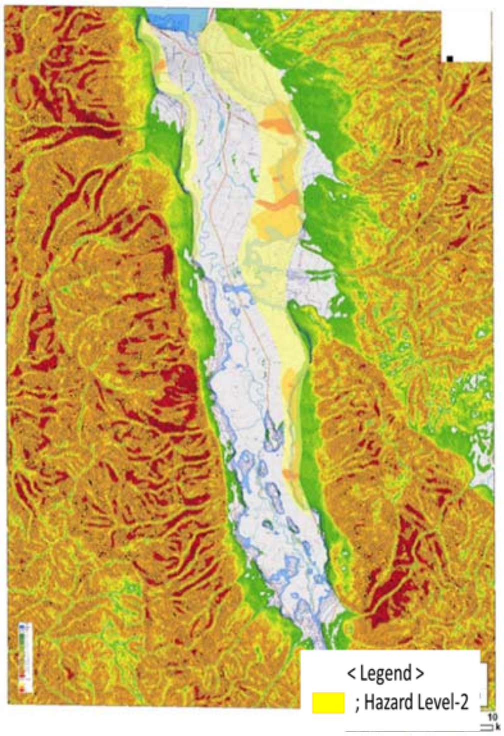
① Hazard area (Observed + Calculated Spring factor)

② Hazard area (Geological factor)

① + ② Hazard area for hazard level 2

Figure 6-31 Hazard level-2 Area

Source: JICA Expert and JICA Study Team
Note: In short, the designated areas may be damaged by Nalodo or similar disaster in the future based on the geographical characteristics and groundwater conditions, although there was no damage in the earthquake 2018.



Source: JICA Expert and JICA Study Team

Figure 6-32 Hazard level-2 Map

b) Identifying Hazard Level-4 and level-3 Areas

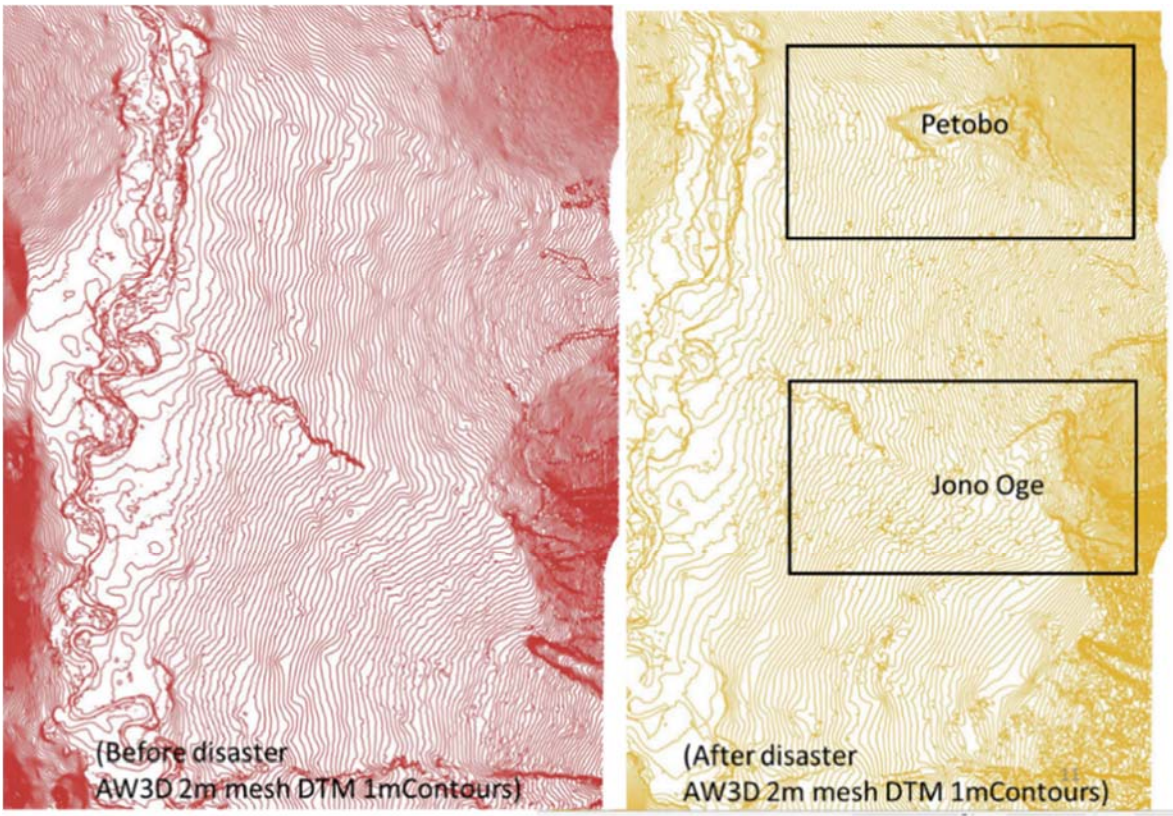
Hazard level-4 and level-3 are set based on the actual large ground displacement occurrence with actual damages in the target area.

Table 6-8 Conditions of Nalodo Occurrence

Hazard Level	Phenomena	Outline of the zone
Hazard Level 4	If it meets all conditions • High-speed fluid landslide • Mudflow • Movement over 10m (The area where human disaster occurred.)	Lateral movement occurrence area this time
Hazard Level 3	Latera movement 1~10m (The area which did not reach human damage, but great damage occurred to farmland.)	Creep deformation occurrence area this time

Source: JICA Expert and JICA Study Team

The method used is to measure the amount of displacement of the ground using satellite photographs and topographical data before and after the earthquake. Targeting the place where Nalodo occurred, topographical comparison using satellite data (before / after disaster) is shown below.

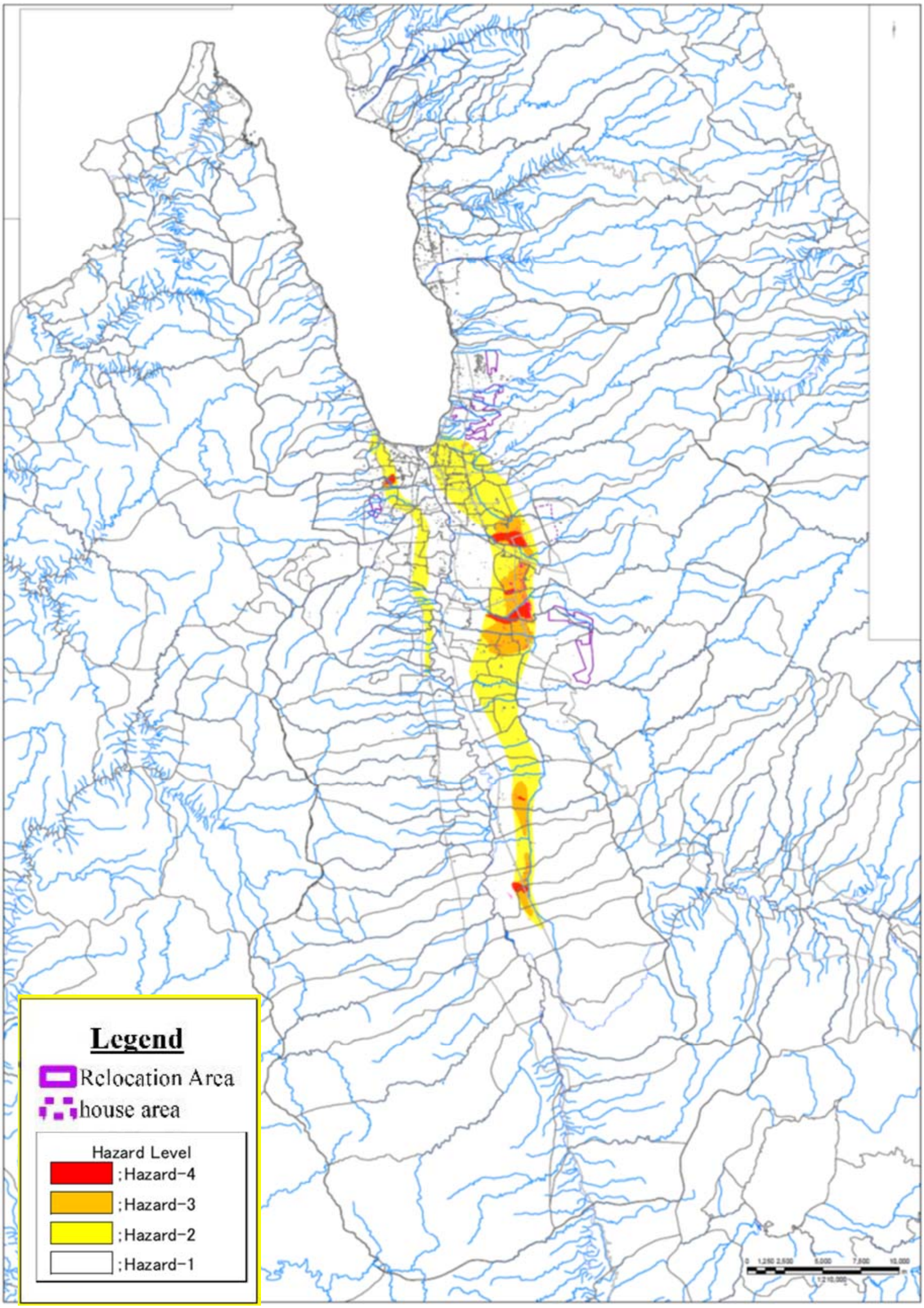


Source: JICA Expert and JICA Study Team

Figure 6-33 Topographic Comparison of Place affected by Nalodo (East area)

c) Setting the hazard level

The refined hazard map based on the above examination results is shown below.

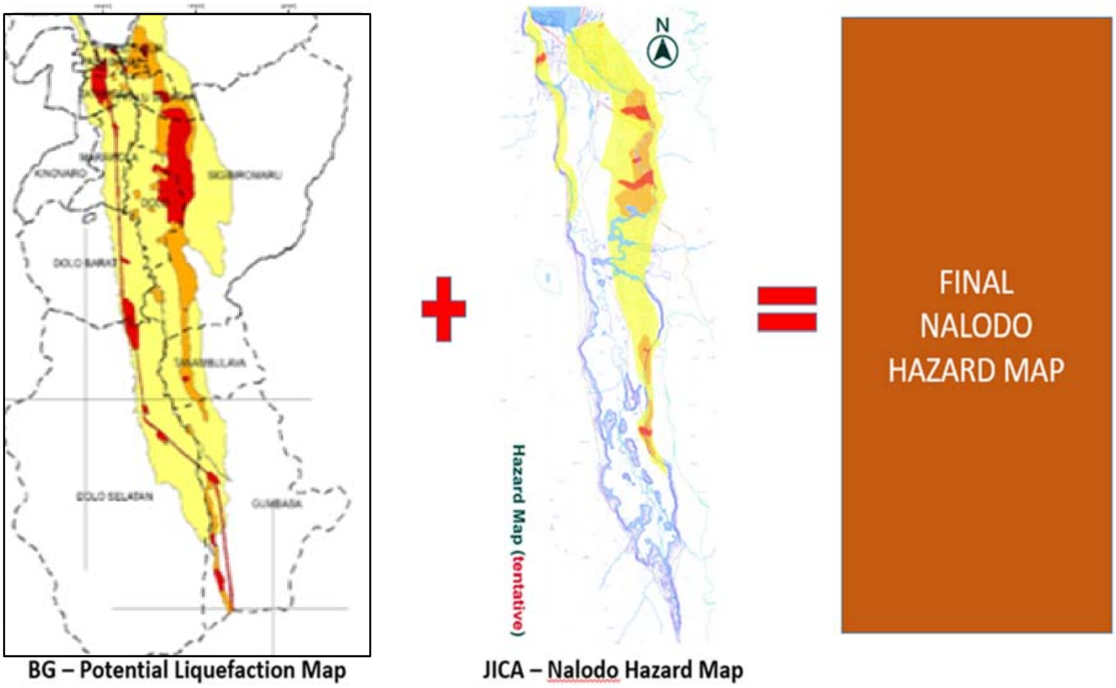


Source: JICA Expert and JICA Study Team

Figure 6-34 Refined Hazard Map for Nalodo

2) Finalization of Hazard Maps by converting maps prepared by JICA Study Team (JICA Study Team) and by Badan Geologi (BG)

JICA Study Team and BG have discussed and agreed to submit the refined hazard map to ATR together. In this regard, two hazard maps prepared by both JICA Study Team and BG are superimposed to make a final map. Both hazard maps prepared by BG and JICA Study Team are shown below.

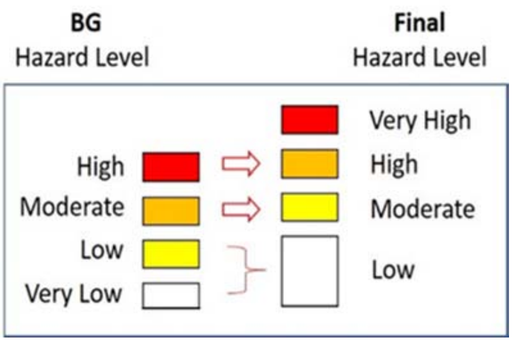


Source: JICA Expert and JICA Study Team

Figure 6-35 Refined Hazard Map for Nalodo

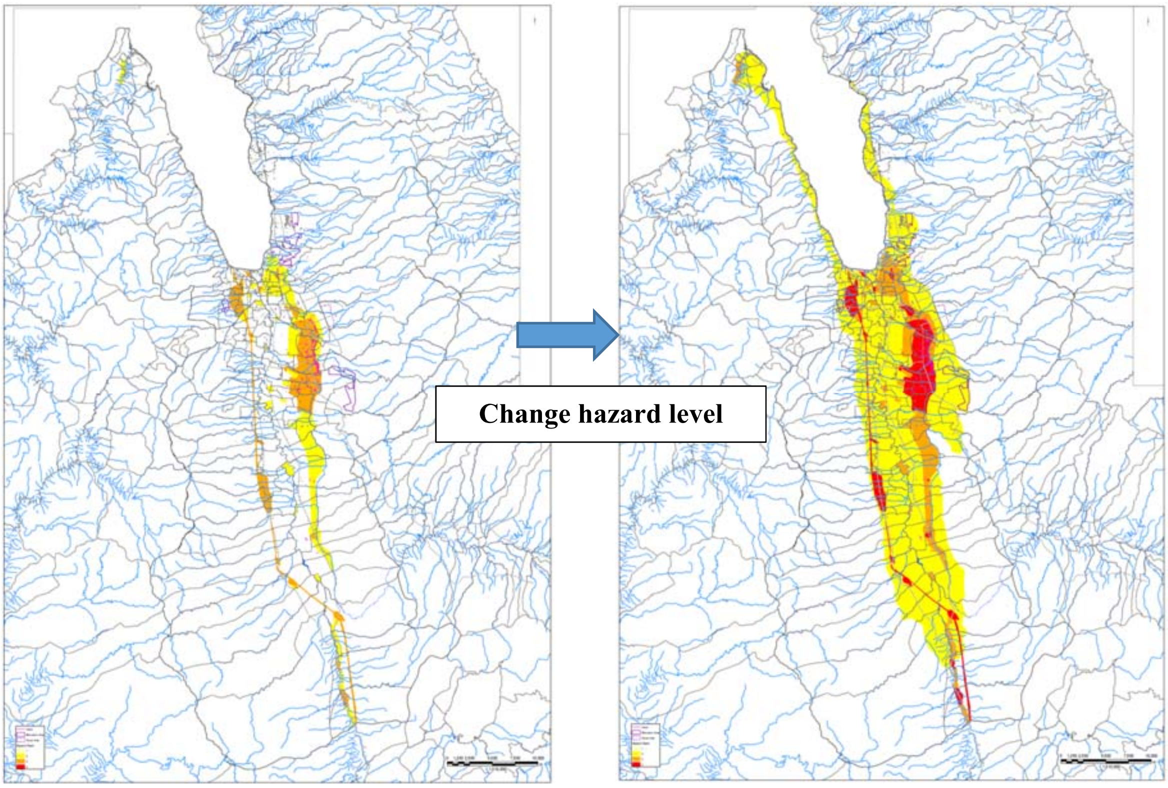
a) Review of hazard level

It is also agreed that the final disaster hazard and safety criteria shall be set with reference to JICA's evaluation criteria (four categories) also as shown below, while the hazard evaluation of BG is classified into three categories. The hazard level of BG basically consists of three categories, namely; "high", "moderate" and "low". The hazard level of Nalodo hazard map created by BG has been lowered by one level.



Source: JICA Expert and JICA Study Team

Figure 6-36 Categorization of Hazard Level

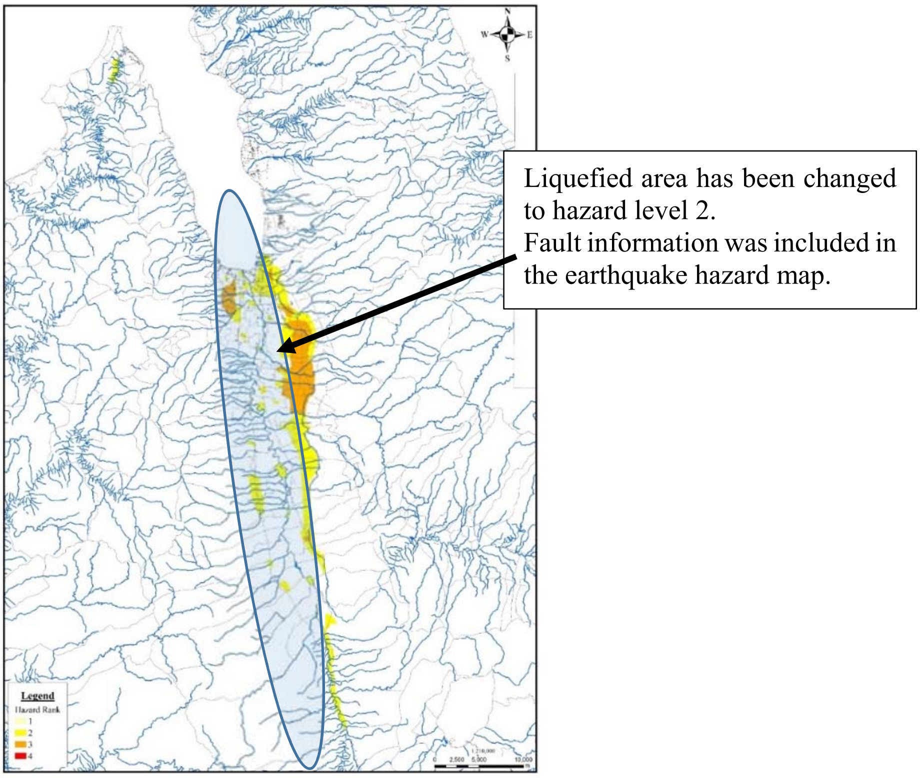


Initial BG hazard map　　　　　　BG hazard map with JICA's criteria applied (1)

Source: JICA Expert and JICA Study Team

Figure 6-37　Categorization of Hazard Level

Finally, since the hazard map of BG contained information on the fault and information on the liquefaction area (the Pal River left bank side), that information was deleted and finalized.

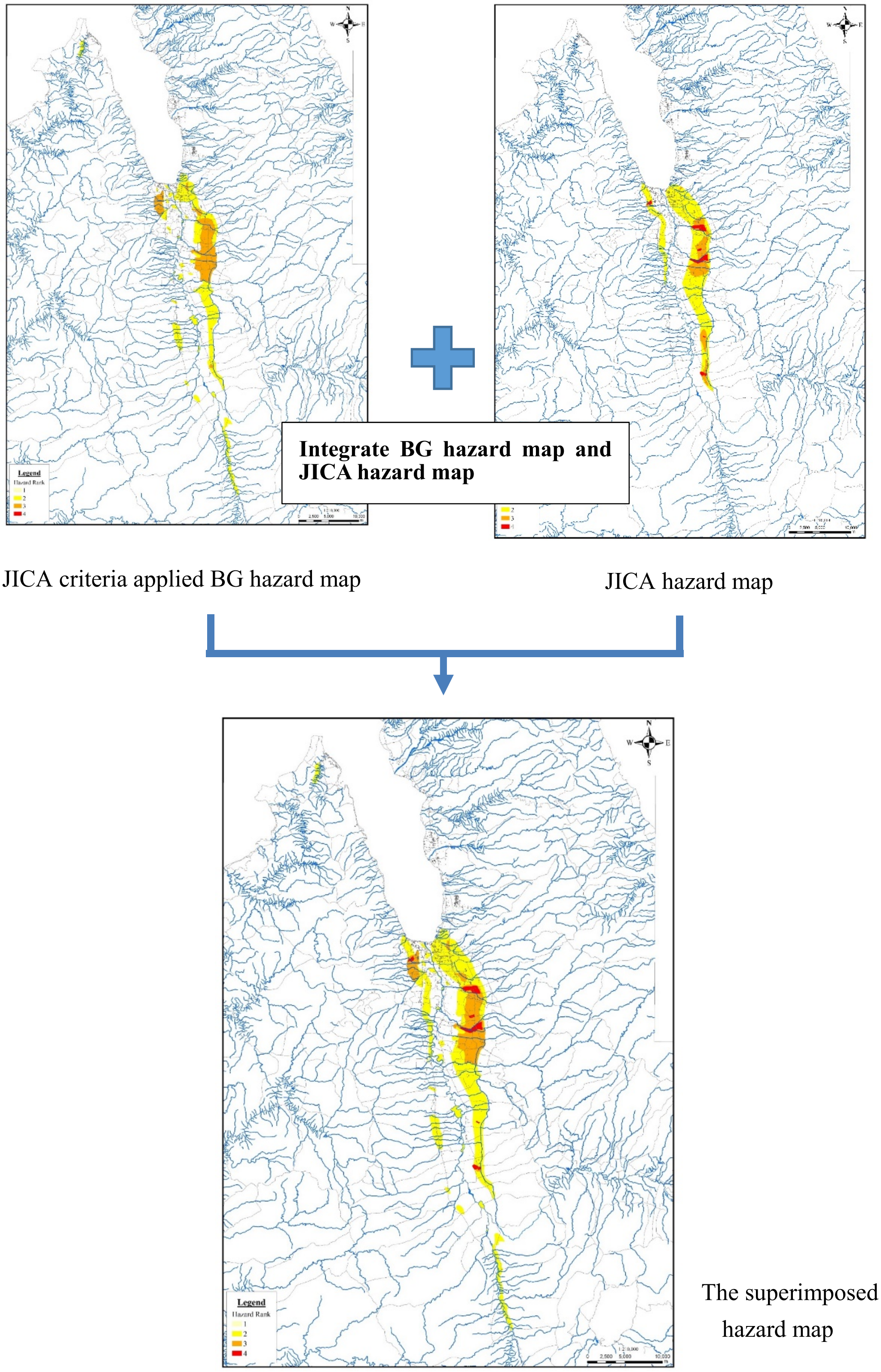


Source: JICA Expert and JICA Study Team

Figure 6-38　BG Hazard Map with JICA Criteria Applied

b) Combine Hazard Map

The Nalodo hazard map created by JICA Study Team and the BG's Nalodo hazard map after adjusting the hazard level are combined and finalized.

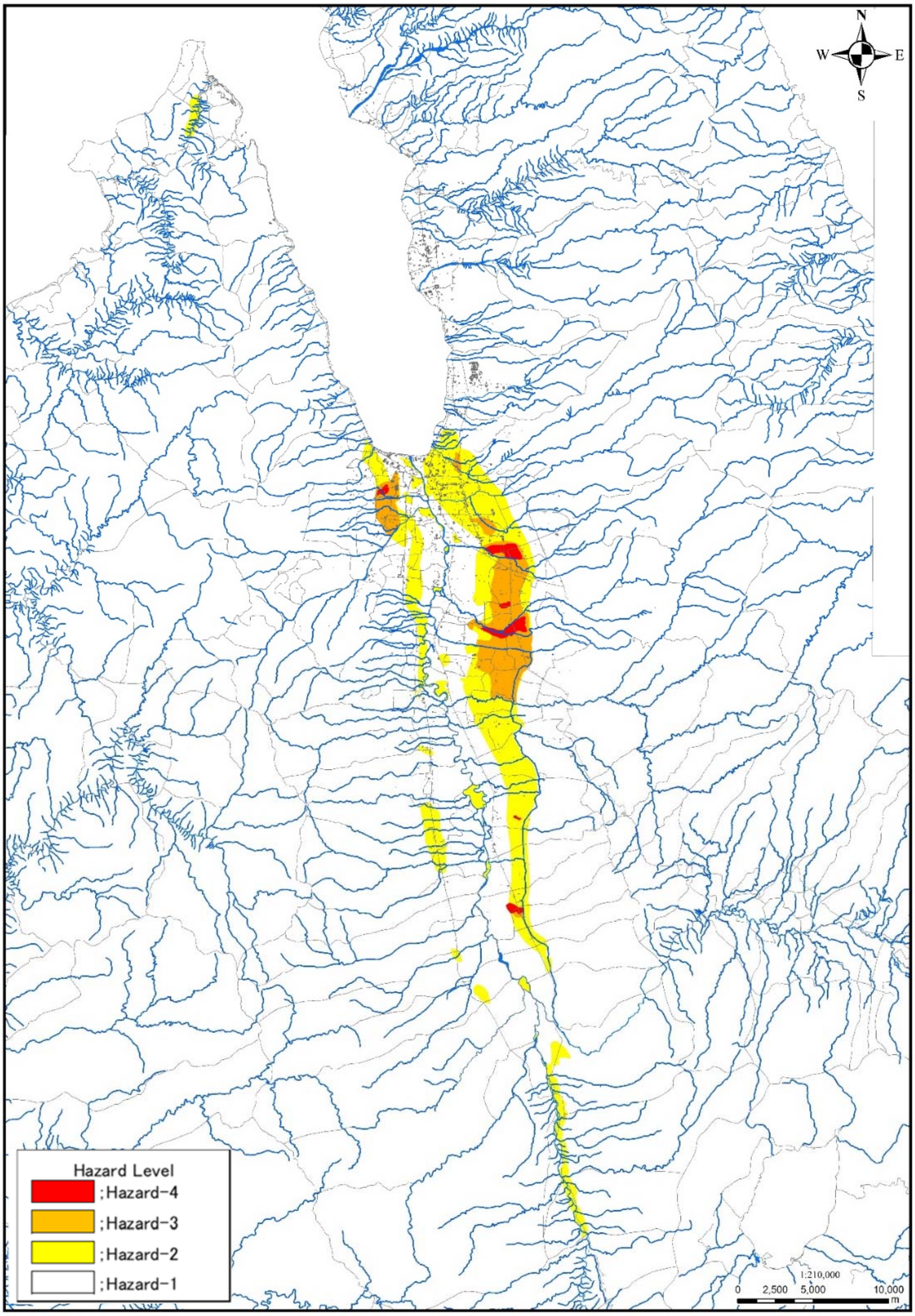


Source: JICA Expert and JICA Study Team

Figure 6-39 Overlaid Nalodo Hazard Map

c）Final Hazard Map

The finalized Nalodo Hazard Map integrating BG's and JICA Study Team's maps is shown below.



Source: JICA Expert and JICA Study Team

Figure 6-40 Final Nalodo Hazard Map

6-1-3 Seismic (Fault)

(1) Basic concept of hazard map preparation

Direct seismic hazard is divided into two types: (i) ground surface deformation due to fault rupture and (ii) ground surface motion. The former, ground surface deformation due to fault rupture, happens depending on the fault depth, scale of rupture, etc., and the occurrence of this type is mainly limited to places along the fault line. As for the latter, ground surface motion shows the characteristics of shaking on the ground surface due to soil conditions in places, and the trends of influence is difficult to understand uniformly. This due to the extent of the influence is hardly related to the natural period depending on the distance to the epicenter and the rigidity and height of the building.

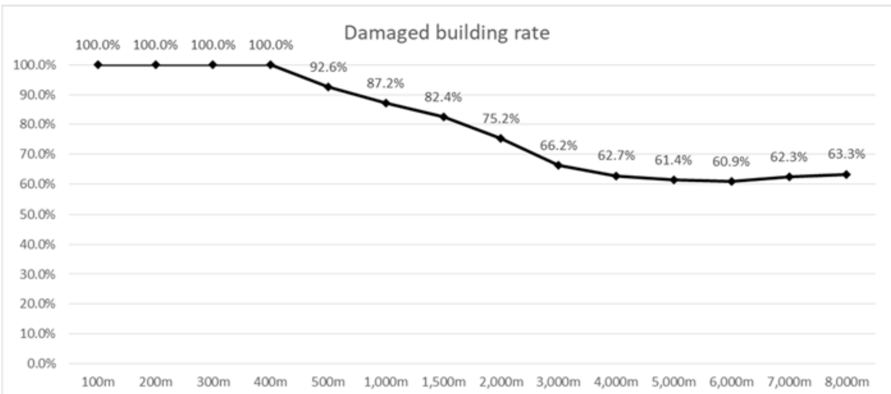
In principal, JICA Study Team follows the methodology of the ZRB map 2018 by ATR which had been created by evaluating and setting up hazard areas along the fault line focusing on ground surface deformation due to fault rupture.

(2) Criteria of hazard level

The target of the seismic hazard assessment was only along the Palu-Koro fault line that was moved by the earthquake and is a major active fault identified in Palu. The coordinates of the fault line were provided by ATR.

Although ZRB4 area in ZRB 2018 by ATR is a 10 m buffer of both sides from the centerline of the active fault, about 38% of the buildings located in the ZRB4 area experienced no damage according to the results of the building damage survey conducted by the JICA Study Team. In the ZRB3, which is 10 m to 50 m of both sides of the active fault, is assumed that the deformation energy become smaller the area away the fault line and the damage to the building become smaller.

The PGA map prepared by BMKG indicated that seismic motion in northern area along to the fault line is comparatively stronger than southern area. JICA Study Team accumulated the percentage of the damaged building among existed building along the Palu-Koro fault line 10 m buffer by each distance from the coast and realized that 100% of the existed buildings were seriously damaged until 400 m from the coast, as shown below.



Source: JICA Experts and JICA Study Team

Figure 6-41 Damaged building rate by each distance from coast

Therefore, the JICA Study Team set the hazard level of the seismic hazard map as hazard level 4 within the 10 m of both side from the Palu Koro fault line from Palu bay coast to 400 m. While hazard level 3 is within 10 m of both side from the Palu-Koro fault line in the southern area than 400 m from Palu bay coast. Further, the hazard level 2 is 10-50 m of both side from the fault line. These are summarized below as criteria.

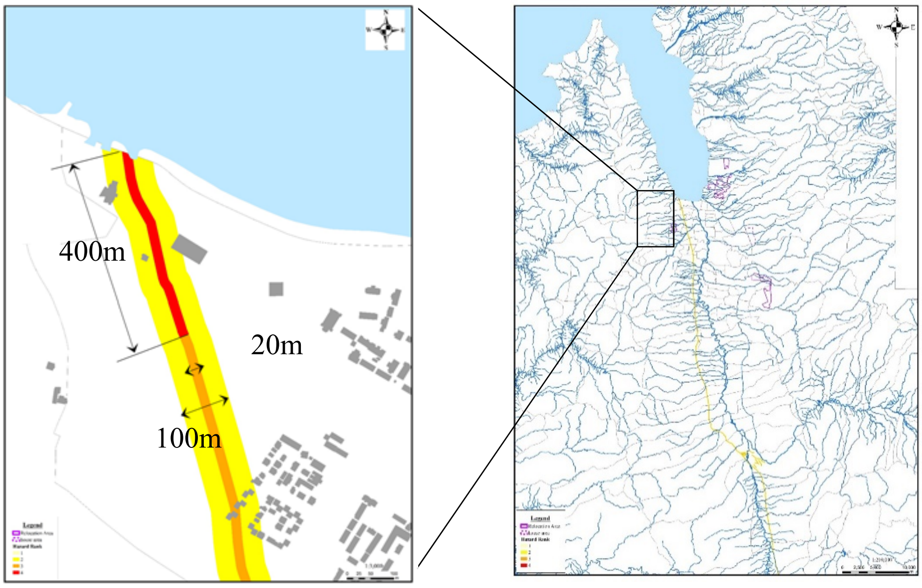
Hazard Level 4	"Within 10m of both side from the Palu Koro fault line from Palu bay coast to 400m"
Hazard Level 3	"Within 10m of both side from the Palu-Koro fault line in the southern area than 400m from Palu bay coast"
Hazard Level 2	"10m – 50m of both side from the fault line"

Source: JICA Experts and JICA Study Team

Figure 6-42 Criteria of Seismic hazard level

(3) Seismic hazard map after the refinement

Based on the above criteria, seismic hazard map is shown below.

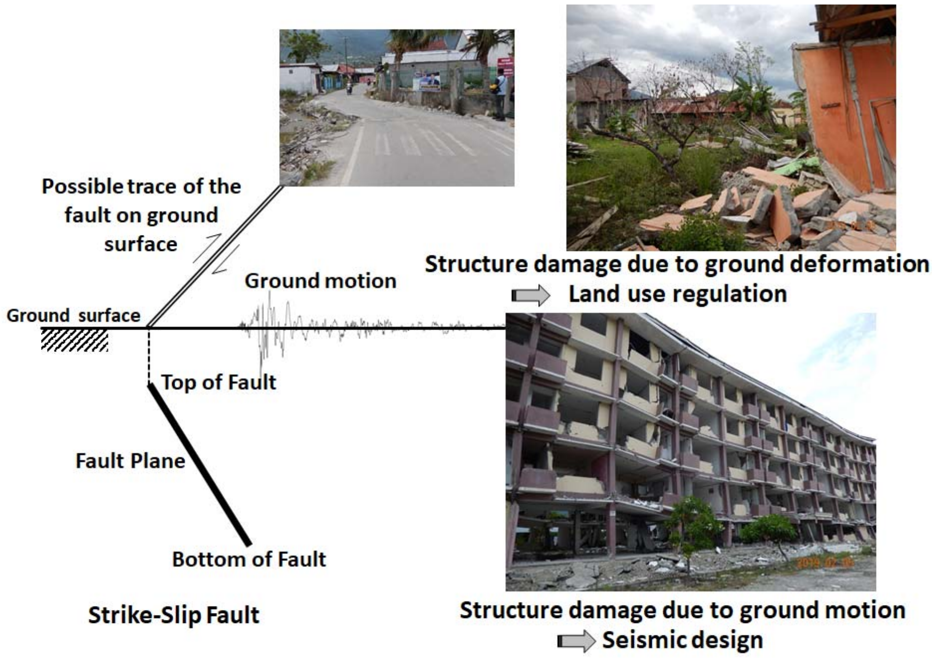


Source: JICA Experts and JICA Study Team

Figure 6-43 Seismic Hazard Map for Palu Koro Active Fault

(4) Methodology of Hazard Map

Direct seismic hazard is divided into two types: (i) ground surface deformation due to fault rupture and (ii) ground surface motion. The former, ground surface deformation due to fault rupture, may happen depending on the fault depth, scale of rupture, etc., and the occurrence of this type is mainly limited to places along the fault line. Structure damage due to ground deformation is difficult to be reduced by structural measures because of the tremendous force which causes deformation. In this regard, the recommended method to reduce disaster risk of ground deformation is to limit land use by land use regulations. As for the latter, ground surface motion, it could affect a large area and the degree varies depending on the distance to the epicenter and local soil condition. The common practice to deal with seismic hazard of ground motion is to implement seismic design. In Indonesia, the existing seismic design standard is the Seismic Resistance Design Standard for Buildings SNI 1726-2012 and it is under revision. The two types of seismic hazard are illustrated in the figure below.

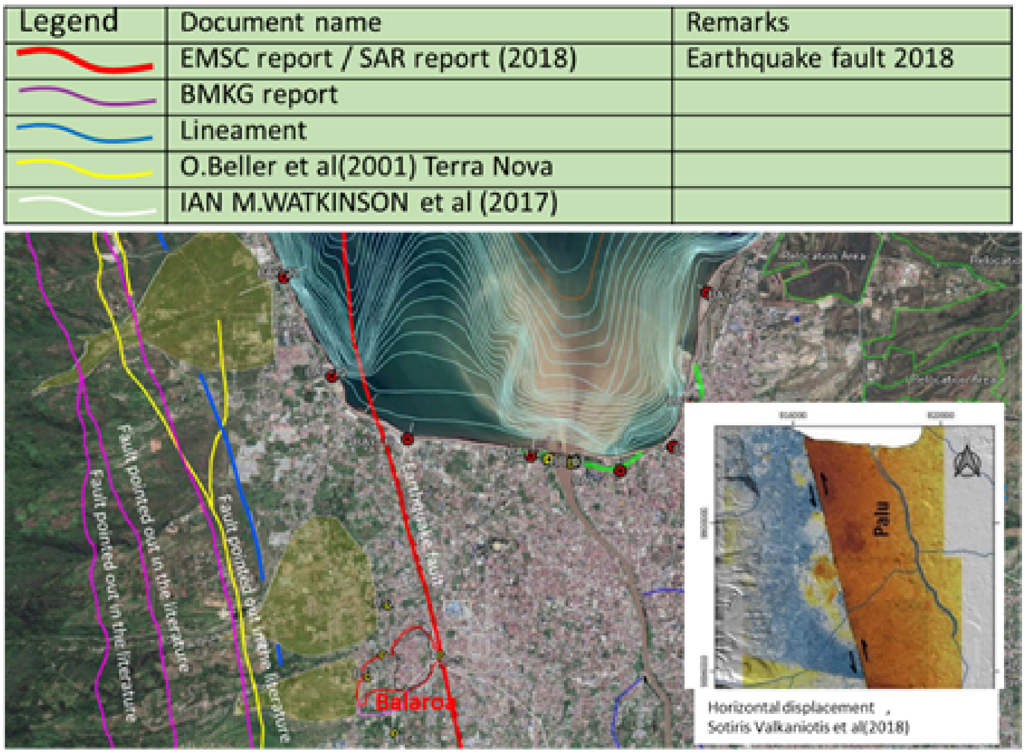


Source: JICA Expert and JICA Study Team

Figure 6-44 Two Types of Seismic Hazard

1) Hazard Map for Active Fault

Taking into consideration of different characteristics that ground deformation and ground motion have, ground deformation due to fault rupture is incorporated in the hazard map to be used for formulating land use regulation. The major active fault in Palu is Palu Koro fault, which is the source of the earthquake on 28th September 2018. The fault was examined before the earthquake, and the fault line from this previous study and that of 2018 are compared in figure. It is found that the previous study has a similar line to the actual fault but is located slightly to the westward.



Source: JICA Expert and JICA Study Team

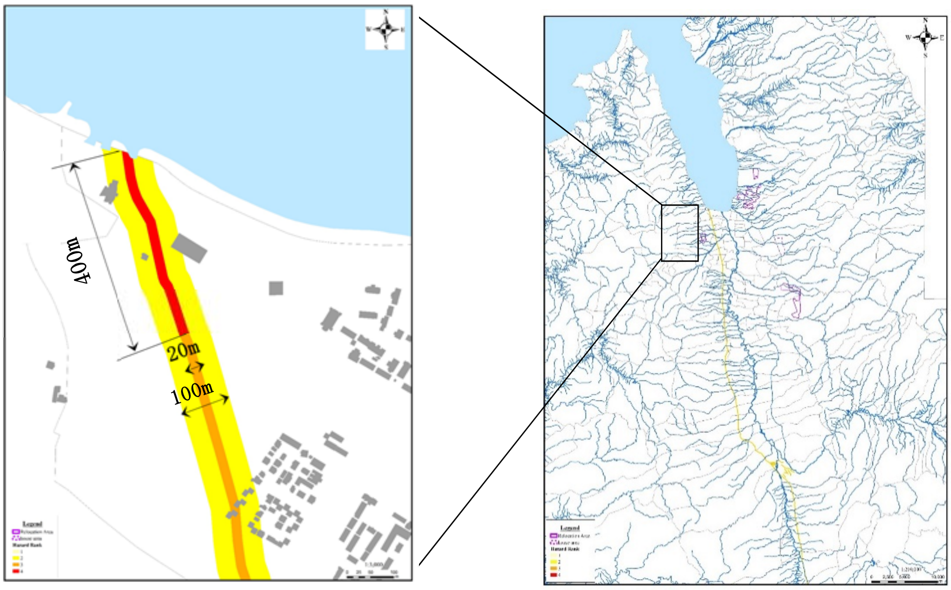
Figure 6-45 Fault Line of Previous Study and the Actual Fault Line

In order to regulate land use, Indonesian government has developed a Disaster Prone Zone (ZRB) map in December 2018, where the ZRB due to Palu Koro active fault is defined as below;

ZRB Zone	Definition
ZRB4	Palu Koro active fault line buffer zone, 0-10 m (active fault deformation hazard zone)
ZRB3	Palu Koro active fault line buffer zone, 10-50 m (active fault boundary)

It is noted that only ZRB4 and ZRB3 are defined by the active fault, because buildings in the area, located far from the active fault line, are not considered to have risk caused by the effect of ground deformation.

Since new development of residential housings and important facilities in ZRB4 and ZRB3 are strictly regulated, the actual ground surface deformation of the earthquake is used as the only main fault line in the hazard map. The coordinates of the fault line were shared from ATR. In accordance with the definition of ZRB zone, the seismic hazard map for Palu Koro fault is shown in Figure on the next page. This seismic hazard map is same as that in the PuSGeN Progress Report on Confirmation of ZRB Palu Koro Fault Post-earthquake September 28, 2019.



Source: JICA Expert and JICA Study Team

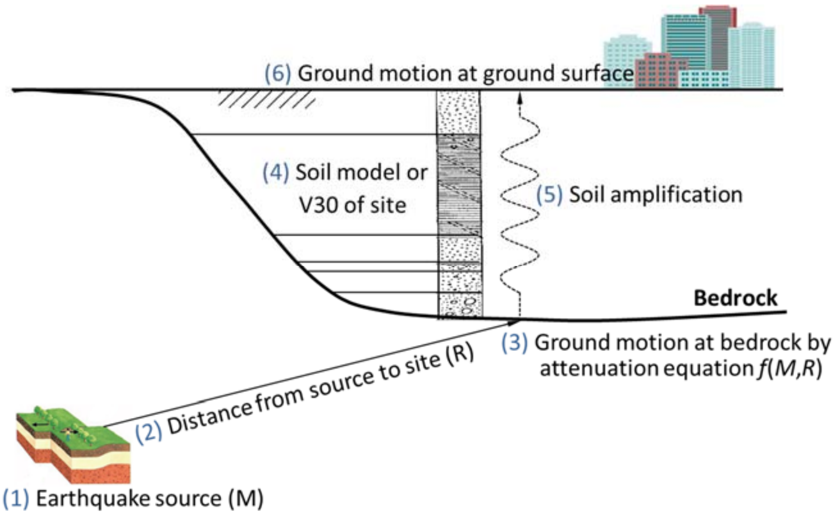
Figure 6-46 Seismic Hazard Map for Palu Koro Active Fault

Meanwhile, although there might be minor or potential faults in the area, with no significant proof or investigation of reoccurrence, they will not be included in the current hazard map. This is to avoid the over-regulation of economic activities and development activities in the area. However, this could be reconsidered in the future; if further studies are implemented for the mechanism and reoccurrence of the fault are confirmed based on concrete evidence.

2) Hazard Map for Ground Motion

There are mainly two approaches to estimate seismic hazard of ground motion: (a) deterministic method and (b) probabilistic method (usually called as probabilistic seismic hazard analysis, PSHA). The former is often used to target a scenario earthquake for estimating the degree of structure damage, life loss and affected people for the purpose of formulating disaster management plan, creating emergency standard operation procedure (SOP) and preparing stockpiling of materials, like food and tent, etc. for emergency response. The latter is generally used to determine the ground motion for seismic design, as used in the Indonesia seismic design standard SNI 1726-2012.

Seismic hazard of ground motion is generally represented by the ground motion parameters, such as peak ground acceleration (PGA), peak ground velocity (PGV) and response spectrum, etc. They are affected by the characteristics of earthquake source, such as magnitude, wave propagation (attenuation) and local soil condition (amplification). The general procedure to deterministically estimate ground motion is shown in Figure 6-47, followed by the explanation on each step.



Source: JICA Expert and JICA Study Team

Figure 6-47 Procedure for Deterministic Estimation of Ground Motion

i. Determination of the epicenter, depth, magnitude and fault plane, if possible, for the targeting earthquake from historical earthquake data, information of tectonics and active fault, etc.,

ii. Calculation of the distance from source to site concerned. It could be the distance from site to epicenter, fault line or fault plane, depending on the attenuation equation, or ground motion prediction equation (GMPE),

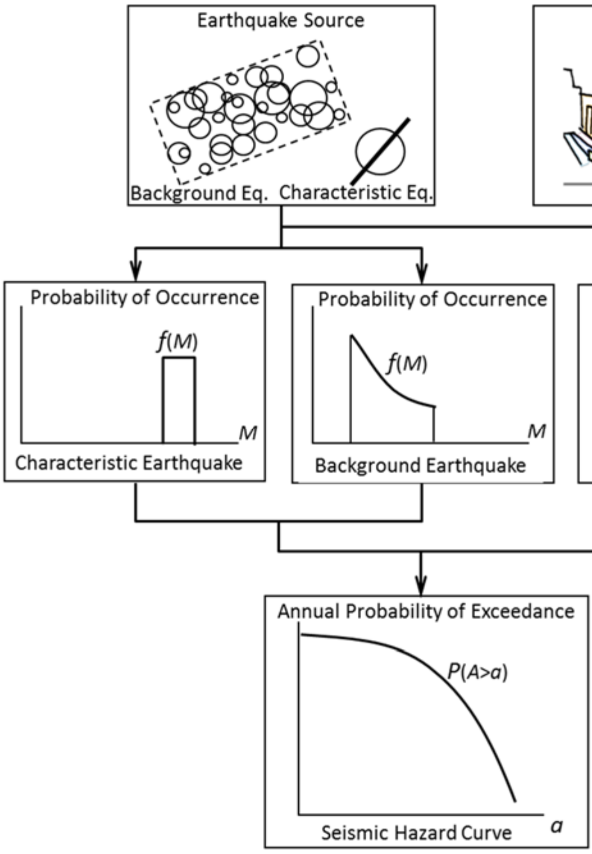
iii. Estimation of the ground motion at bedrock by attenuation equation. The so-called new generation attenuation (NGA) was developed about 10 years ago. There is a large number of attenuation equations in the world and it is important to select the one that best fits the attenuation characteristics of the considered area,

iv. Creation of site model by site survey, such as standard penetration test, boring, etc., to estimate the local soil amplification. A simple site model is the average shear wave velocity of the top soil layer up to 30 meters in depth (V30),

v. Calculation of soil amplification by soil dynamic response analysis, if possible, which requires detailed soil information. The commonly used method for soil dynamic response analysis is one-dimensional equivalent linear analysis. For simplicity, V30 is used for soil amplification by the statistical relationship between V30 and soil amplification,

vi. Calculation of ground motion at ground surface. This is done by multiplying the bedrock ground motion with soil amplification factor, in case of the simple method of V30 being used.

Probabilistic method (PSHA) needs high expertise and complicated calculation. In addition to the procedure for estimating ground motion deterministically described above, it needs to take into account the all possible earthquakes for a concerned site with defining the probability of each earthquake occurrence and the probabilistic distribution of ground motion from attenuation. The procedure of PSHA is shown in the next figure.



Source: JICA Expert and JICA Study Team

Figure 6-48 Procedure of Probabilistic Seismic Hazard Analysis

PuSGeN (Pusat Studi Gempa Nasional) published a book titled *"The Indonesia Earthquake Source and Hazard Map 2017"*, which accommodated the latest research results on tectonics, active fault and seismicity in Indonesia. The book provides the bedrock ground motion and includes several kinds of hazard map: deterministic PGA, probabilistic PGA and response spectrum with different probability of exceedance, which can be used for different purposes. The hazard map covers the whole Indonesia and will be used for updating the seismic design standard of building and other structures. The PuSGeN hazard map of PGA at bedrock with 2% probability of exceedance in 50 years, shown in Figure 6-49, will be used for the estimation of ground motion at ground surface here. Since the bedrock ground motion is obtained from PuSGeN, the procedure for estimation of ground motion at ground surface will be the steps of (4), (5) and (6) in the next Figure.

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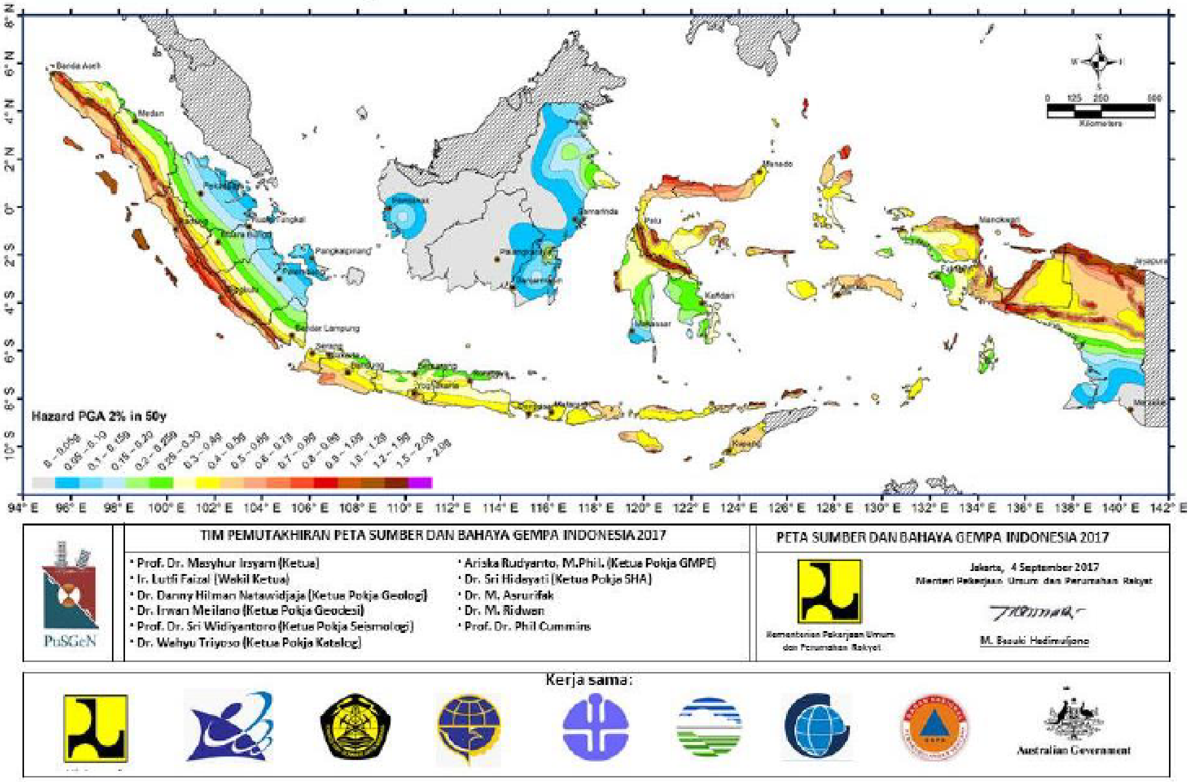


Source: PuSGeN

Figure 6-49 Bedrock PGA with 2% Probability of exceedance in 50 years

For calculation of soil amplification, a simple method using V30, specified in SNI 1726, is applied. In accordance with SNI-1726, the ground is classified into five types based on V30, shown in Table 6-9. The amplification factor of each soil type is listed in Table 6-10, which is the function of both the bedrock PGA and V30. The table is taken from the draft version of updated SNI-1726, which is envisaged to be enacted in the near future.

Table 6-9 Site Classification based on V30

Site classification	V30 (m/s)
SA (hard rock)	> 1,500
SB (rock)	750 - 1,500
SC (hard soil, soft rock)	350 - 750
SD (medium soil)	175 - 350
SE (soft soil)	< 175

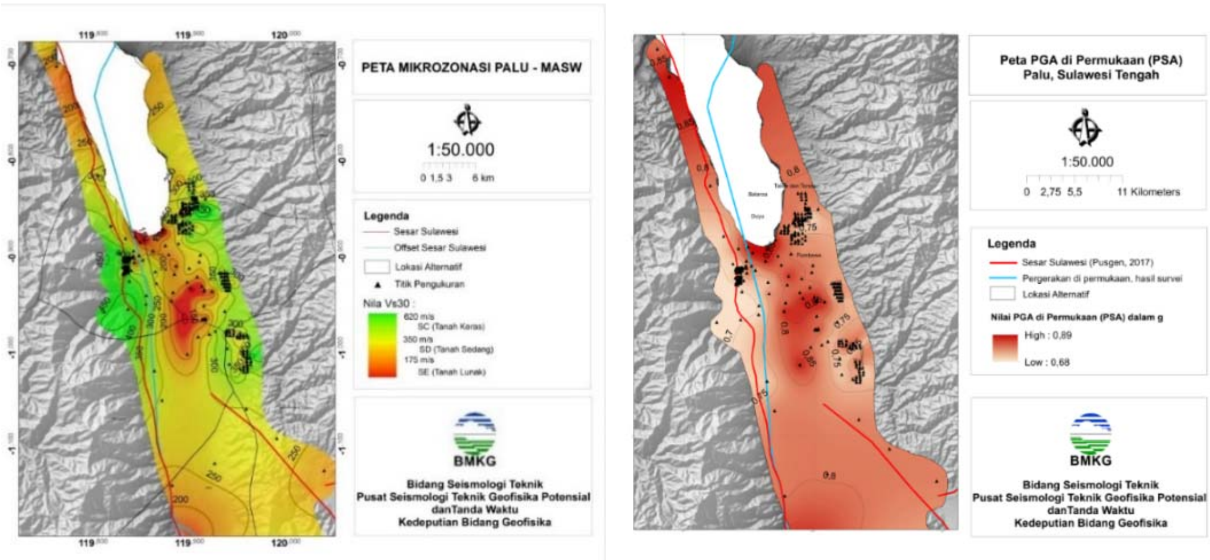
Source: SNI 1726

Table 6-10 Soil Amplification Factor

Soil Type	Bedrock PGA					
	0.1	0.2	0.3	0.4	0.5	0.6
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.9	0.9	0.9	0.9	0.9	0.9
ZC	1.3	1.2	1.2	1.2	1.2	1.2
ZD	1.6	1.4	1.3	1.2	1.1	1.1
ZE	2.4	1.9	1.6	1.4	1.2	1.1

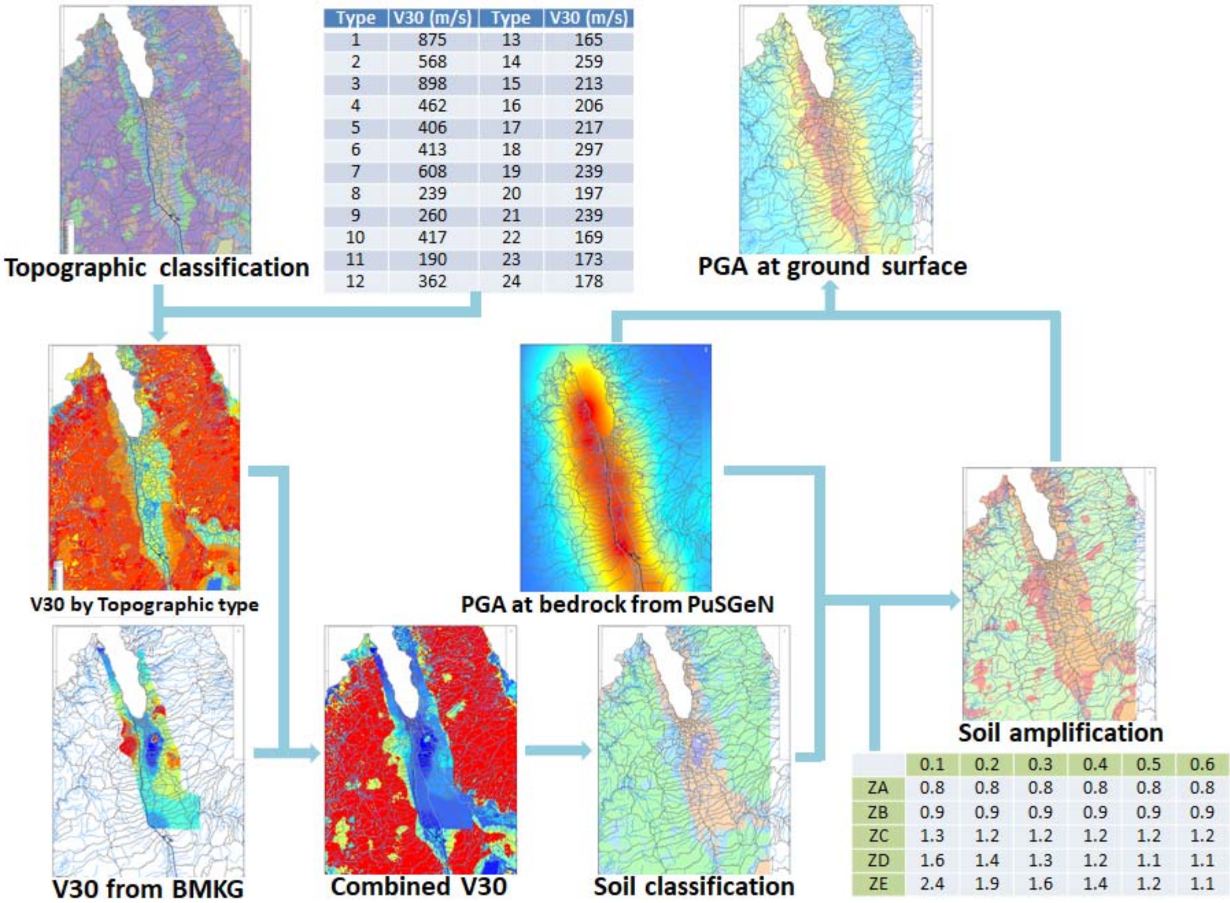
Source: SNI 1726 revision draft

BMKG has made the multichannel analysis of surface wave (MASW) survey after the Palu earthquake in 2018, created the micro zonation map for V30 and estimated ground surface ground motion shown in Figure 6-50. On the other hand, the BMKG hazard map does not cover the whole ZRB area. Then, the ground motion for whole ZRB area is estimated here with the V30 of BMKG and the V30 proposed by Sugio Imamura et al. (2015) and Prof. Masyhur Irsyam et al. (2017) based on auto topographic classification for the area not covered by BMKG. The procedure of calculation is shown in Figure 6-51 and the estimated ground motion at ground surface is given in the Figure 6-52.



Source: BMKG

Figure 6-50 V30 and Ground Motion Distribution of BMKG

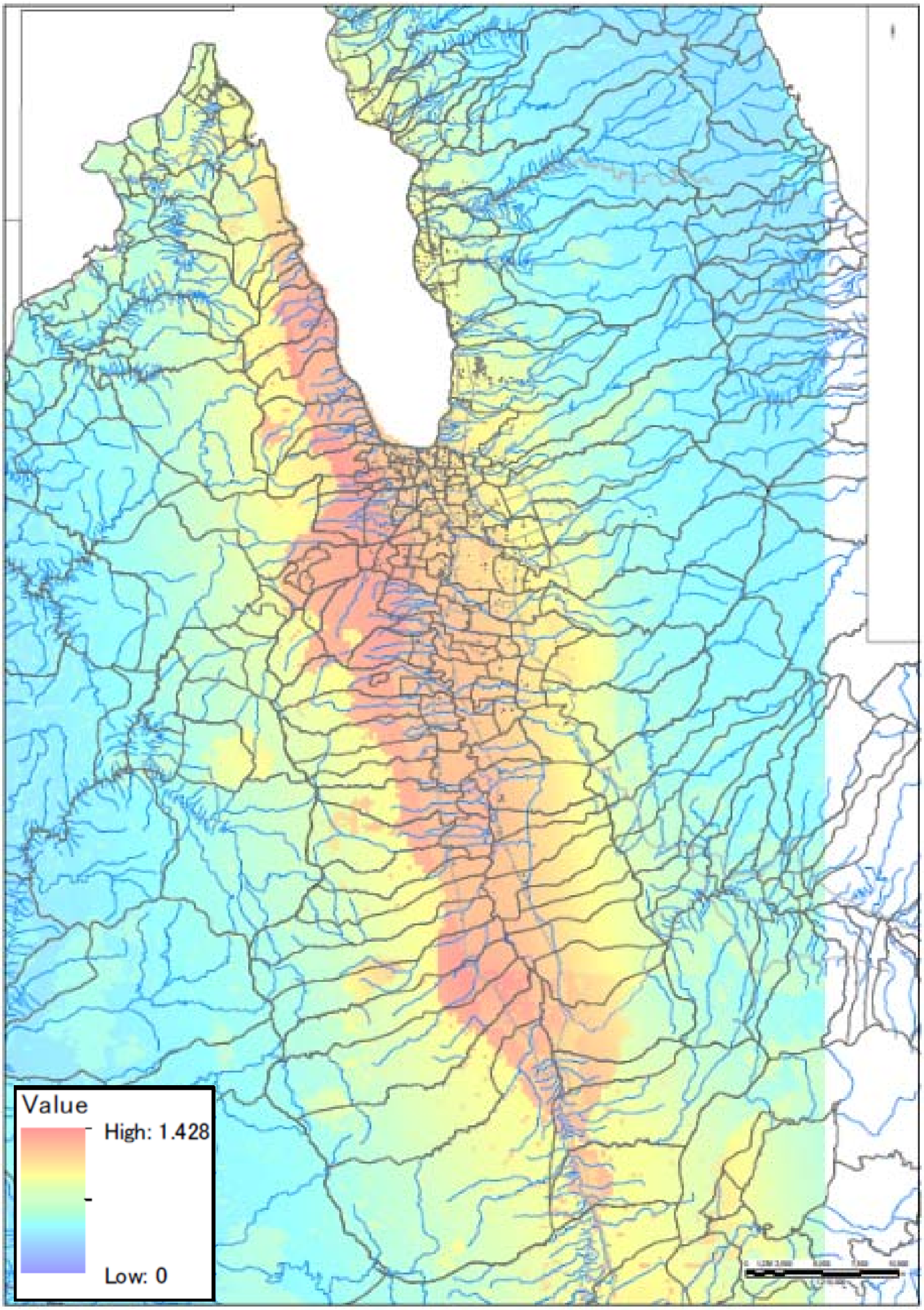


Type	V30 (m/s)	Type	V30 (m/s)
1	875	13	165
2	568	14	259
3	898	15	213
4	462	16	206
5	406	17	217
6	413	18	297
7	608	19	239
8	239	20	197
9	260	21	239
10	417	22	169
11	190	23	173
12	362	24	178

	0.1	0.2	0.3	0.4	0.5	0.6
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.9	0.9	0.9	0.9	0.9	0.9
ZC	1.3	1.2	1.2	1.2	1.2	1.2
ZD	1.6	1.4	1.3	1.2	1.1	1.1
ZE	2.4	1.9	1.6	1.4	1.2	1.1

Source: JICA Expert and JICA Study Team

Figure 6-51 Procedure of Estimation of Ground Motion at Ground Surface



Source: JICA Expert and JICA Study Team

Figure 6-52 Ground Motion at Ground Surface

6-1-4 Flood

(1) Basic concept of hazard map preparation

Analysis of rainfall, runoff, and inundation analysis using RRI models were generally simulated using information such as meteorological and hydrological data and basin data. Then the results were evaluated for flood hazards.

In order to carry out the inundation analysis, daily rainfall data for 30 to 50 years and hourly rainfall data for major floods are necessary. However, since the data is insufficient in the target area, the analysis was conducted using satellite data (GiSMap). The target rainfall in this study was the October 2016 rainfall (return period of 1/30 year), which caused damaged in recent years. The analysis area is the basin of Palu River and the small and medium rivers flowing into Palu Bay.

(2) Criteria of hazard level

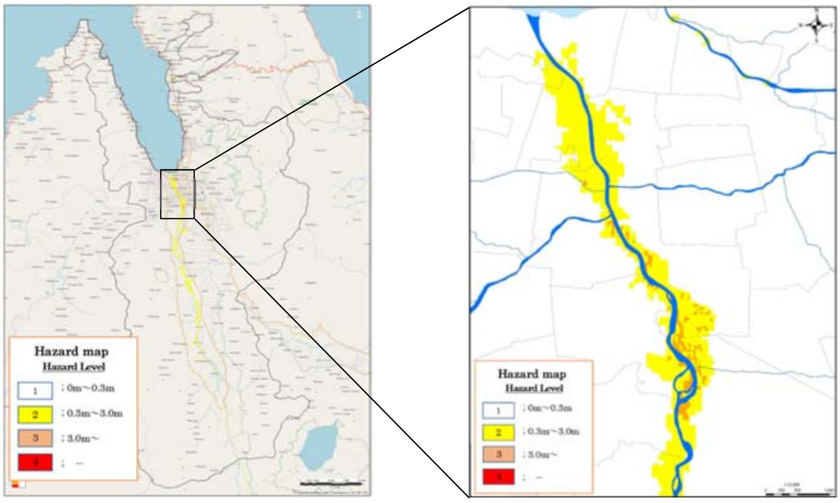
The flood hazard level was set based on the analysis results of the inundation depth. Hazard level 4 was not set because flood does not occur soon after rainfall started, thus the scale of damage is easy to be predicted based on raining time or total amount of rainfall, and thus secure evacuation time. The criteria of hazard level is summarized in table below.

Table 6-11 Flood Hazard Level

Hazard Level	Inundation Depth	Description
4	-	Not set; Because evacuation is possible The situation is different from the disaster caused by the earthquake. Since evacuation time is possible to be secured because flood occurs when rainfall continues.
3	$H \geq 3.0$ m	Where inundation depth exceeds 3.0 m, the first floor level could be flooded, thus the area expected for over 3.0 m inundation depth should be prepared for earlier evacuation for human life protection. Any property could be lost or damaged in this area.
2	0.3 m $\leq H < 3.0$ m	Where inundation depth is from 0.3 m to 3.0 m, flood can exceeds above the ground flood level. However, evacuation to the first floor may protect human lives. Besides, any property on the ground level could be lost or damaged.
1	$H < 0.3$ m	There is hardly flood occurring and the level of flood is around the ground level. Therefore, there is not much damage or loss to the lives and properties.

Source: JICA Experts and JICA Study Team

A flood hazard map was created based on the simulation results of inundation area and inundation depth as shown as follows.



Source: JICA Experts and JICA Study Team

Figure 6-53 Flood Hazard Map in Palu City

(3) Methodology of Flood Hazard Map

1) General

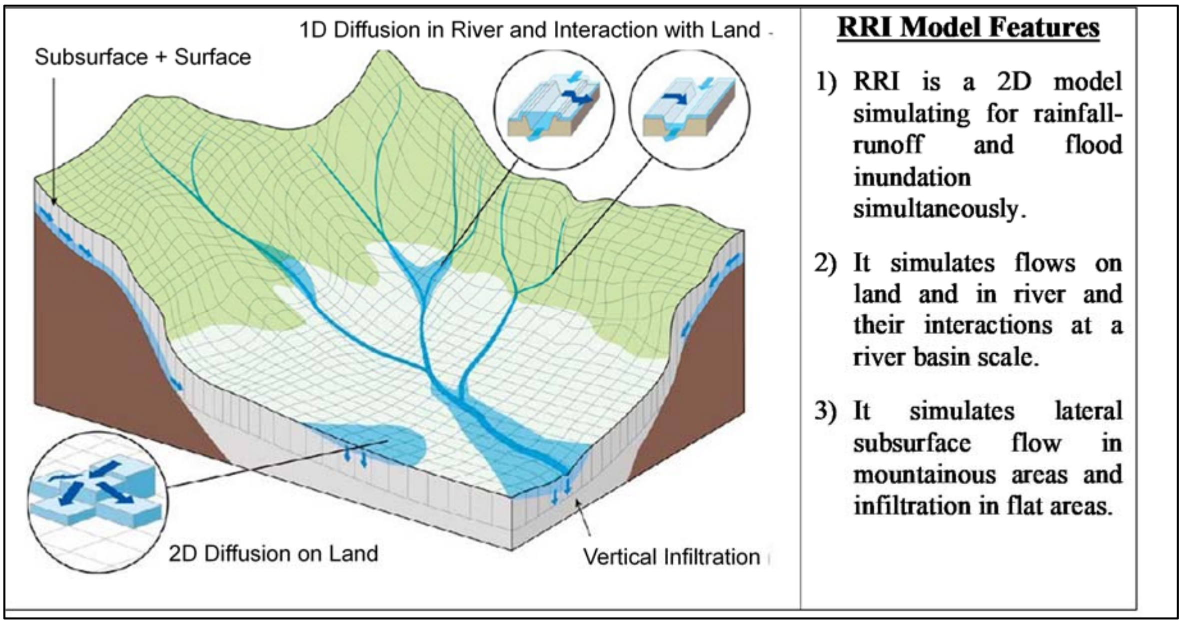
Flood hazards are assessed through conducting simulations and calculated by using analytical models and software such as the RRI (Rainfall-Runoff-Inundation) model, the HEC-RAS (U.S. Hydrologic Engineering Center's River Analysis System), MIKE11 and so on.

Basically, analyses based on scientific evidence are implemented by using information including hydrometeorology, hydrography and geography.

For the hazard assessment in Central Sulawesi (Palu), RRI model (Rainfall-Runoff-Inundation) was applied since the RRI model has the following advantages.

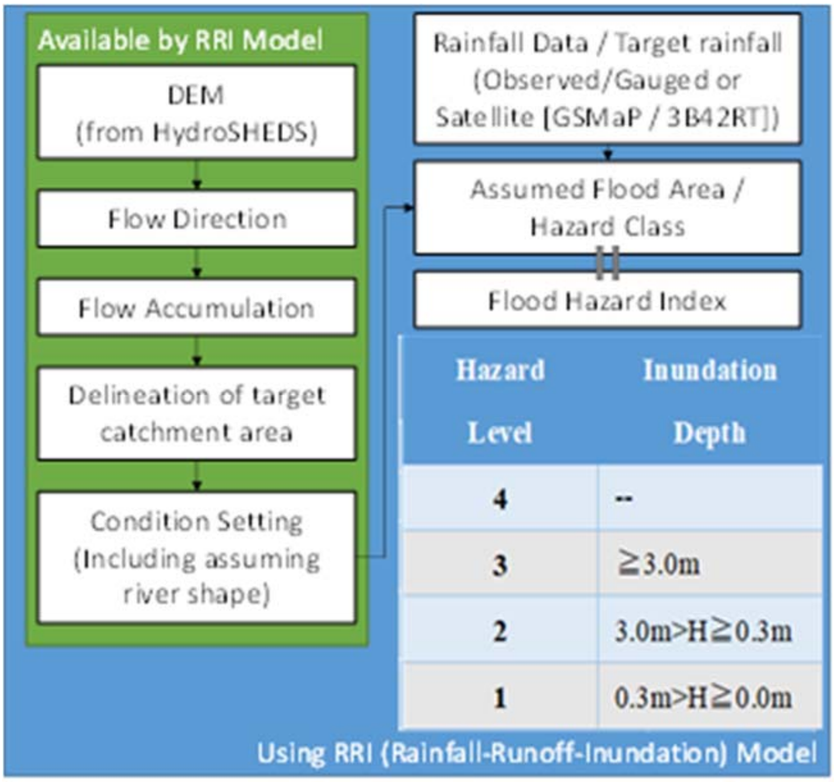
- The RRI model analyzes river channels one-dimensionally and land area two-dimensionally. It is applicable to basins including mountains and plains.
- The RRI model is capable of simulating rainfall-runoff and flood inundation simultaneously
- It can simulate lateral subsurface flows in mountainous areas, vertical infiltration flows in plain areas, structures such as levees, dams and diversion channels.
- The RRI model is disclosed to public as free software.
- The RRI model is user friendly model with a Graphical User Interface (GUI)
- The RRI model is simplified model utilizing the free input data, such as DEM and satellite rainfall data. Even though the availability of actual observed data for whole Indonesia is very limited and considering the technical and budgetary constraints, this model can be applied.

Schematic diagram of RRI model is shown in Figure 6-54. “The RRI model (Rainfall-Runoff-Inundation)” can be applied for whole Indonesia.



Source: RRI model manual

Figure 6-54 Schematic Diagram of RRI model

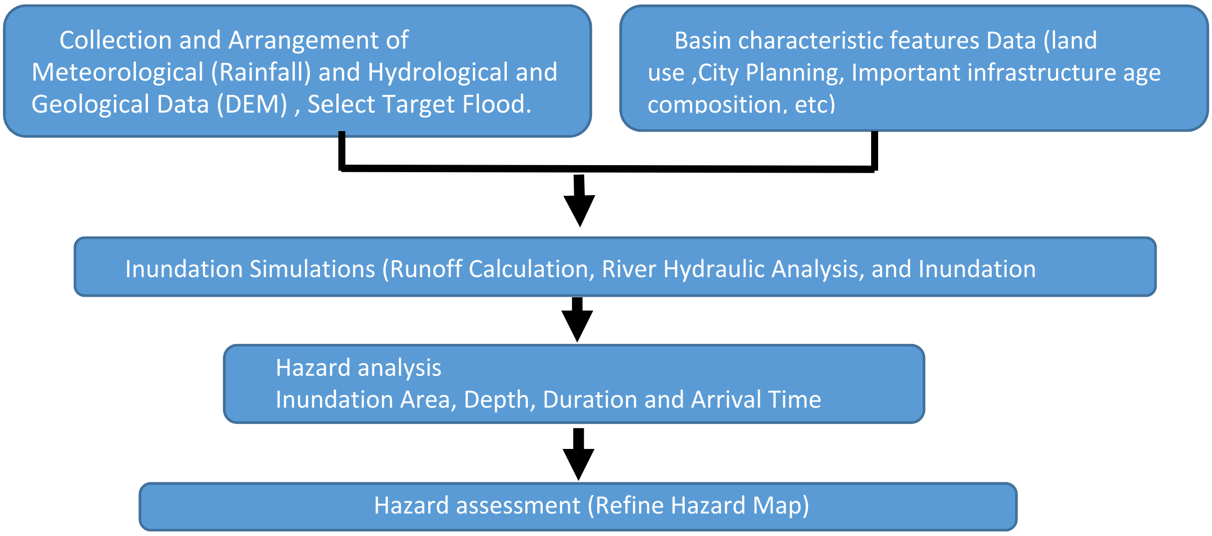


Note: for hazard classification and inundation depth, case of Japan is used as a reference.

Figure 6-55 Flowchart of Hazard Assessment using the RRI Model

Flowchart of hazard assessment using the RRI model is shown in Figure and flood hazard indexes are estimated based on the flood simulation result, assumed flood area. In the same manner, meteorological / hydrological data (especially rainfall) and basin data (especially topography data) are the data fundamental to assess / simulate a flood hazard.

The first step in conducting a hazard assessment for river floods is to collect and arrange data on characteristics of river basins, meteorological and hydrological data, and other relevant information, such as the condition of maintenance of flood management facilities. The data is used to set rainfall scales and other external forces. This data is then used to run inundation simulations that provide runoff calculations, river hydraulic analyses, and inundation analyses. The hazard assessments provide an estimation of direct and indirect damages based on identified hazards (inundation areas, depth, duration, and arrival times).



Source: JICA Expert and JICA Study Team

Figure 6-56 Procedure of River Flood Hazard Assessment

2) Procedure of River Flood Hazard Assessment

a) Collection and Arrangement of Data

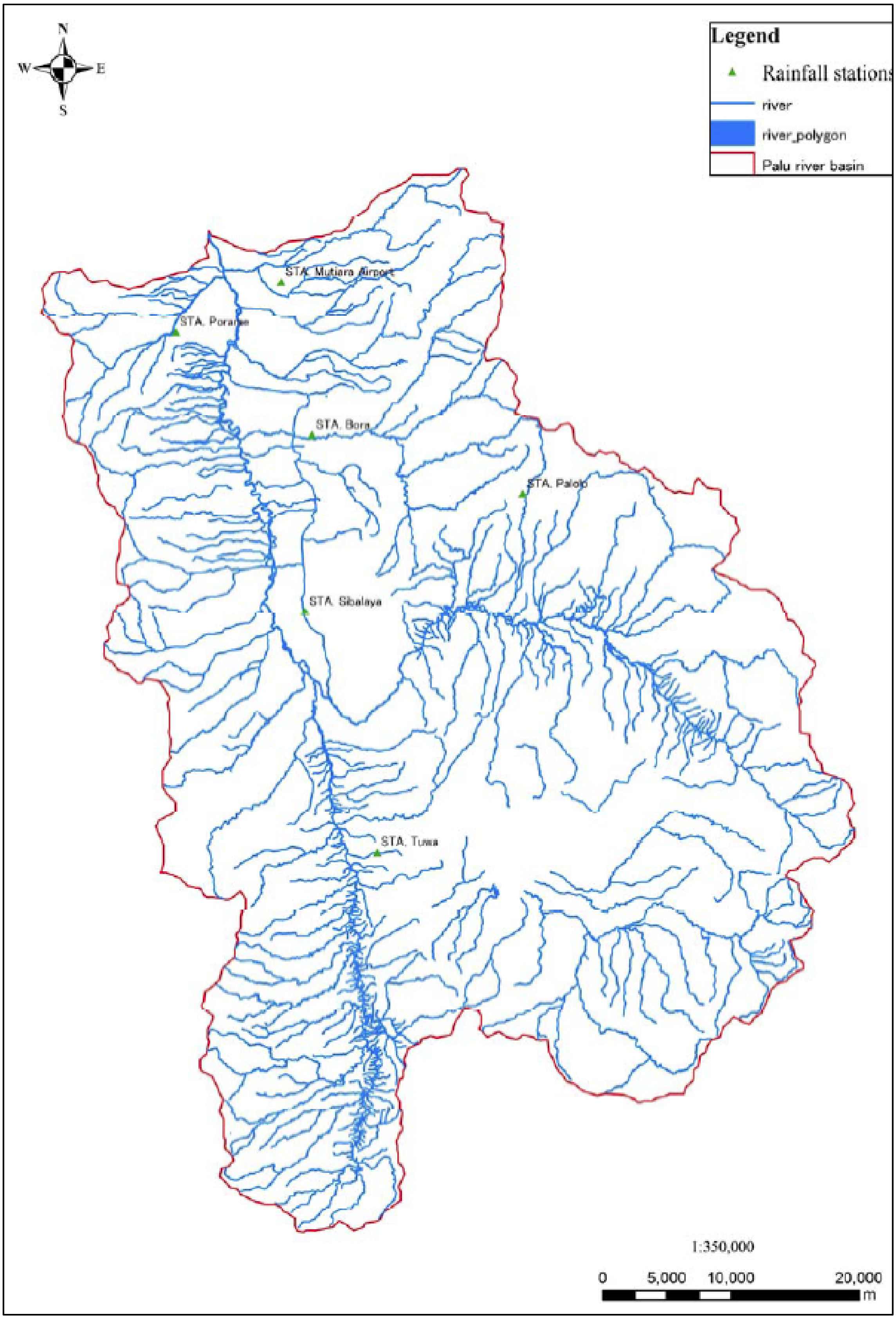
The first step is to collect data necessary for inundation simulation, such as rainfall, storm surge scale, geological data (DEM) etc. The second step is to arrange the collected data for simulation.

< Current situation>

- The target for simulation was the same area as ZRB map created by ATR (2018). That means the target area was setting Palu river basin and small and medium size river basins around Palu Bay. (sinformation about rivers and basins cannot)
- Geological data was used DEM (30m mesh) data.
- Rainfall data was used the satellite data (hourly rainfall), since there is almost no hourly rainfall data on the entire target area.
- There are 16 ground-based rainfall stations in and surround Palu river basin. However, there are 10 stations that cannot be applied because of unstable and lack of data (reference table 20). Only six stations have long period and stable observation of daily rainfall data which are Mutiara, Porame, Bora, Palolo, Sibalaya, Tuwa (refer to Figure in the next page). However, these ground-based rainfall data are considered to be uncertain due to instrument failure caused by

inappropriate maintenance of observation facilities or weather conditions. Ground-based rainfall data was collected in the period of 2000 - 2017.

- It is general to calculate the scale of rainfall in each river basin and then select the target flood for each river. However, since the rainfall information of each river basin was hardly obtained in the preparation of the hazard map this time, the flood that occurred in recent years was selected as the target flood.



Source: JICA Expert and JICA Study Team

Figure 6-57 Rainfall Stations Map in Palu River Basin (Only Stations Used)

Table 6-12 Ground Rainfall Stations and Observation Status in the Palu River Basin

Station	BANGGA ATAS	BANGGA BAWAH	BORA	NUPABOMBA	MUTIARA	OMU	OO PARESE	PALOLO
Observation	1992-	1992-	1976-		1976-	1976-	1976-	1976-
2000	------------	------------	------------	------------	************	------------	------------	------------
2001	------------	------------	------------	------------	************	------------	------------	------------
2002	**--o-******	***-o*******	*******-****	------------	************	------------	------------	************
2003	************	*****o******	************	------------	************	------------	------------	************
2004	************	************	************	------------	************	------------	------------	************
2005	************	************	**********-*	------------	************	------------	------------	************
2006	************	************	************	------------	************	------------	------------	************
2007	************	************	**********-*	------------	************	------------	------------	************
2008	********--**	********----	************	------------	************	------------	------------	---*********
2009	*-**********	*-**********	------------	------------	************	------------	------------	************
2010	************	************	------------	------------	************	------------	------------	************
2011	************	************	-------*****	------------	************	------------	------------	************
2012	************	****-*******	**-*********	------------	************	------------	------------	************
2013	************	************	************	------------	************	------------	------------	************
2014	************	************	************	------------	************	------------	------------	************
2015	------------	--**********	************	------------	************	------------	------------	************
2016	------------	************	***o-**ooooo	************	************	************	************	------------
2017	************	************	************	************	************	************	************	************

Station	PANTOLOAN BOYA	PORAME	SIBALAYA	SIBOWI	TOMPI BUGIS	TONGOA	TUWA
Observation	2000-	2002-	1976-	2008-	2014-	2014-	1992-
2000	------------	------------	************	------------	------------	------------	------------
2001	------------	------------	************	------------	------------	------------	------------
2002	------------	------------	************	------------	------------	------------	************
2003	------------	************	************	------------	------------	------------	************
2004	------------	************	************	------------	------------	------------	************
2005	------------	************	************	------------	------------	------------	************
2006	------------	************	************	------------	------------	------------	************
2007	------------	************	************	------------	------------	------------	************
2008	------------	************	************	------------	------------	------------	************
2009	------------	************	************	------------	------------	------------	************
2010	------------	************	************	------------	------------	------------	************
2011	------------	************	************	************	------------	------------	************
2012	------------	************	************	************	------------	------------	************
2013	------------	************	************	************	------------	------------	************
2014	------------	************	************	************	------------	------------	************
2015	------------	************	************	************	************	------------	************
2016	--****------	************	************	************	************	************	************
2017	-***********	************	************	************	************	************	************

- Missing observation
*Data available
o Partly missing observation

- **Preparation of DEM**
  - The DEM data or the ASTER GDEM shall be collected.
  - DEM data (approximately 90 m / 500 m / 1 km DEM) are available from HydroSHEDS
  - (https://hydrosheds.cr.usgs.gov/index.php)
  - Also ASTER GDEM (approximately 30 m) is available from LP DAAC Global Data Explorer (https://gdex.cr.usgs.gov/gdex/)
- **Preparation of Flow direction, Flow accumulation and Delineation of target catchment area**
  - The point shape file for identifying a catchment outlet shall be created and the target catchment with the outlet and flow direction information shall be delineated.
  - The DEM, flow direction and accumulation using the catchment raster shall be extracted.
  - The DEM, flow direction and accumulation shall be converted to ASCII data.
  - Above procedure can be conducted using the "Hydrology tool set of the ArcGIS"

➢ Condition Setting

River condition and River shape shall be produced based on the following methodology

A one-dimensional diffusive wave model is applied to river grid cells. The geometry is assumed to be rectangle, whose shapes are defined by width (W), depth (D) and embankment height (He). When detailed geometry information is not available, the width and depth are approximated by the following function of upstream contributing area A [km2].

$$W=C_W A\text{^}(S_W), \qquad D=C_D A\text{^}(SD)$$

Where, C_W, S_W, C_D and S_D are geometry parameters. Here the units of "W" and "D" are meters.

Some other conditions such as simulation time step, roughness of river channel / cells will be set

➢ Preparation of Rainfall Data

There are 3 options for collection method of rainfall data. The rainfall data shall be arranged for RRI model format after download.

- o Gauged rainfall with Thiessen polygon interpolation
- o GSMaP satellite based rainfall (it has high resolution than 3B42RT)
- o 3B42RT satellite based rainfall

b) Hydrologic analysis

The basin average rainfall at the main points shown below is calculated using Thiessen method and the annual maximum daily rainfall was extracted. The probability rainfall was calculated using the extracted annual maximum daily rainfall. Main rainfall stations are, namely: Mutiara, Porame, Bora, Palolo, Sibalaya, Tuwa.

< Basin average annual maximum daily rainfall>

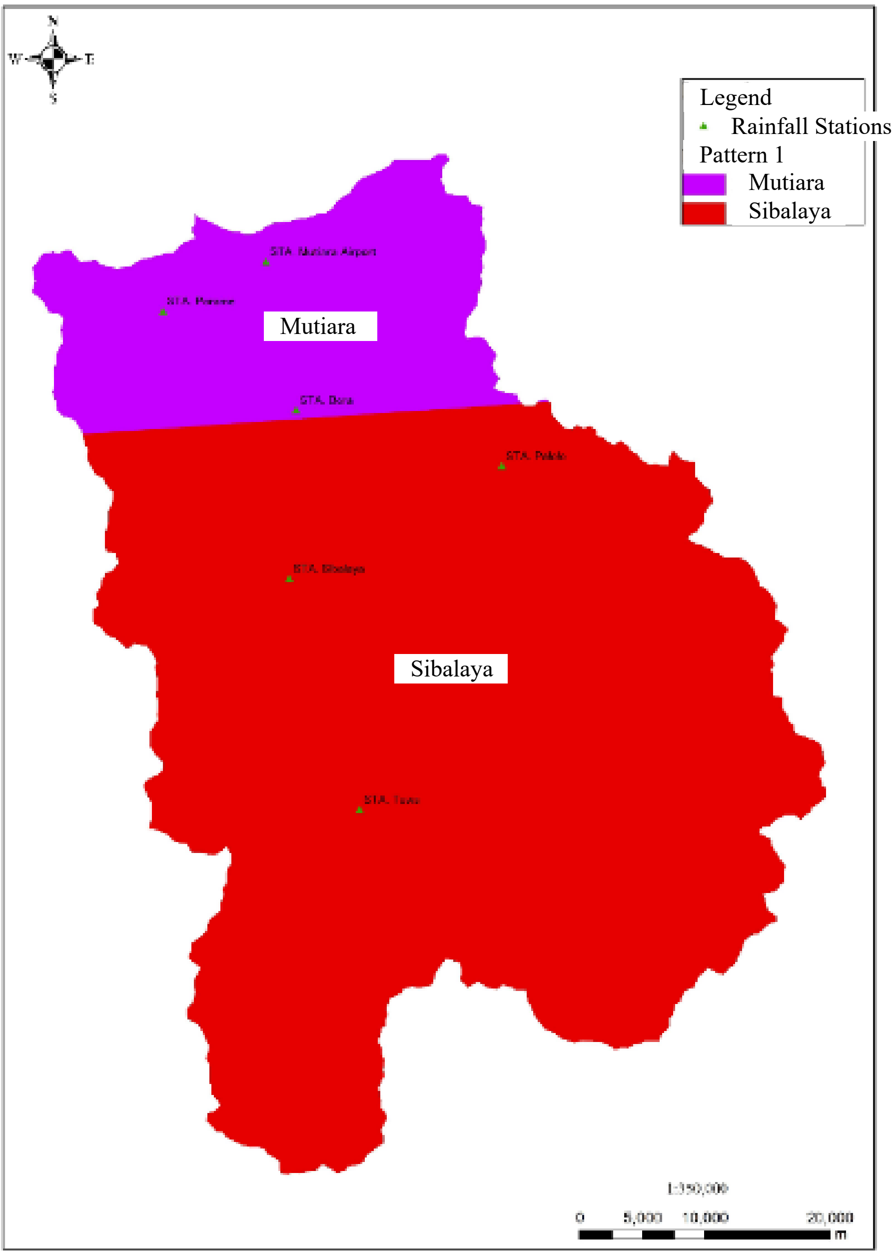
The Thiessen method pattern used to determine the average basin rainfall at each rainfall station and the control rate of each station in the basin are shown below.

Table 6-13 Thiessen Pattern

Station	BORA	MUTIARA	PALOLO	PORAME	SIBALAYA	TUVA	Pattern
Observation	1976-	1976-	1976-	2002-	1976-	1992-	
2000	- - - - - - - - - - - -	* * * * * * * * * * * *	- - - - - - - - - - - -	- - - - - - - - - - - -	* * * * * * * * * * * *	- - - - - - - - - - - -	1
2001	- - - - - - - - - - - -	* * * * * * * * * * * *	- - - - - - - - - - - -	- - - - - - - - - - - -	* * * * * * * * * * * *	- - - - - - - - - - - -	1
2002	* * * * * * * - * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	- - - - - - - - - - - -	* * * * * * * * * * * *	* * * * * * * * * * * *	2
2003	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	3
2004	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	3
2005	* * * * * * * * * * - *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	7
2006	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	3
2007	* * * * * * * * * * - *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	4
2008	* * * * * * * * * * * *	* * * * * * * * * * * *	- - - * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	5
2009	- - - - - - - - - - - -	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	4
2010	- - - - - - - - - - - -	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	4
2011	- - - - - - - * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	4
2012	* * - * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	4
2013	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	3
2014	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	3
2015	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	3
2016	* * * o - * * o o o o o	* * * * * * * * * * * *	- - - - - - - - - - - -	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	6
2017	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	* * * * * * * * * * * *	3

Source: JICA Expert and JICA Study Team

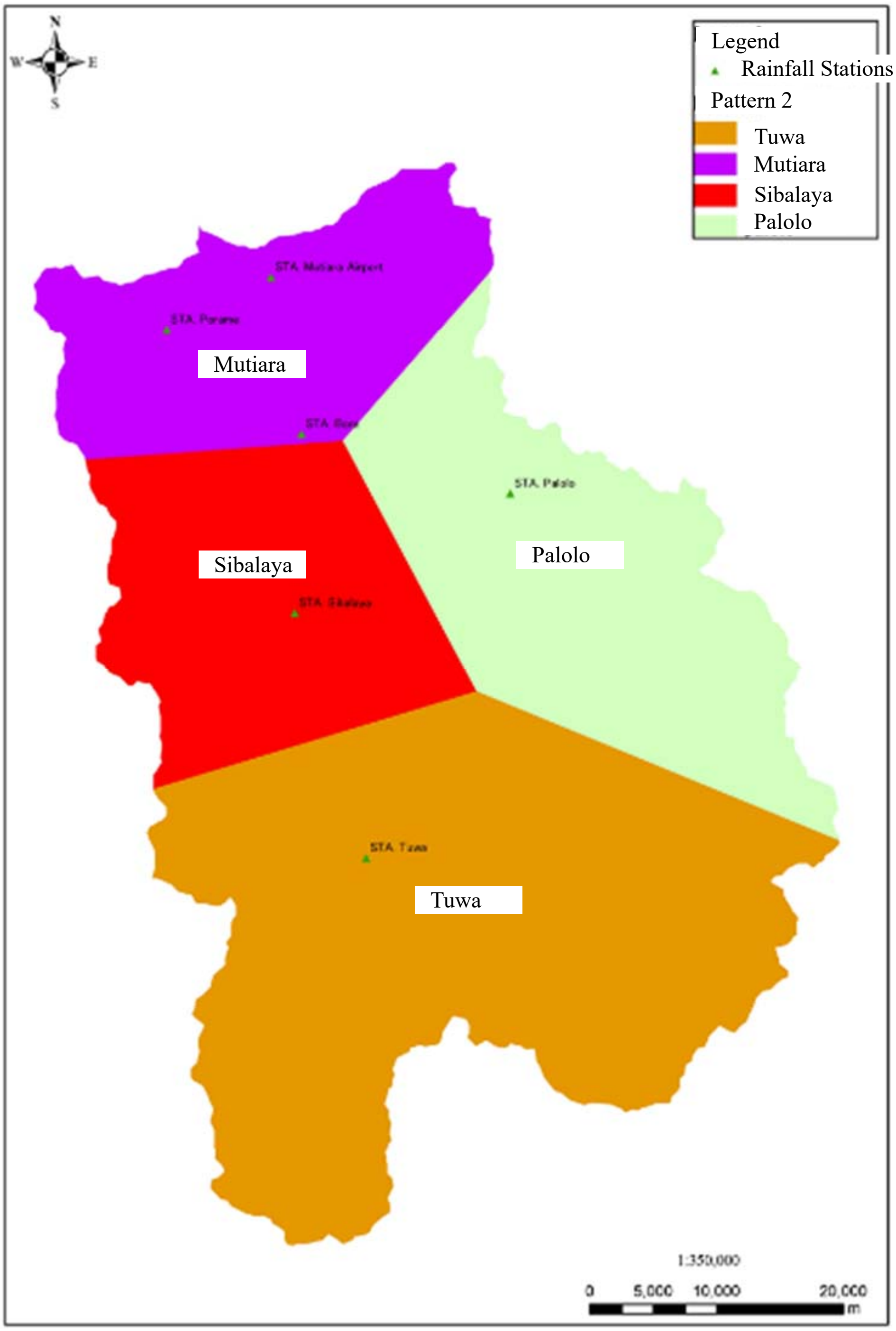
Total Area (km2)	Station	Accumulative Area (km2)	Proportion(%)
3051.986	Mutiara	569.065	18.6
3051.986	Sibalaya	2482.921	81.4



Source: JICA Expert and JICA Study Team

Figure 6-58 Thiessen Pattern 1

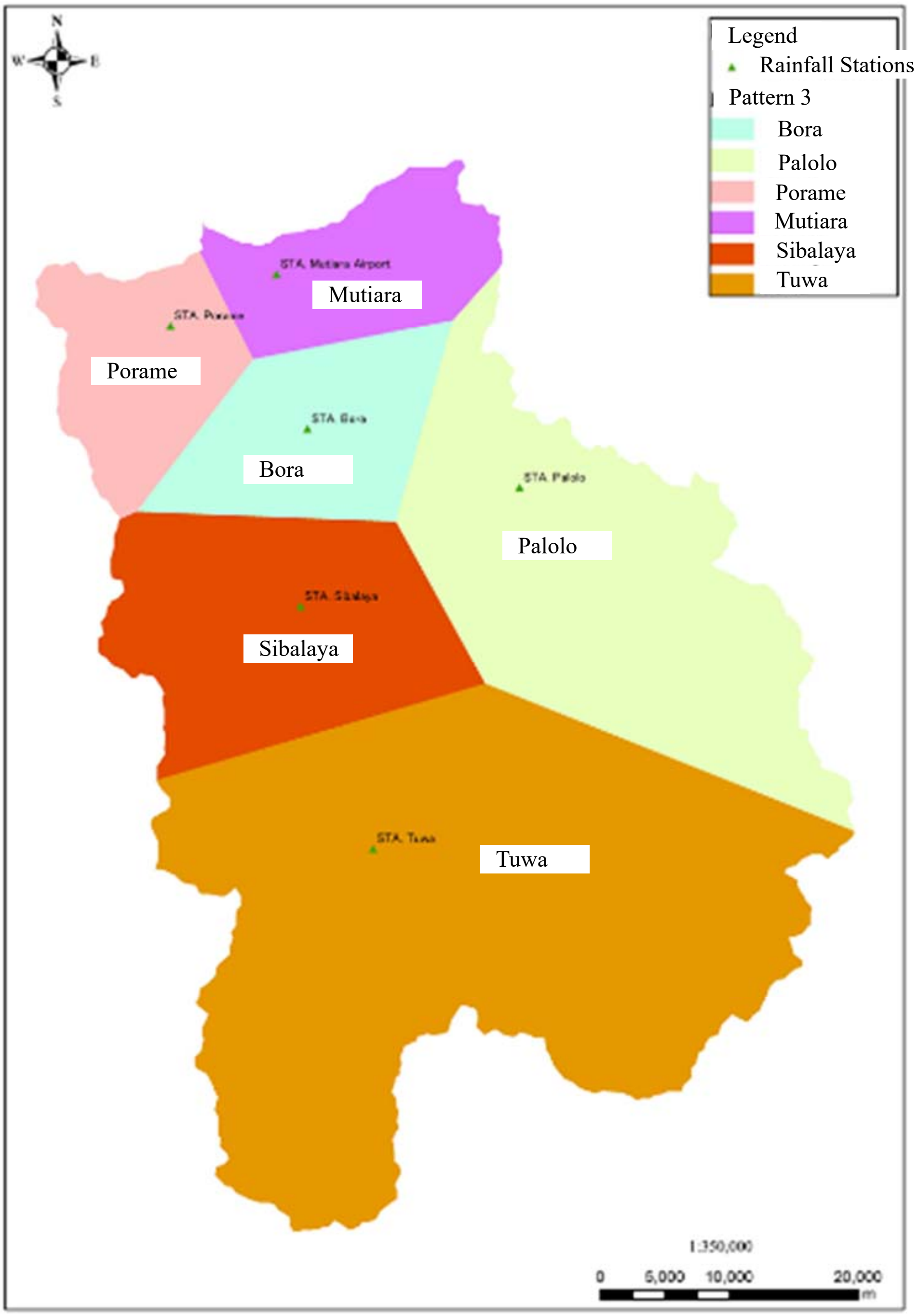
Total Area (km2)	Station	Accumulative Area (km2)	Proportion(%)
3051.986	Mutiara	494.360	16.2
3051.986	Sibalaya	539.699	17.7
3051.986	Palolo	696.913	22.8
3051.986	Tuwa	1321.014	43.3



Source: JICA Expert and JICA Study Team

Figure 6-59 Thiessen Pattern 2

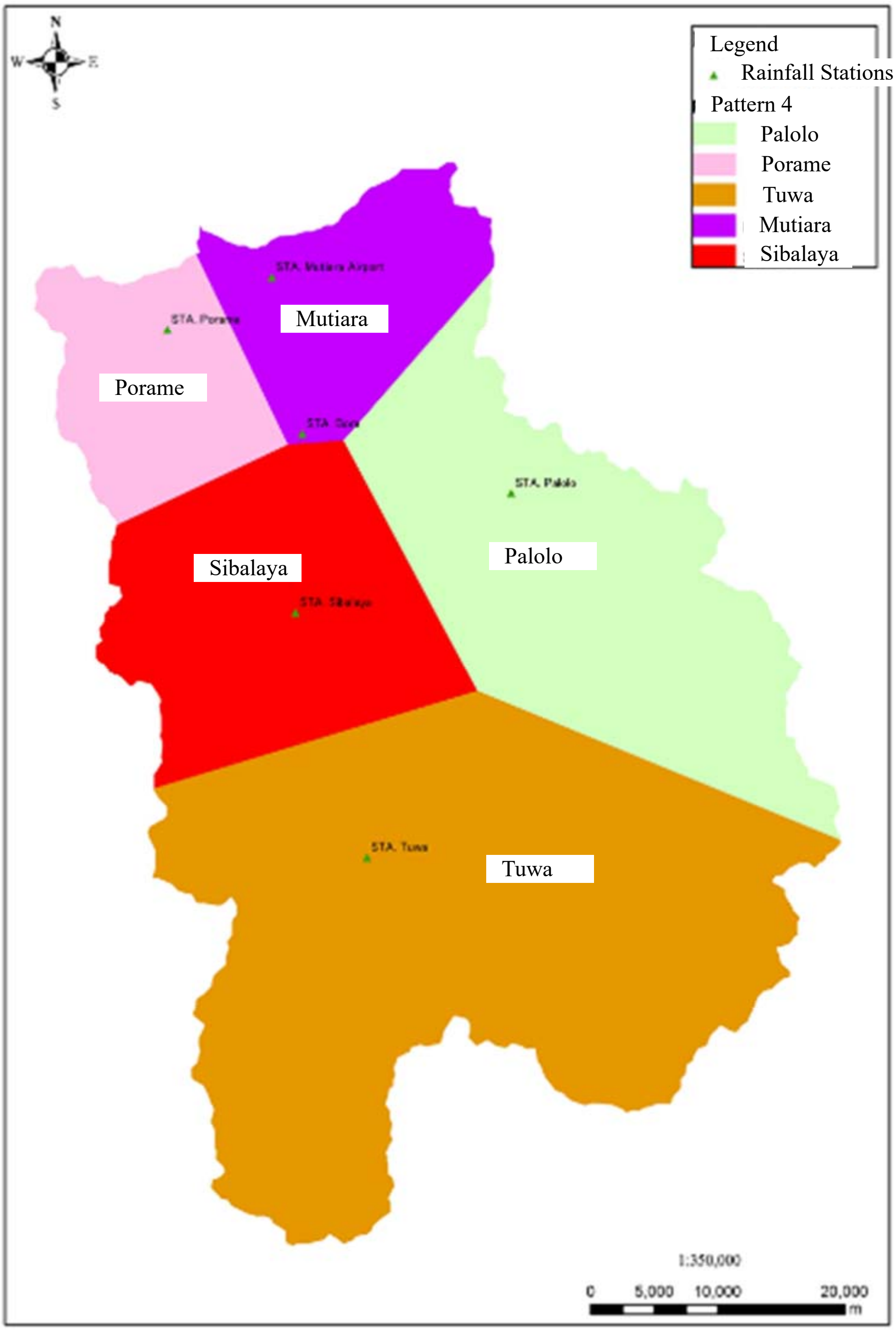
Total Area (km2)	Station	Accumulative Area (km2)	Proportion(%)
3051.986	Mutiara	211.806	6.9
3051.986	Sibalaya	421.191	13.8
3051.986	Palolo	653.912	21.4
3051.986	Tuwa	1321.014	43.3
3051.986	Bora	236.395	7.7
3051.986	Porame	207.669	6.8



Source: JICA Expert and JICA Study Team

Figure 6-60 Thiessen Pattern 3

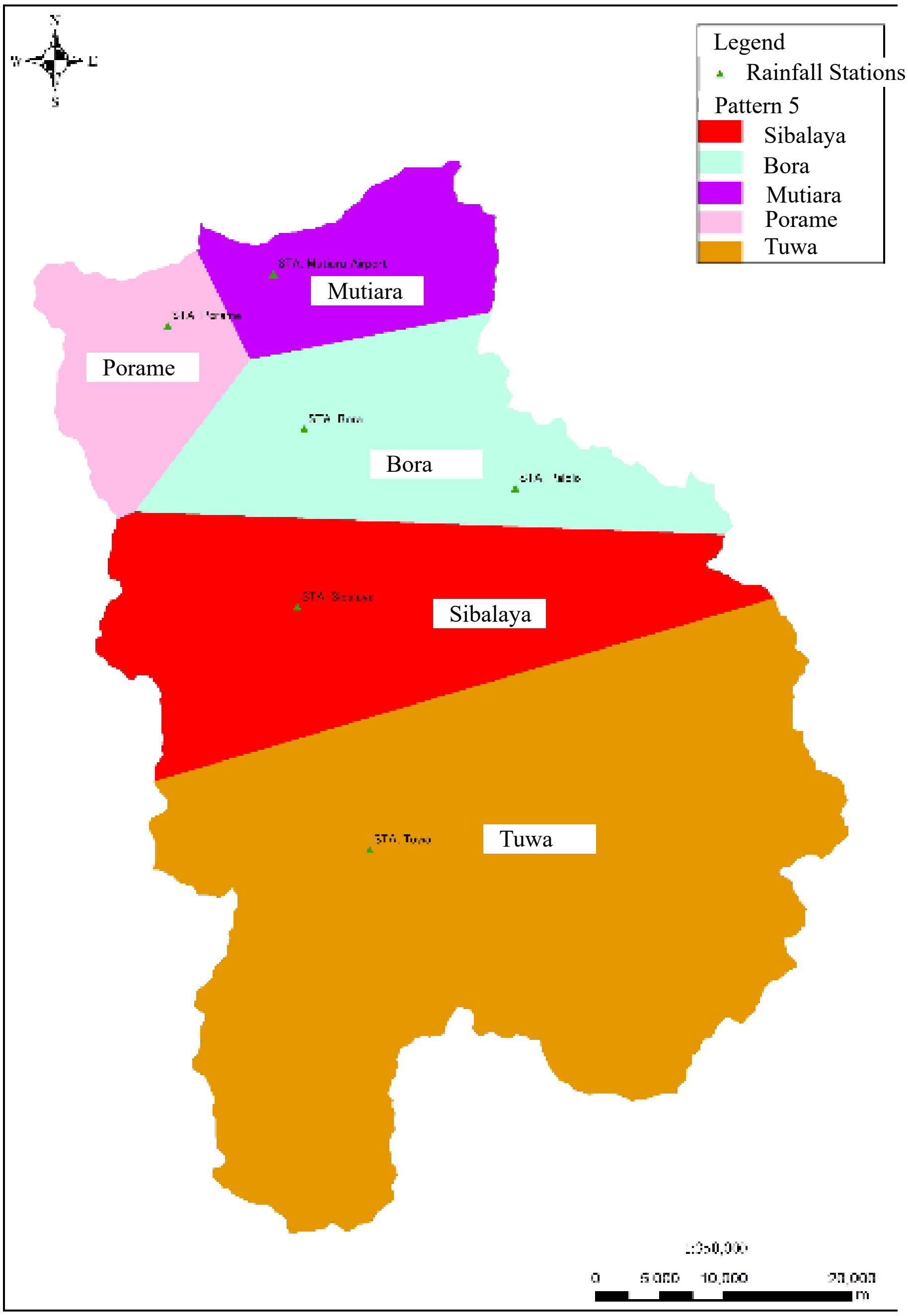
Total Area (km2)	Station	Accumulative Area (km2)	Proportion(%)
3051.986	Mutiara	283.269	9.3
3051.986	Sibalaya	496.722	16.3
3051.986	Palolo	696.913	22.8
3051.986	Tuwa	1321.014	43.3
3051.986	Porame	254.067	8.3



Source: JICA Expert and JICA Study Team

Figure 6-61 Thiessen Pattern 4

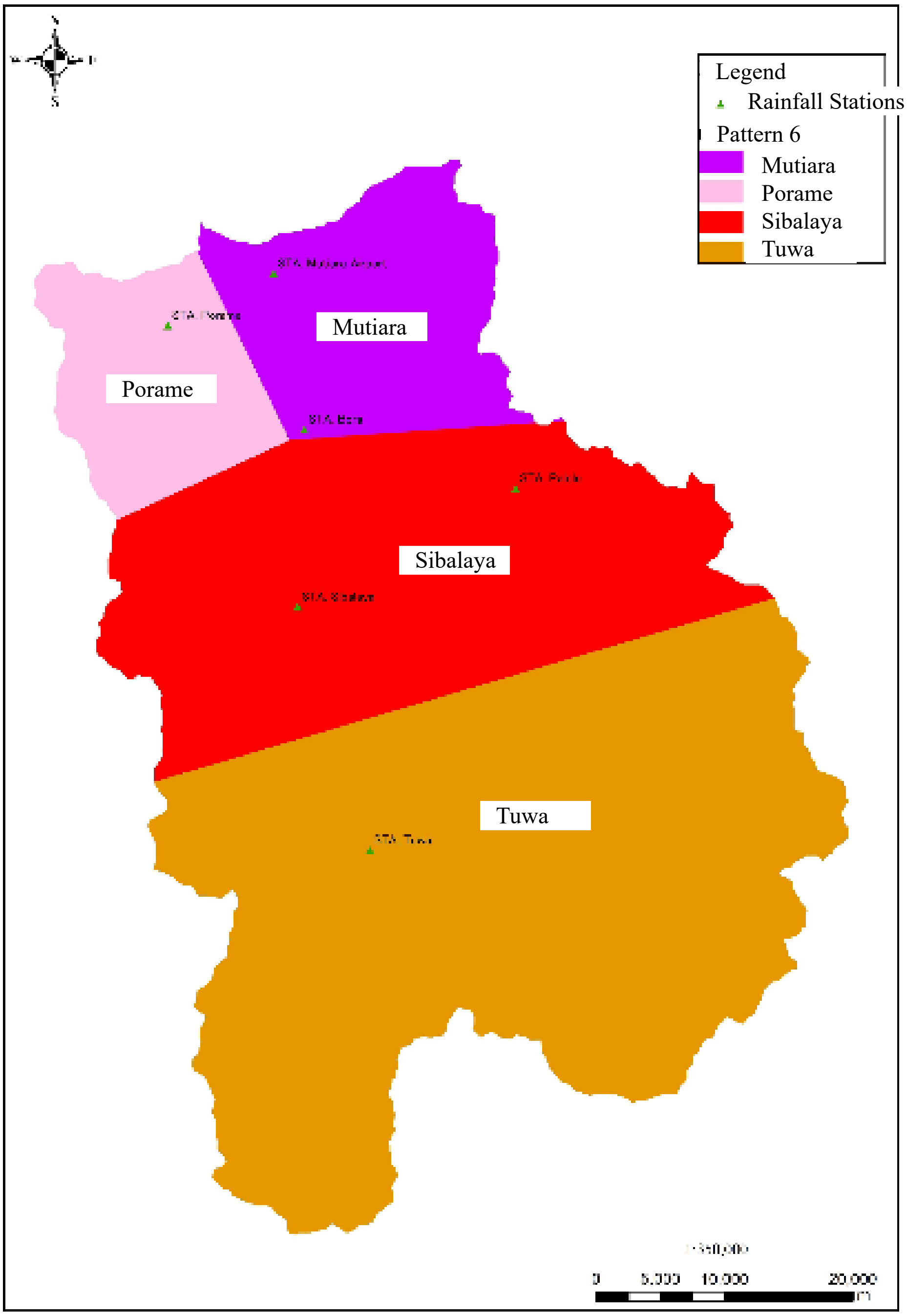
Total Area (km2)	Station	Accumulative Area (km2)	Proportion(%)
3051.986	Mutiara	217.485	7.1
3051.986	Sibalaya	642.988	21.1
3051.986	Bora	438.806	14.4
3051.986	Tuwa	1545.038	50.6
3051.986	Porame	207.669	6.8



Source: JICA Expert and JICA Study Team

Figure 6-62　Thiessen Pattern 5

Total Area (km2)	Station	Accumulative Area (km2)	Proportion(%)
3051.986	Mutiara	357.973	11.7
3051.986	Sibalaya	894.898	29.3
3051.986	Tuwa	1545.048	50.6
3051.986	Porame	254.067	8.3



Source: JICA Expert and JICA Study Team

Figure 6-63 Thiessen Pattern 6

The basin average annual maximum daily rainfall in the Palu River basin was extracted. The basin average annual maximum daily rainfall is shown below.

Table 6-14 Average Maximum Daily Rainfall in Palu River Basin

Year	Day	Basin average annual maximum daily rainfall
		(mm/day)
2000	1/26	89.19
2001	11/26	61.93
2002	1/23	48.70
2003	12/19	15.93
2004	2/17	19.19
2005	6/16	45.19
2006	1/29	20.16
2007	5/6	46.56
2008	3/7	47.63
2009	2/23	45.57
2010	7/29	45.51
2011	3/14	33.43
2012	12/30	41.61
2013	9/6	18.53
2014	11/27	14.84
2015	12/9	19.82
2016	9/21	37.97
2017	10/21	22.68

< Probability of Rainfall>

Rainfall analysis was conducted for a maximum of daily rainfall per year, and the rainfall probability was calculated. The calculation method of the probability rainfall is 6 methods, and the method are shown in table below.

Table 6-15 Condition for Distribution Calculation

Rainfall station	Mutiara, Porame, Bora, Palolo, Sibalaya, Tuwa
Calculation period	2000 - 2017
Rainfall duration	24 hour
Distribution method	Gumbel distribution (Gev), Square root exponential distribution (SqrtEt), General extreme value distribution (Gev), Log Pearson III distribution (Lp3Rs / Logp3), Takashi Ishihara (IshiTaka), Lognormal distribution (quantile method (LN3Q), probability weighted moment) Law (LN3PM)

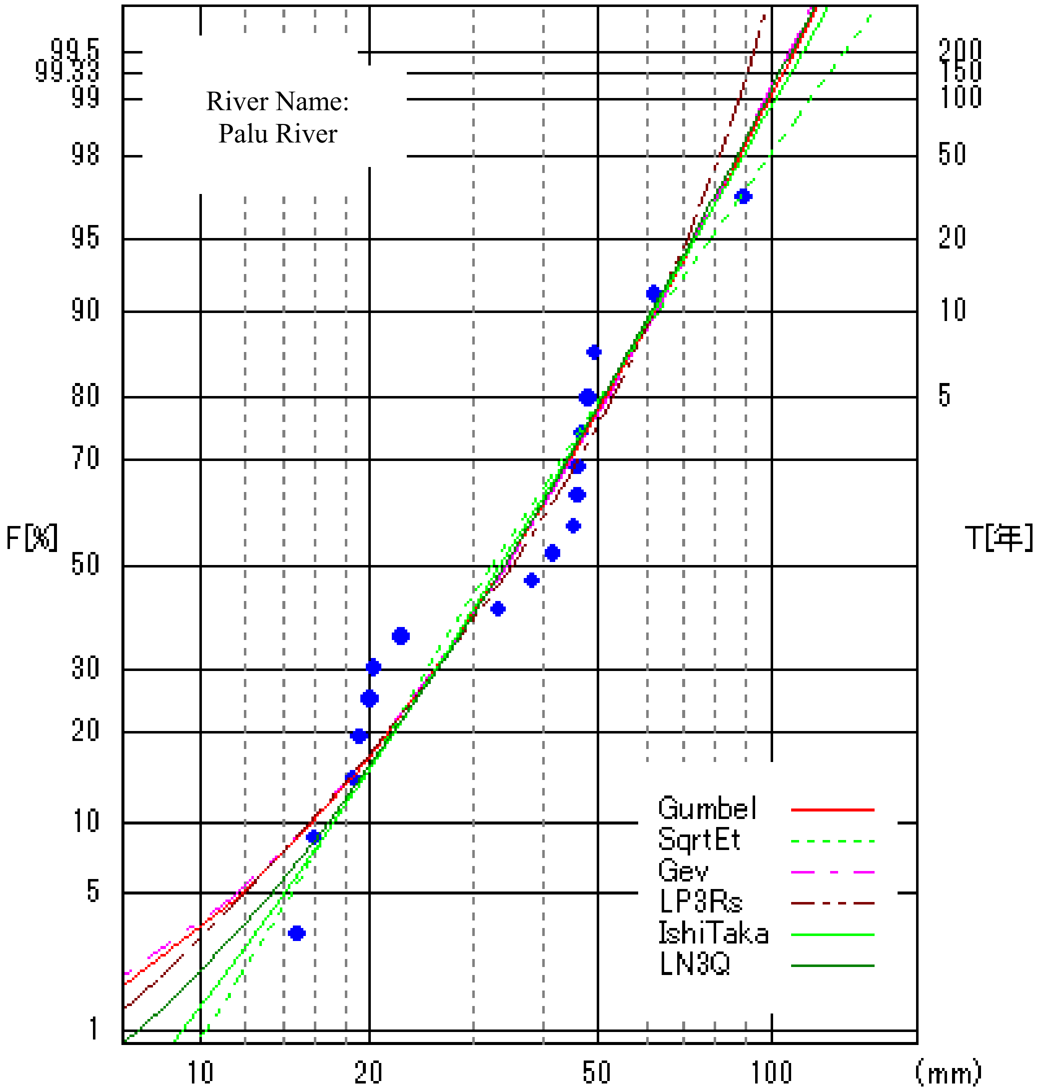
Source: JICA Expert and JICA Study Team

Table 6-16 Calculation Results for Probability of Rainfall

Return Period (year)	Probability Distribution					
	Gumbel	SqrtEt	Gev	LP3Rs	IshiTaka	LN3Q
2	34.3	32.5	34.4	35.2	33.6	34.1
3	42.4	40.6	42.6	43.7	41.5	42.1
5	51.5	50.4	51.7	52.7	50.6	50.9
10	63	64.1	62.9	62.8	62.3	62.1
20	73.9	78.5	73.6	71.3	73.8	72.8
30	80.2	87.4	79.7	75.8	80.6	79
50	88.1	99.1	87.2	81	89.2	86.8
80	95.3	110.4	94.1	85.3	97.2	94
100	98.7	116	97.3	87.2	101.1	97.4
150	104.9	126.4	103.2	90.6	108.2	103.6
200	109.3	134	107.3	92.8	113.3	108.1
400	119.9	153.1	117.1	97.8	125.9	119

Source: JICA Expert and JICA Study Team

Lognormal probability paper



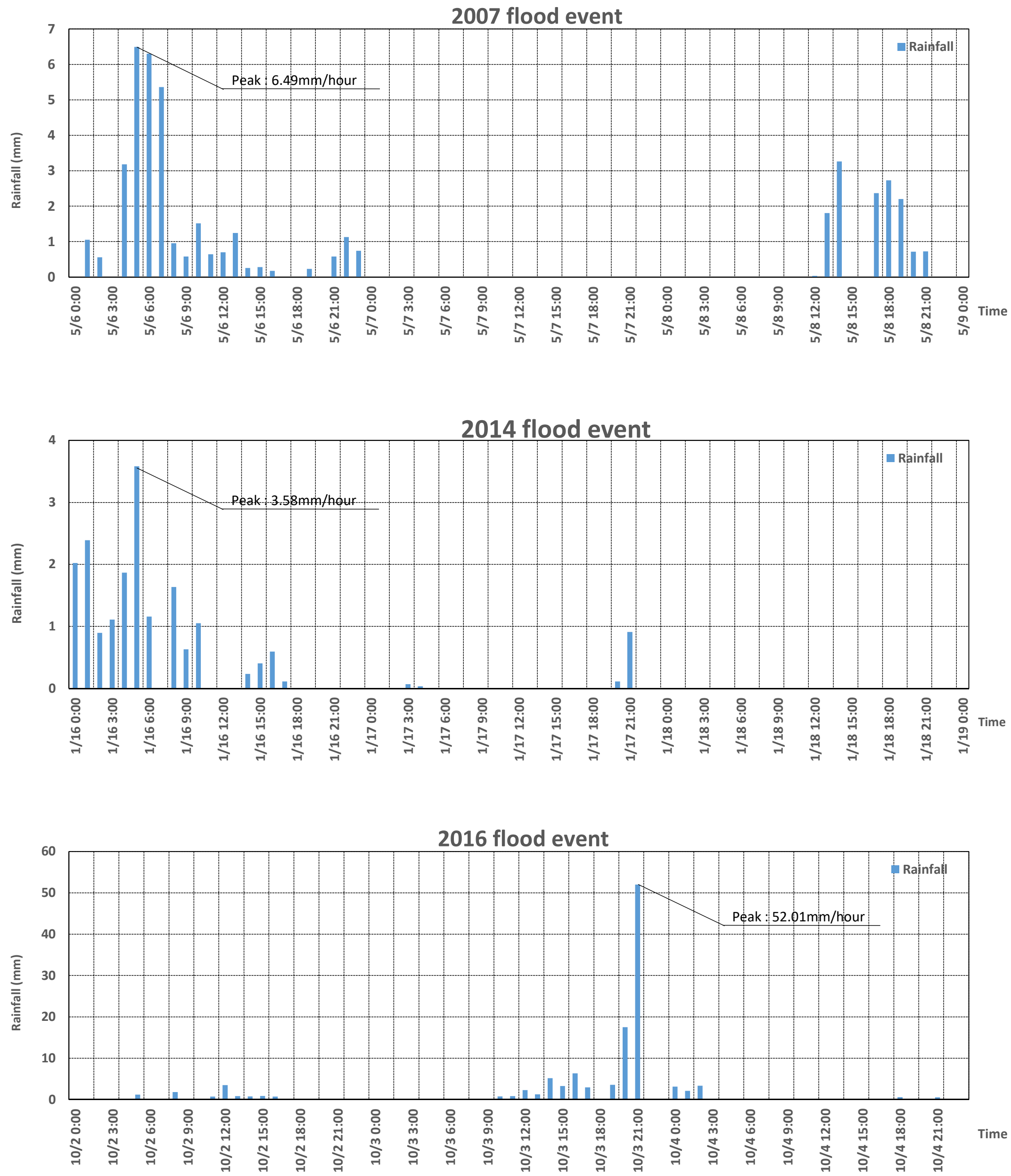
Source: JICA Expert and JICA Study Team

Figure 6-64 Result of Rainfall Analysis (2000 – 2017 maximum daily rainfall)

< Rainfall selection>

Basically, when selecting rainfall, it is essential to select from previous large-scale floods. Based on the results of previous floods data collection and actual field surveys and hearings, the inundation caused by floods in 17 Jan 2014, 3 Oct 2016, and 7 May 2007 were the largest. Therefore, this study selected these three flood events for first step of selection.

For the rainfall waveform (temporal and spatial distribution of rainfall), the rainfall waveform is basically based on the hourly rainfall. In this study, the satellite hourly rainfall data is used as mention above. The rainfall waveform of three events are shown in figure below.

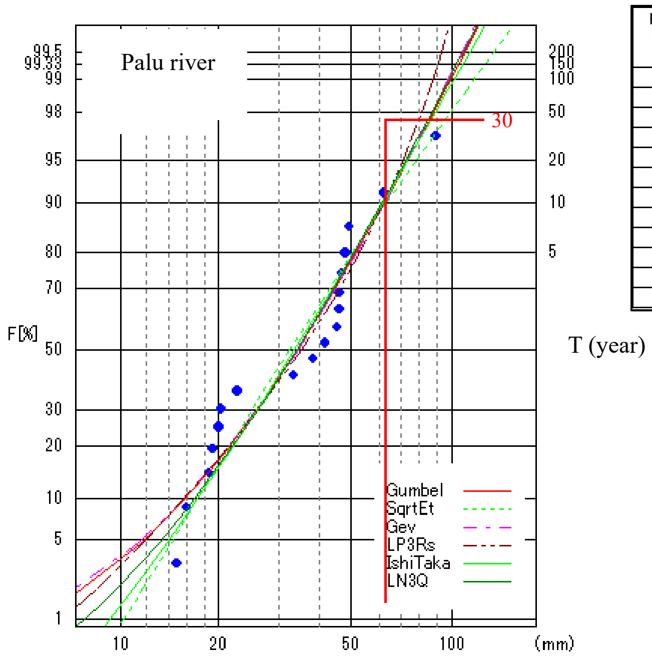


Source: JICA Expert and JICA Study Team

Figure 6-65 Rainfall Waveform of Three Flood events (Satallite Rainfall Data)

In the comparison of three rainfall waveform, the flood 2016 is the most reasonable rainfall in considering the amount of rainfall and rainfall duration. The amount of rainfall in the 3rd of October, 2016 is 95.83mm equal to more than 1/30 of probability. The rainfall waveform in 2016 is selected for inundation simulation.

Lognormal probability paper



Return Period (year)	Probability Distribution					
	Gumbel	SqrtEt	Gev	LP3Rs	IshiTaka	LN3Q
2	34.3	32.5	34.4	35.2	33.6	34.1
3	42.4	40.6	42.6	43.7	41.5	42.1
5	51.5	50.4	51.7	52.7	50.6	50.9
10	63	64.1	62.9	62.8	62.3	62.1
20	73.9	78.5	73.6	71.3	73.8	72.8
30	80.2	87.4	79.7	75.8	80.6	79
50	88.1	99.1	87.2	81	89.2	86.8
80	95.3	110.4	94.1	85.3	97.2	94
100	98.7	116	97.3	87.2	101.1	97.4
150	104.9	126.4	103.2	90.6	108.2	103.6
200	109.3	134	107.3	92.8	113.3	108.1
400	119.9	153.1	117.1	97.8	125.9	119

Source: JICA Expert and JICA Study Team

Figure 6-66 Return Period of Simulation Rainfall

c) Inundation simulation

Inundation depth will be estimated from the result for the simulation. Also it is important to compare the result of calculation with the actual inundation data of historical flood to calibrate accuracy of simulation. As mentioned above, flood hazard is created based on the flood simulation mainly considering the elevation and rainfall.

➢ **Running the RRI model**

The RRI model shall be run using the above prepared simulation model and input data. The calculation time differs depending on the number of calculation grids, calculation period and simulation time steps (it may take more than several hours / one day)

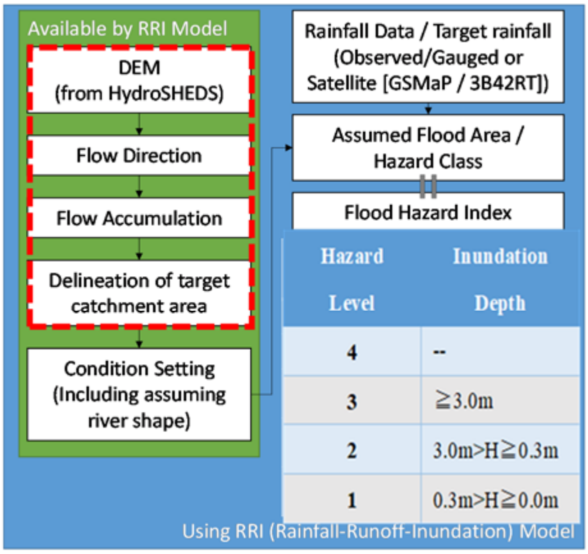
➢ **Visualize Output Data**

Flood inundation depth in each time step, maximum inundation depth, river discharge and water depth and so on will be visualized using the RRI_VIEWER. Also, calculation output can be visualized using the GIS and Google Earth and so on. The brief explanation of procedure of the RRI model is shown below.

➢ Brief explanation of procedure of the RRI model

Detailed procedure of the RRI model is explained by "Rainfall-Runoff-Inundation (RRI) Model ver. 1.4.2 (ICHARM, PWRI, Kyoto University, Takahiro SAYAMA)".

Table 6-17 General Description of each Step of the RRI Model (1/3)



< Preparation of DEM >

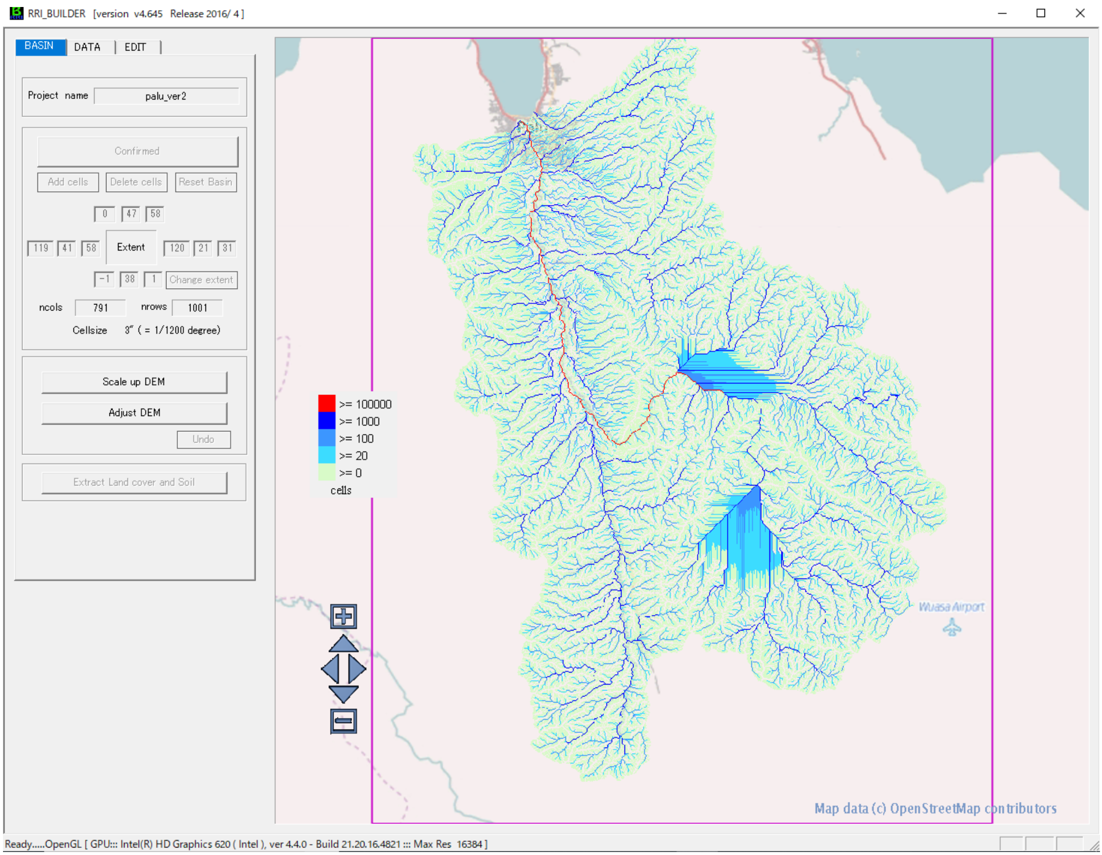
- ✓ DEM data (approximately 90 m / 500 m / 1 km DEM) are available from HydroSHEDS (https://hydrosheds.cr.usgs.gov/index.php)
- ✓ Also ASTER GDEM (approximately 30 m) is available from LP DAAC Global Data Explorer (https://gdex.cr.usgs.gov/gdex/)

< Preparation of Flow direction / Flow accumulation / Delineation of target catchment area using GIS >

- ✓ Create a point shapefile to identify a catchment outlet
- ✓ Delineate a target catchment with the outlet and flow direction information
- ✓ Extract DEM, flow direction and accumulation using the catchment raster
- ✓ Convert the DEM, flow direction and accumulation to ASCII data

Above procedure can be conducted using the "Hydrology tool set of the ArcGIS"

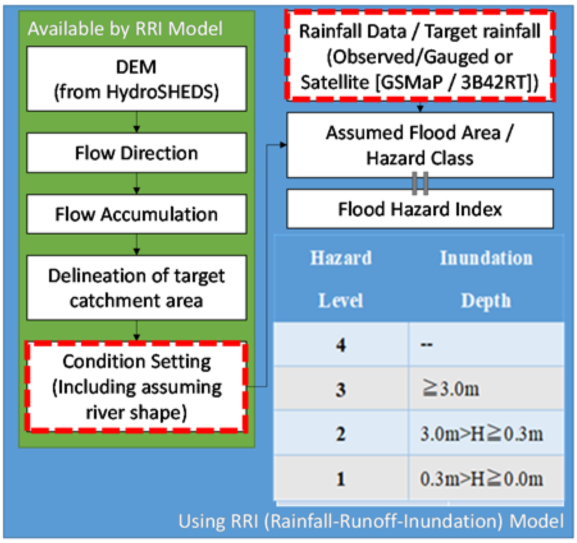
Source: JICA Expert and JICA Study Team



Source: JICA Expert and JICA Study Team
Note: Example of the Palu River, the map showing the flow accumulation

Figure 6-67 GUI of the RRI Model

Table 6-18 General Description of each Step of the RRI Model (2/3)



< Condition Setting (including assuming river shape) >

✓ River condition / River shape can be produced based on the following methodology

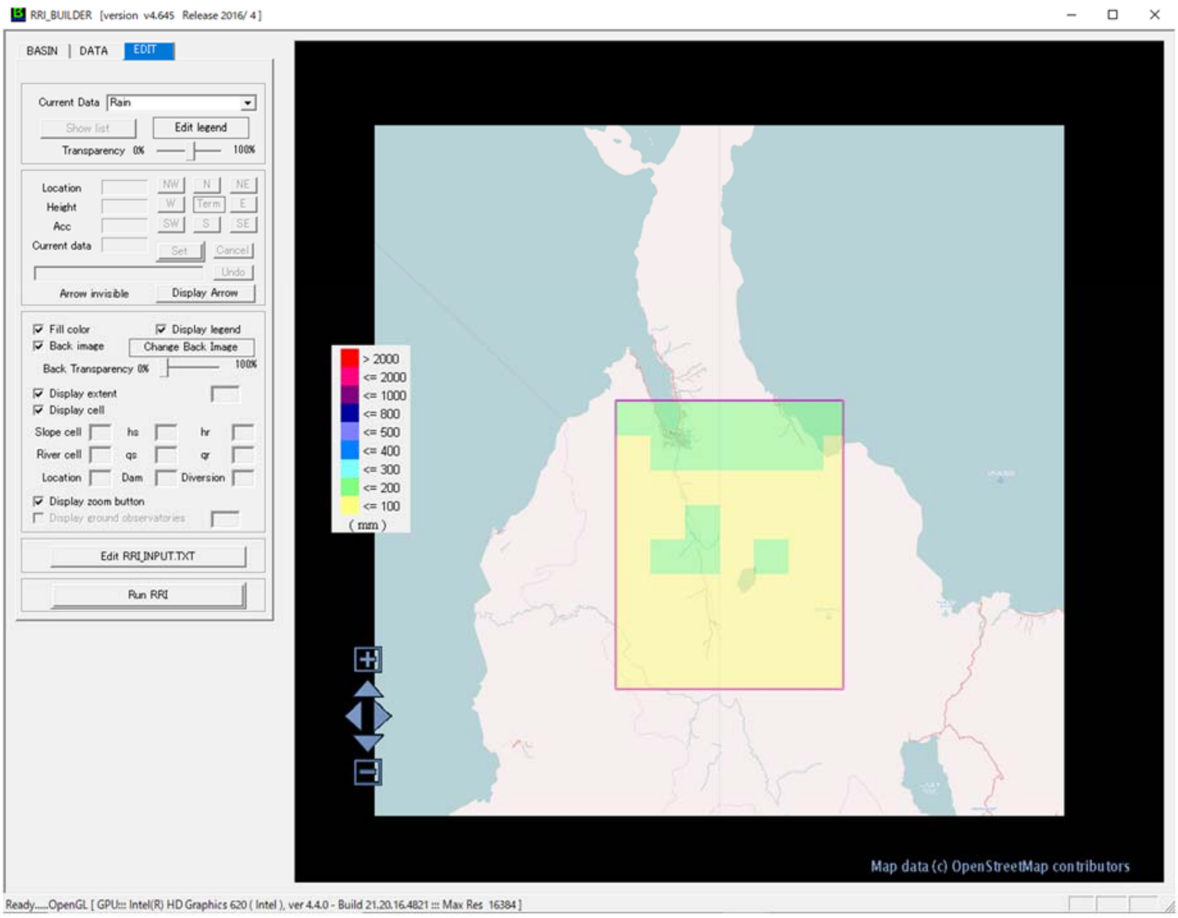
> A one-dimensional diffusive wave model is applied to river grid cells. The geometry is assumed to be rectangle, whose shapes are defined by width W, depth D and embankment height He. When detailed geometry information is not available, the width and depth are approximated by the following function of upstream contributing area A [km2].
>
> $W = C_w A^{S_w}, \quad D = C_D A^{S_D}$
>
> Where, Cw, Sw, C_D and S_D are geometry parameters. Here the units of "W" and "D" are meters.

✓ Some other conditions, such as simulation time step, roughness of river channel / cells will be set

< Rainfall Data >

✓ There are 3 options for preparation of rainfall data
1) Gauged rainfall with Thiessen polygon interpolation
2) GSMaP satellite based rainfall (it has high resolution than 3B42RT)
3) 3B42RT satellite based rainfall

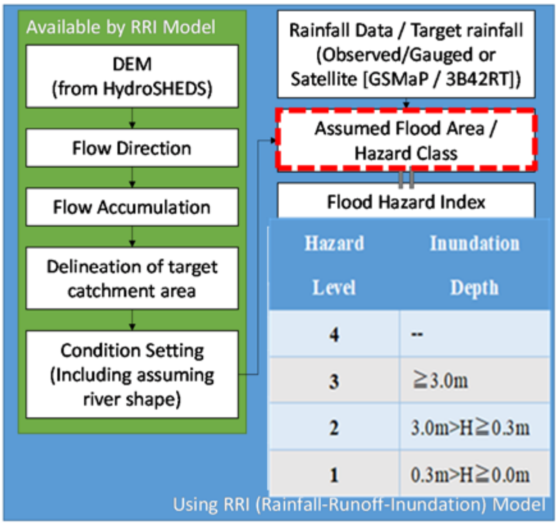
✓ Download the data and arrange the data for the RRI model format



Source: JICA Expert and JICA Study Team

Figure 6-68 Example of the Rainfall Data used for the Palu River

Table 6-19 General Description of each Step of the RRI Model (3/3)



Hazard Level	Inundation Depth
4	--
3	≧3.0m
2	3.0m>H≧0.3m
1	0.3m>H≧0.0m

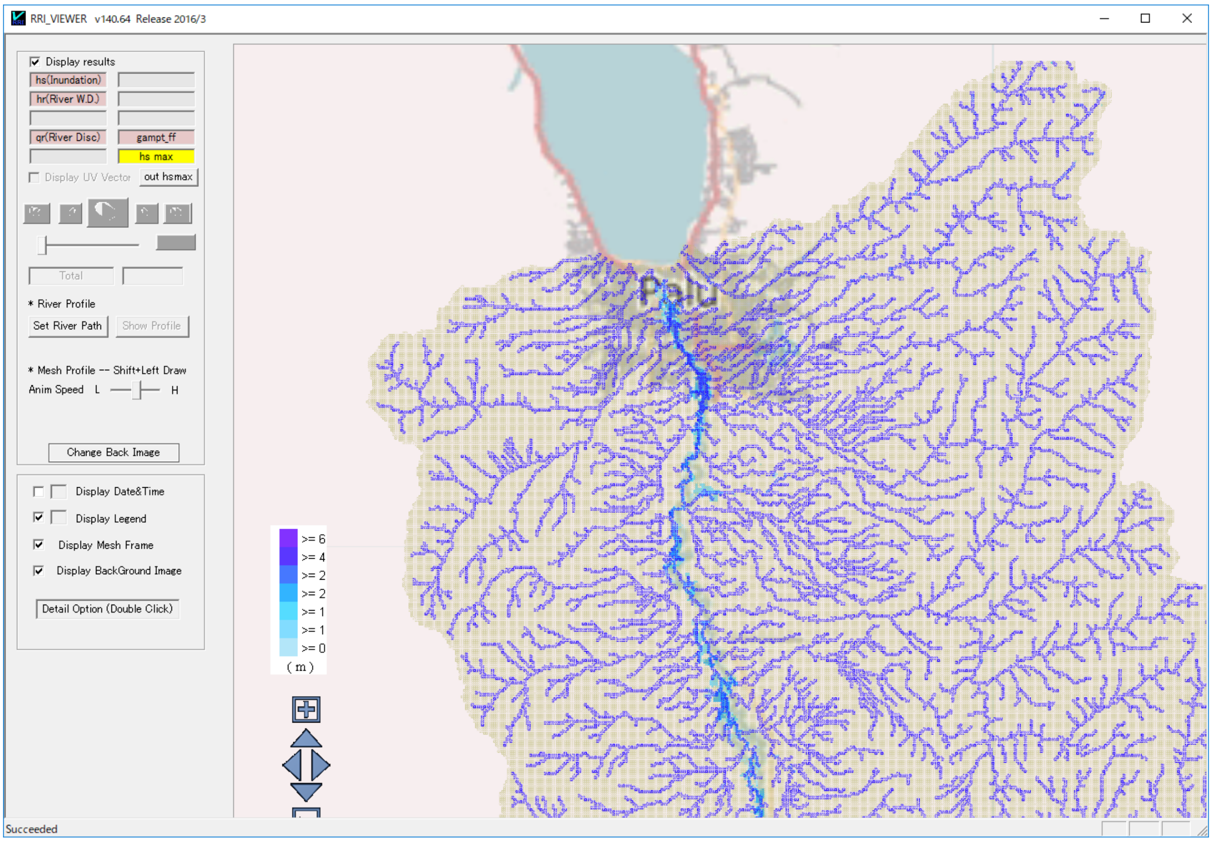
< Running the RRI model >

- ✓ Run the RRI model using the above prepared simulation model and input data
- ✓ Calculation time differs depending on the number of calculation grids, calculation period and simulation time steps (it may take more than several hours / one day)

< Visualize Output Data >

- ✓ Flood inundation depth in each time step, maximum inundation depth, river discharge and water depth and so on can be visualized using the RRI_VIEWER
- ✓ Also, calculation output can be visualized using the GIS and Google Earth and so on

Source: JICA Expert and JICA Study Team



Source: JICA Expert and JICA Study Team

Figure 6-69 Example of the Calculation Result (Maximum Inundation Depth)

3) Setting up Hazard Level

Flood hazard level should be set based on the RRI simulation of inundation depth. Particular condition listed below shall be considered to set the hazard level. Flood disaster occurs based on the longer rainfall duration or total amount of rainfall instead of immediate impact, and the level of flood disaster is somewhat assumable. Therefore, HL-4 is not set in the flood hazard map since evacuation time can be secured easily.

When the water level exceeds 3.0m, which is about second floor level of the buildings, the safety of the ground floor level could become danger for life so that water level more than 3.0m is set as HL-3. In addition, when flood level exceeds 0.3m, the ground level of buildings should also begin to flood, so flood level 0.3m is set as HL-2. The following table summarize the flood hazard level.

Table 6-20 Flood Hazard Level

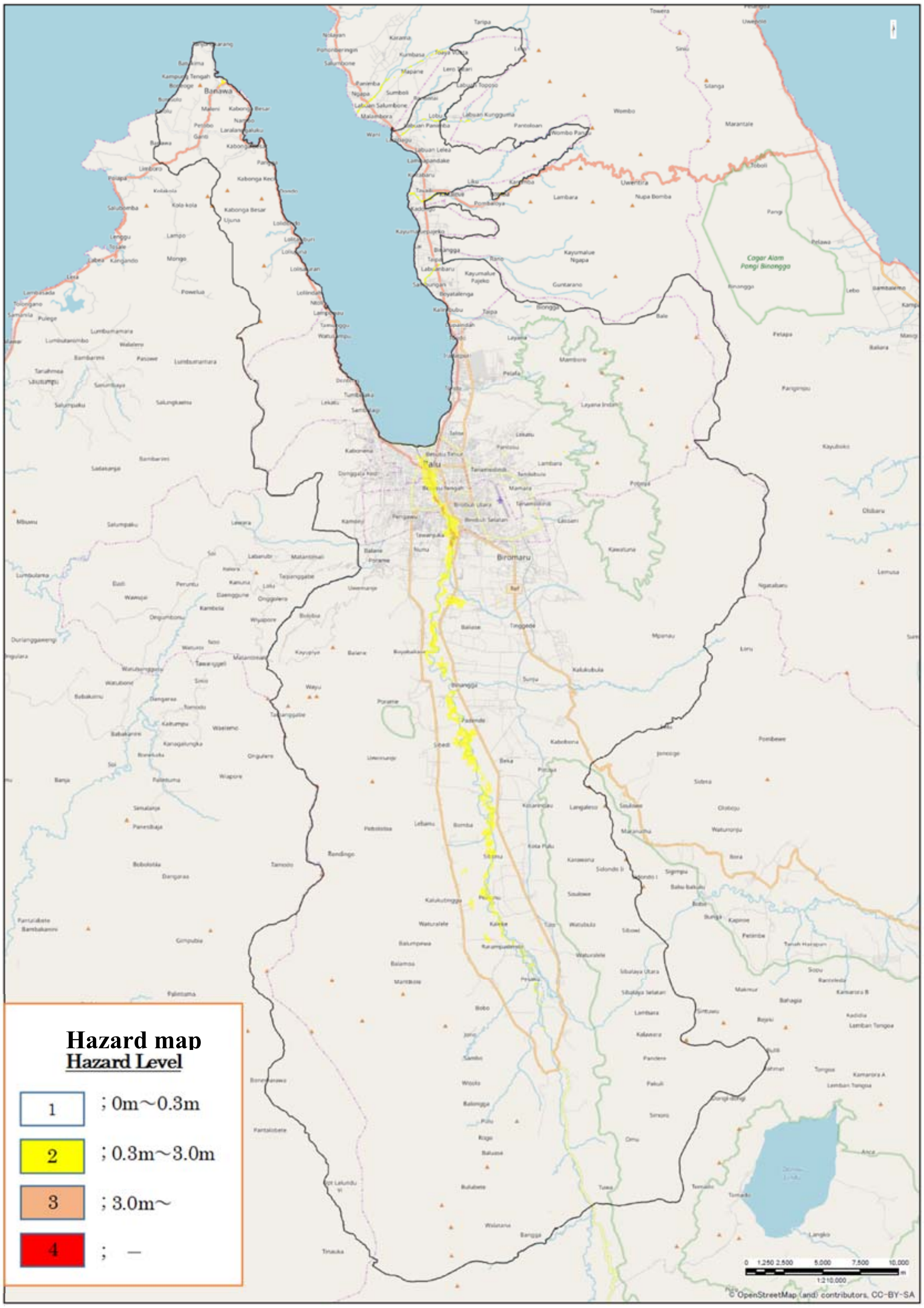
Hazard Level	ZRB	Inundation Depth	Description
HL-4	ZRB-4		Flood inundation depth could be easily assumed through the duration of rainfall. Therefore, HL-4 (ZRB-4) is not set as evacuation is possible.
HL-3	ZRB-3	H≧3.0m	Where inundation depth exceeds 3.0m, the second floor level could be flooded, thus the area expected for over 3.0m inundation depth should be prepared for earlier evacuation for human life protection. Any property could be lost or damaged in this area.
HL-2	ZRB-2	0.3m≦H＜3.0m	Where inundation depth is from 0.3m through 3.0m, flood can exceeds above the ground flood level to second floor level. However, evacuation to the second floor may protect human lives. Besides, any property on the ground level could be lost or damaged.
HL-1	ZRB-1	H＜0.3m	There is hardly flood occurring and the level of flood is around the ground level. Therefore, there is not much damage or loss to the lives and properties.

Source: JICA Expert and JICA Study Team

The areas of HL-3 and HL-2 should have the early warning system as a soft component countermeasure.

4) Creation of Hazard Map

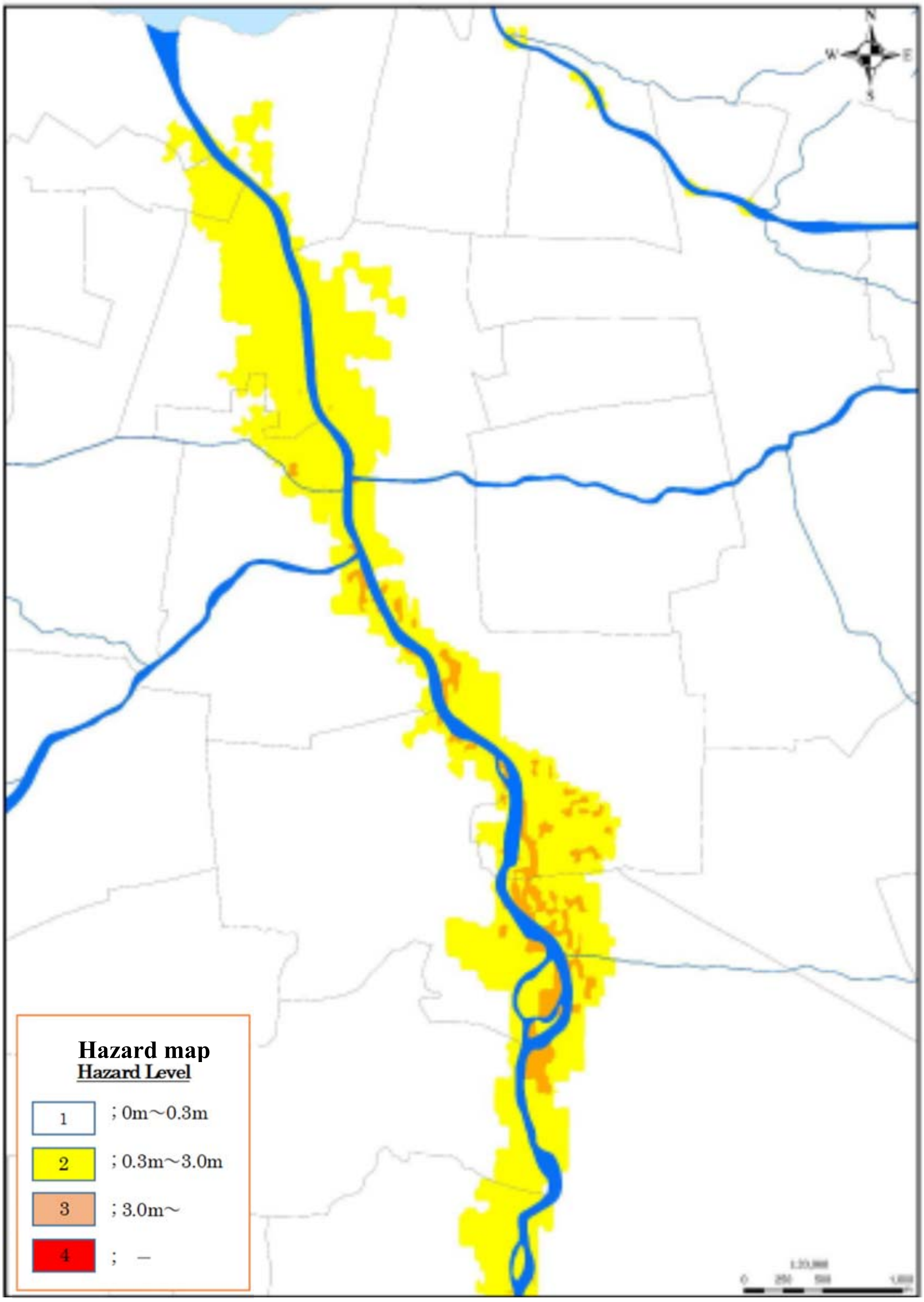
The flood hazard map based on the area and depth of inundation is created from results of the simulation.



Source: JICA Expert and JICA Study Team

Figure 6-70 Example of Flood Hazard Map

In particular, the following is an extract of the hazard map in the Palu city.



Source: JICA Expert and JICA Study Team

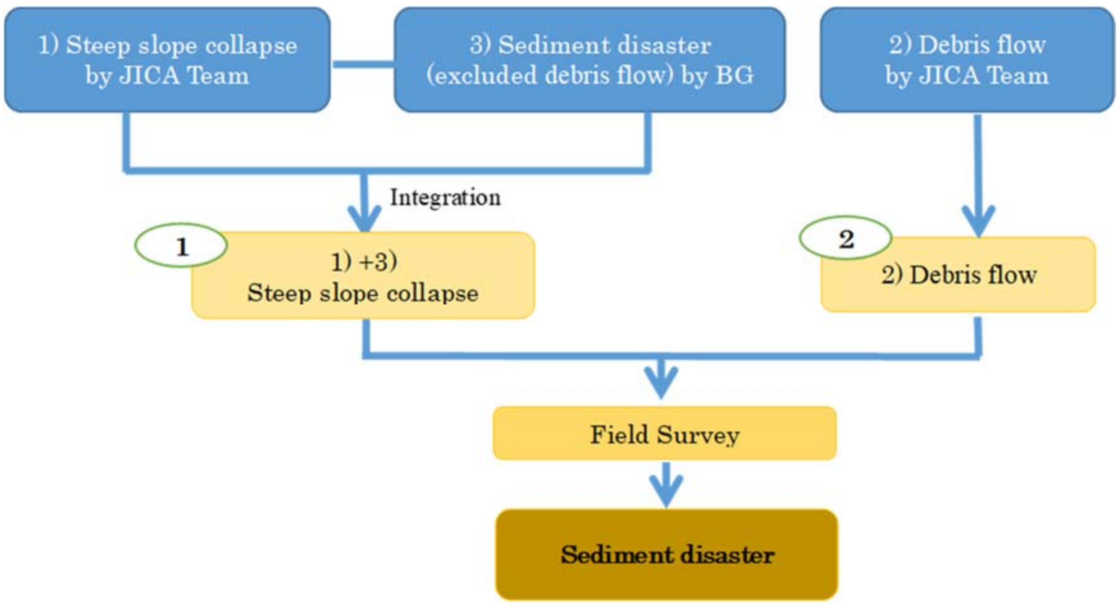
Figure 6-71　Flood Hazard Map in Palu City

6-1-5 Sediment Disaster

(1) Basic concept of hazard map preparation

Sediment hazard maps were classified into three types, i.e. steep slope collapse, debris flow, and landslides. Since landslide is a phenomenon where some or the entire clump of earth on the slope move slowly under the influence of groundwater and gravity and its occurrence is difficult to predict, landslide is excluded from the scope of this sediment hazard map.

Sediment hazard map was prepared for two types of sediment hazard (steep slope collapse and debris flow) by analysis using 30 m mesh satellite data. After creating a draft hazard map based on data analysis, JICA Study Team members conducted a field survey to check the actual field situation, and refined the draft hazard map with the results of the field survey. The following is the flow for preparing the sediment hazard map.



Source: JICA Experts and JICA Study Team

Figure 6-72 Preparation flow of sediment disaster hazard map

(2) Criteria of hazard level

Hazard levels for sediment disasters (steep slope collapse and debris flow) were created based on desk studies and field survey results.

a) Steep slope collapse

The steep slope collapse criteria was created by superimposing the criteria created by BG (Indonesian side) while referring to Japan's steep slope law. The criteria was set with reference to Law on Prevention of Disasters due to Collapse of Steep Slopes in Japan. The steep slope law in Japan is shown in Table 6-21.

Table 6-21 Steep Slope Collapse Hazard Level

Hazard Level	Slope & Height	Setting range
4	Slope ≥ 30° & Height ≥ 5 m	The areas where the slope inclination is 30° or more, and height of steep sloping land is 5 m or more. (Hazard Level-4)
3	Around hazard level 4	The boundaries are drawn at 2 times height of steep sloping land (less than 50 m) outside of the areas from foot of steep sloping land, and 10 m outside of the areas from top of steep sloping land by topography analysis. (Hazard Level-3)
2	30° > Slope ≥ 9°	The areas where the slope inclination is not less than 9° and not more than 30°. (Hazard Level-2)
1	9° > Slope	The areas where the slope inclination is less than 9°. (Hazard Level-1)

Source: JICA Experts and JICA Study Team

Besides, the following criteria of JICA Study Team and BG were adjusted for overlaying both of the hazard maps.

BG slope gradient criteria	BG hazard level
-	-
Sloop≧33°	High
33° ＞Sloop≧17°	Moderate
17° ＞Sloop≧8°	Low
Sloop>8°	Very low

JICA hazard level	JICA criteria	Description
Very high	Sloop≧30 Height≧5m	Very high risk area People's habitation is prohibited
High	Around Hazard Level4	High risk area Countermeasures need to implement
Moderate	30° ＞Sloop ≧9°	Medium risk area
Low	9° ＞Sloop	Low risk area

Source: JICA Experts and JICA Study Team

Figure 6-73 BG and JICA's Hazard criteria comparison, adjustment result

b) Debris flow

Regarding the debris flow, the criteria was set with reference to Japanese technical standard (Sediment Disasters Prevention Act).

Table 6-22 Debris Flow Hazard Level

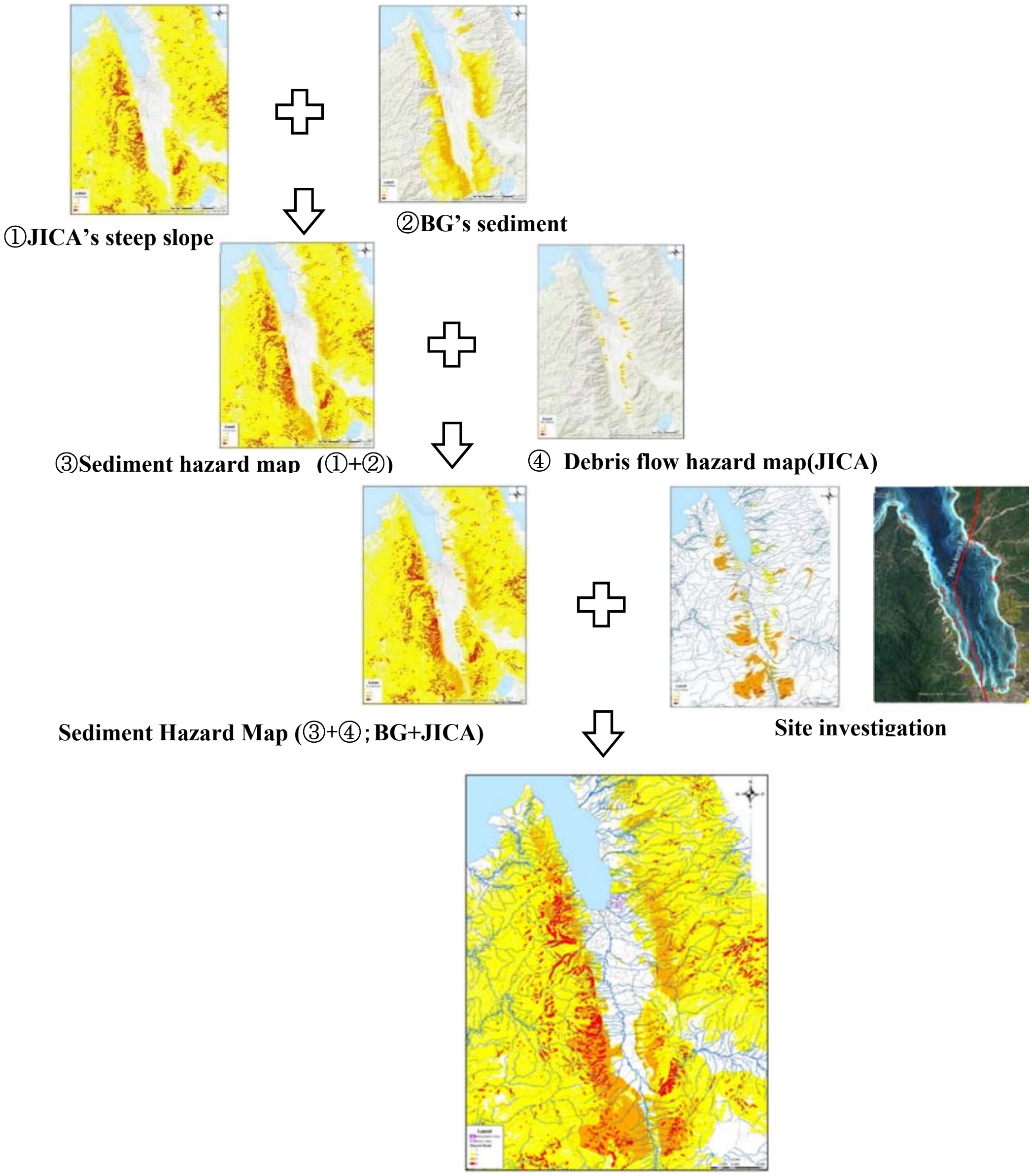
Hazard Level	Slope & Width	Setting range
4	-	Not set, because evacuation time is possible to be secured because debris flow occurs when rainfall continues, different from the disaster caused by the earthquake.
3	Longitudinal section • Start point – 2° slope Cross section • Relative height points which 5 m higher than center point • Spread points which the crossing points of cross section and the spread lines with 10° (as shown in the following paragraph (b))	Debris flow has its straight running tendency. However, if the river has not been improved, natural debris flow is normally spread in 30° angle. If the river was not improved, debris flow can easily overflow the river. Here, the area around the river was judged to be particularly dangerous, and a debris flow spread range of 10° or less was set as a particularly dangerous area. The maximum depth of debris flow is assumed about 5 m. Based on this assumption, Hazard Level-3 is separately defined as around the river and debris flow spread range of 10° or less.
2	Longitudinal section • Start point – 2° slope Cross section • Spread points which the crossing points of cross section and the spread lines with 30°	Based on this assumption, Hazard Level-2 is separately defined as debris flow spread range of 10° to 30°.
1	Other areas	-

Source: JICA Experts and JICA Study Team c）Field Survey

JICA Study Team conducted a field survey of steep slopes and refined the draft hazard map further based on data analysis. The Team conducted a field survey on steep slopes and added it to the results of the above hazard analysis. Based on the field survey results, the steep slope disasters occurred in Poi River and Banga River basins were reflected in the hazard map. Further, coastal steep slope collapses were observed at 16 locations along the Palu Bay. The result of this survey was added into the hazard map. In addition, JICA Study Team also conducted a field survey on debris flow. As a result, traces of debris flow were found in the Poi, Banga, and Salua basins, which were reflected in the hazard map.

1) Sediment disaster hazard map after the refinement

The overall flow of the sediment hazard map and the final hazard map are as follows.



Source: JICA Experts and JICA Study Team

Figure 6-74 Sediment disaster hazard map

(3) Method for Creating Sediment Hazard Map

In order to create hazard map of S=25,000, it is necessary to review and elaborate hazard area. Therefore, the JICA Study Team decided to clarify the hazard area and hazard level using satellite data of 30 m mesh and create the hazard map. The sediment disaster is classified three (3) types such as below.

1) Steep Slope Collapse

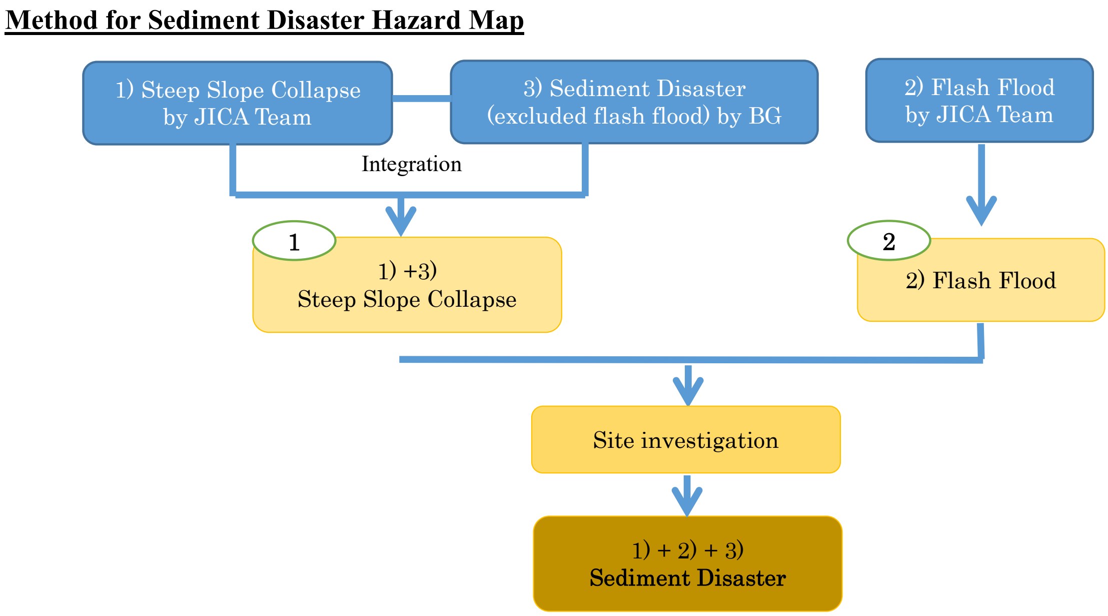
2) Flash Flood

3) Landslide

Landslide is difficult to predict because Landslide's speed is very slow. Therefore, landslide is excluded from target hazard in JICA study, JICA Study Team create the hazard maps of 1) Steep Slope Collapse and 2) Flash Flood.

Moreover, BG had created the hazard map of Sediment Disaster (excluded flash flood disaster) in previous study. Therefore, this study will reflect the result into the hazard map of Steep Slope Collapse created by JICA Study Team. As a result, the hazard map of Steep Slope Collapse and Flash Flood shall be created.

And finally, the hazard map about the whole sediment disaster was put together into one.

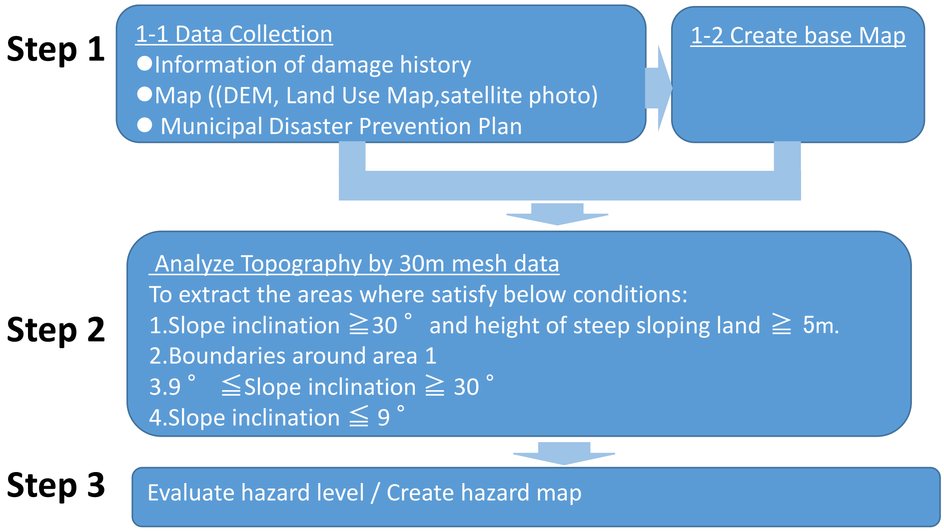


Source: JICA Expert and JICA Study Team
Note: It is important that the site survey results and disaster history of the study site are reflected in the final Sediment Disaster Hazard Map.

Figure 6-75 Method for Creating Sediment Disaster Hazard Map

1） JICA Steep Slope Collapse and BG Sediment Hazard Map(Landslide)

The flowchart of the method of creating a hazard map for Steep Slope Collapse is shown below.



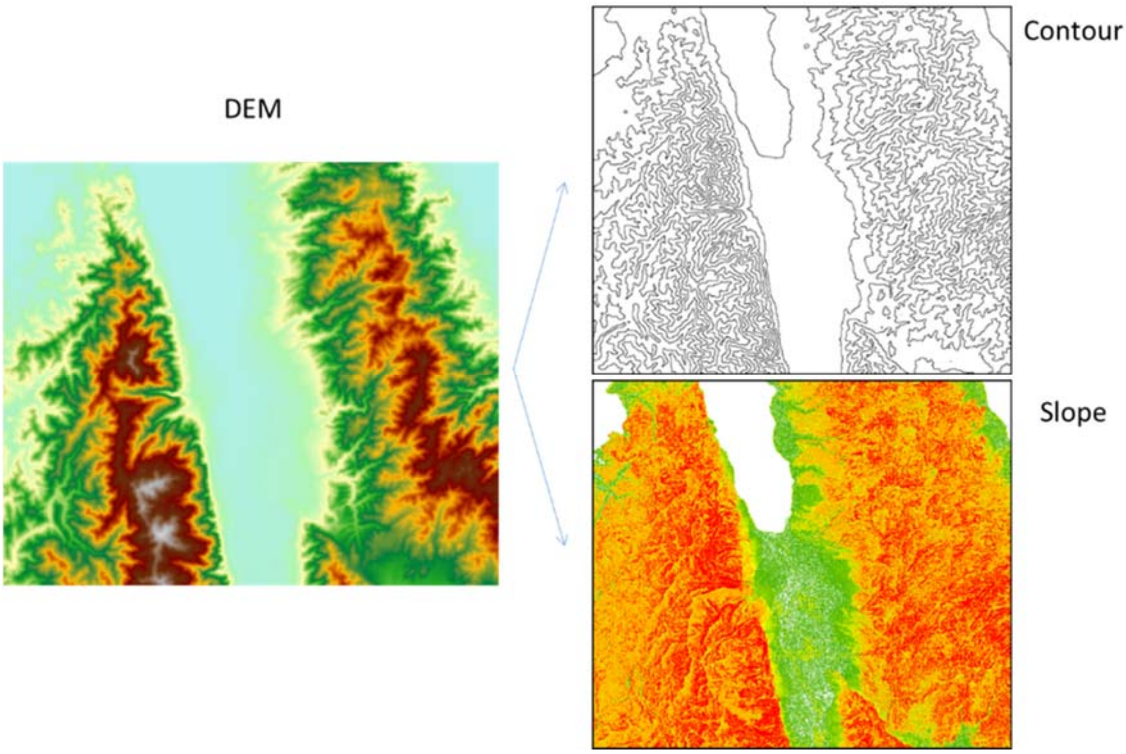
Source: JICA Expert and JICA Study Team

Figure 6-76 Flowchart for Creating a Hazard Map for Steep Slope Collapse

The details of the creation method of hazard map is shown below step by step.

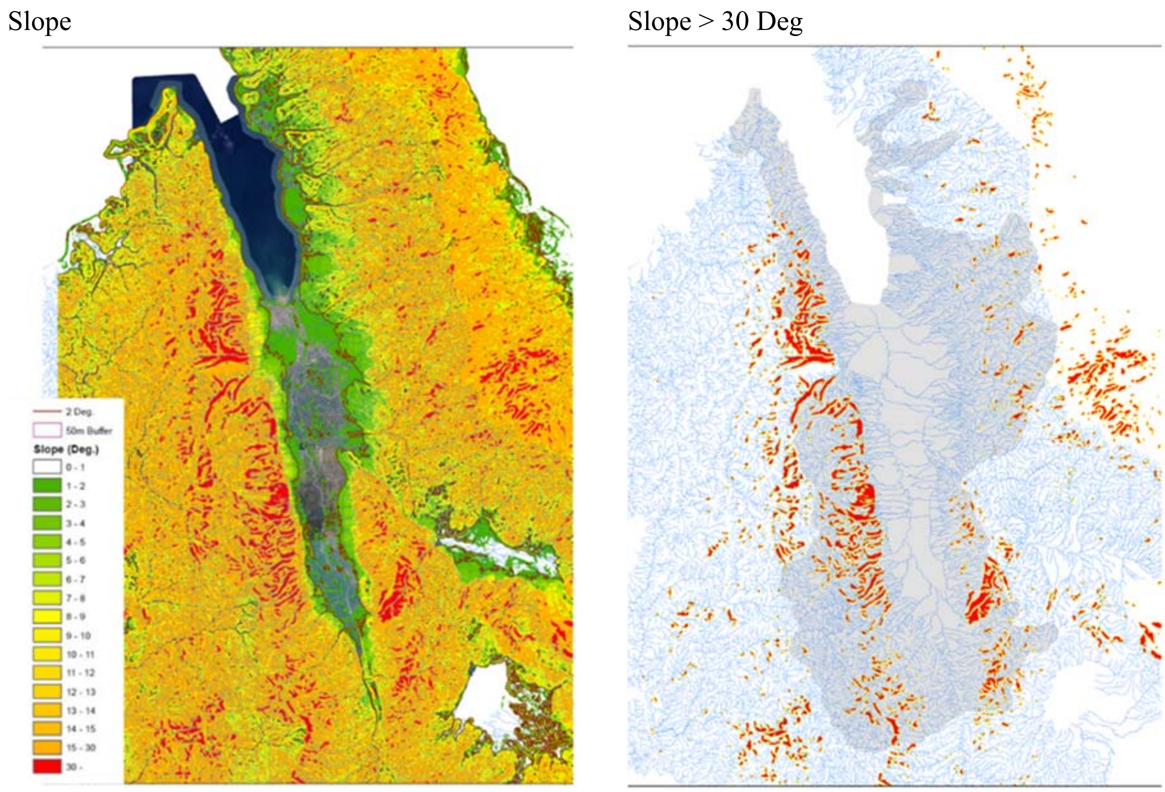
a) Data Collection and Create base map

The satellite image data (DEM) of 30m mesh shall be collected to understand geomorphology characteristics. The hazard of steep slope collapse is mainly evaluated by slope inclination and height of steep sloping land. In order to analyze slope inclination and height of steep slope we created contour map and the slope map of the study site by DEM data. Example of the contour map and the slope map are shown in the following figure.



Source: JICA Expert and JICA Study Team

Figure 6-77 Image of Creating of Contour Map and Slope Map

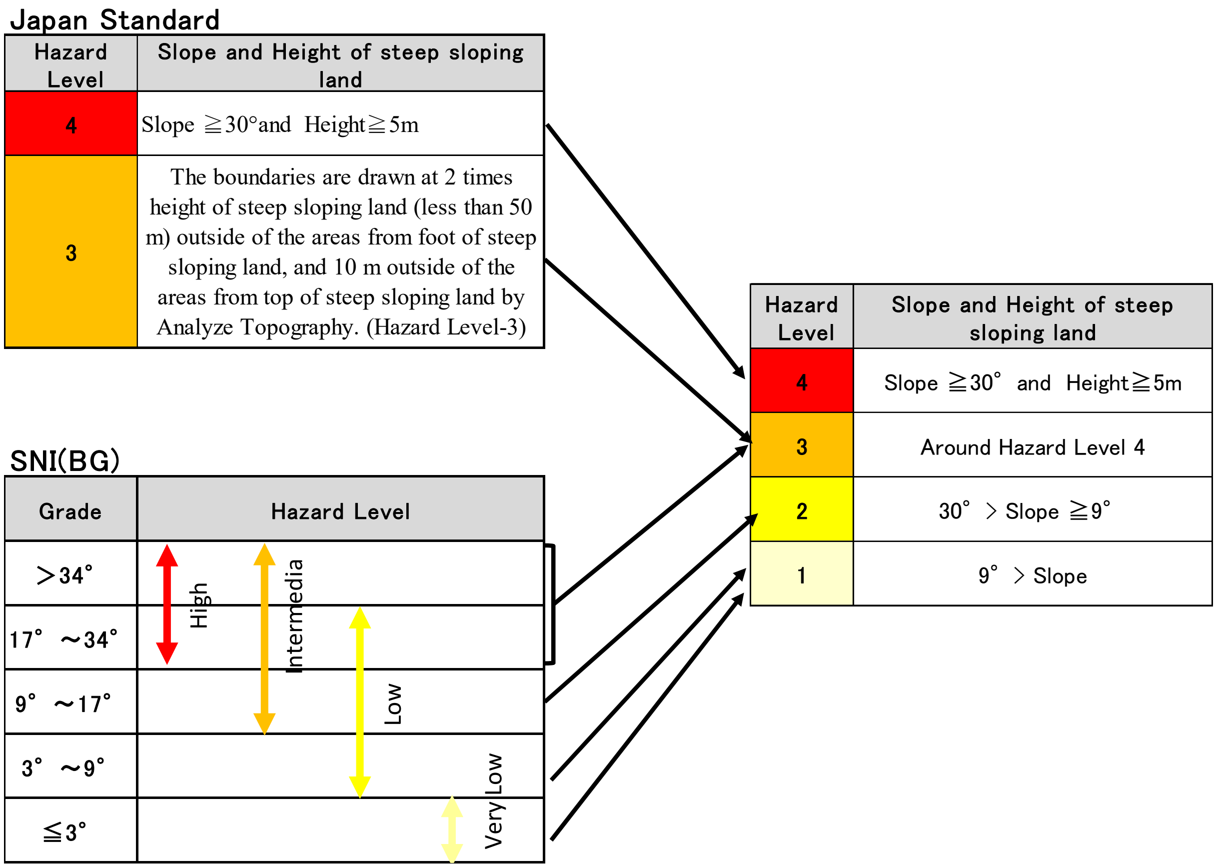


Source: JICA Expert and JICA Study Team

Figure 6-78 Example of Slope Map

b) Hazard Criteria

In order to set up the Disaster Hazard Criteria, Japanese technical standard (Steep Slope Law, Landslide Prevention Law) was borrowed. Under the standard, any sloped lands with 30 degree or steeper angle (over 5m long) are considered as highly dangerous and hazardous (hazard level 4) where people's habitation is prohibited. Also 10m from top of the area of hazard level 4 and 50m from foot of the area of hazard level 4 are considered dangerous zone (to be set as buffer zone/ hazard level 3). This standard should contribute well to evaluate the hazard level of steep sloped lands in Sulawesi region. On the other hand, Standar Nasional Indonesia (SNI) 8291:2016 (Badan Standardisasi Nasional) defines 3 degree, 9 degree, 17 degree and 36 degree slopes for definition of hazard level, and the risk level between 9 degree and 36 degree is basically considered to be medium dangerous (Intermediate). Based on this criterion, the JICA study team has applied 9 degree slope as threshold value for Hazard Level. That means the slope lands with 9 degree or more and less than 30 degree are set as hazard level 2 (has minor disaster risk) and the slope lands with less than 9 degree are set as hazard level 1(refer to Figure 6-79). Finally, the hazard criteria is decided as show in Table 6-23 and Figure 6-80.

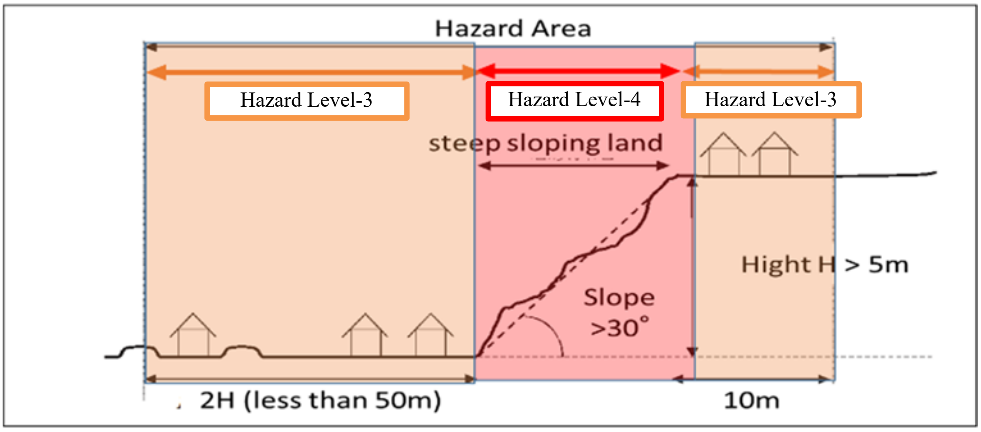


Source: JICA Expert and JICA Study Team

Figure 6-79 Consolidation of Hazard Level

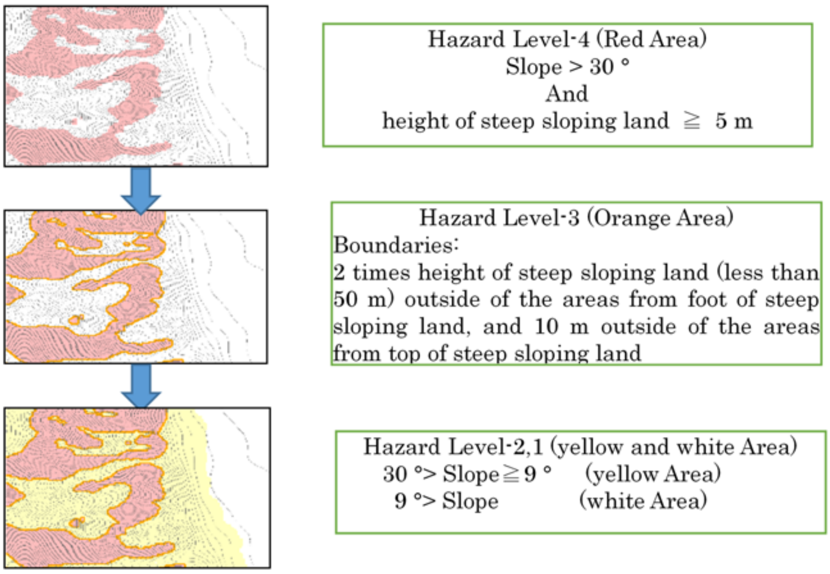
Table 6-23 Classification of Hazard Level for Steep Sloping Collapse

Hazard Level	Sloop & Height	Setting range
4	Sloop≧30° & Height≧5m	The areas where the slope inclination is 30 ° and more and height of steep sloping land is 5 m or more. (Hazard Level-4)
3	Around Hazard Level 4	The boundaries are drawn at 2 times height of steep sloping land (less than 50 m) outside of the areas from foot of steep sloping land, and 10 m outside of the areas from top of steep sloping land by Analyze Topography. (Hazard Level-3)
2	30° > Sloop ≧9°	The areas where the slope inclination is not less than 9 ° and not more than 30 °. ((Hazard Level-2)
1	9° > Sloop	The areas where the slope inclination is less than 9 °. (Hazard Level-1)



Source: JICA Expert and JICA Study Team

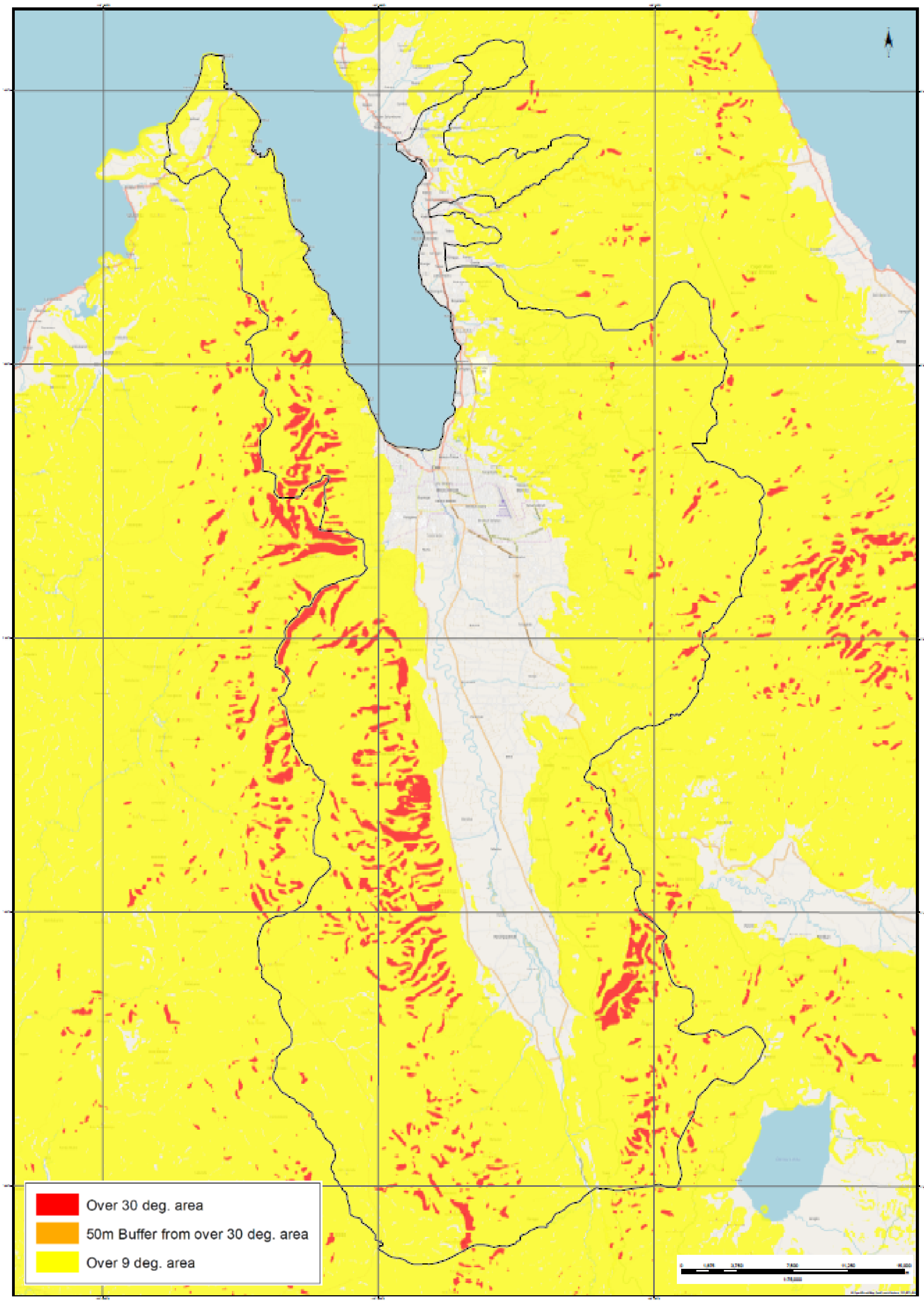
Figure 6-80 Division of Areas of Hazard Level 3 and 4



Source: JICA Expert and JICA Study Team

Figure 6-81 Method of Hazard Map

The hazard map (step 2) formulated based on the above results (1) and (2) is as follows.



Source: JICA Expert and JICA Study Team

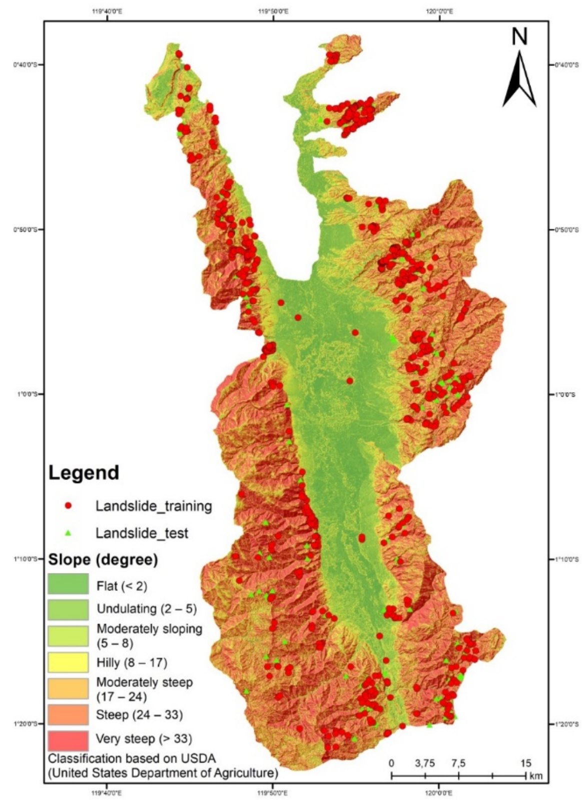
Figure 6-82 Hazard Map for Steep Slope Collapse (Step2)

2） BG Sediment Hazard Map (Landslide)

a） Method of hazard map for BG sediment hazard map (landslide)

The hazard map for Land slide was created by BG based on the six (6) parameters such as Slope Gradient, Elevation, Slope Aspect, Lithology, PGA (Peak Ground Acceleration) and Land Use. BG Landside hazard map was not included flash flood evaluation. The map created by BG is shown below.

In addition, the slope gradient was extracted from the digital elevation model (DEM) of TerraSAR X satellite data as the first derivative of slope. It classified into 7 slope gradient classes (threshold value : 2°,5°, 8°, 17°, 24°, 33°).



Source: BG

Figure 6-83 Slope Gradient Map

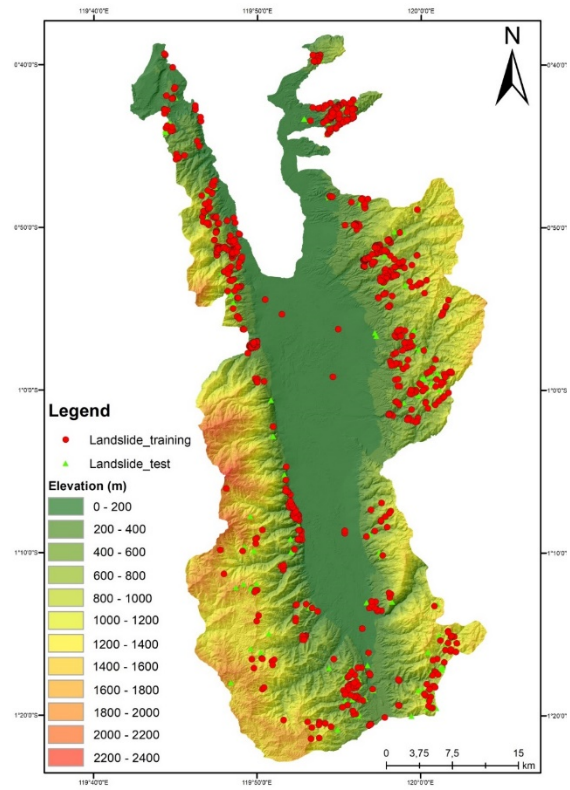


Figure 6-84 Elevation Map

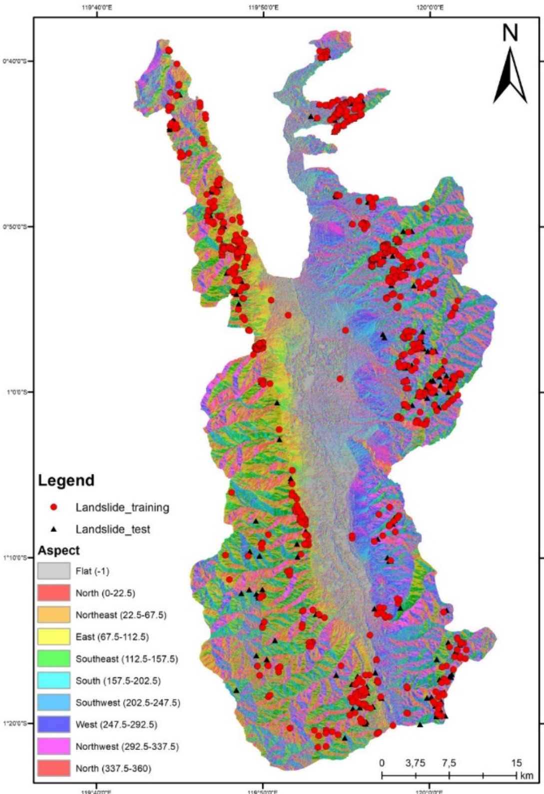


Figure 6-85 Slope Aspect Map

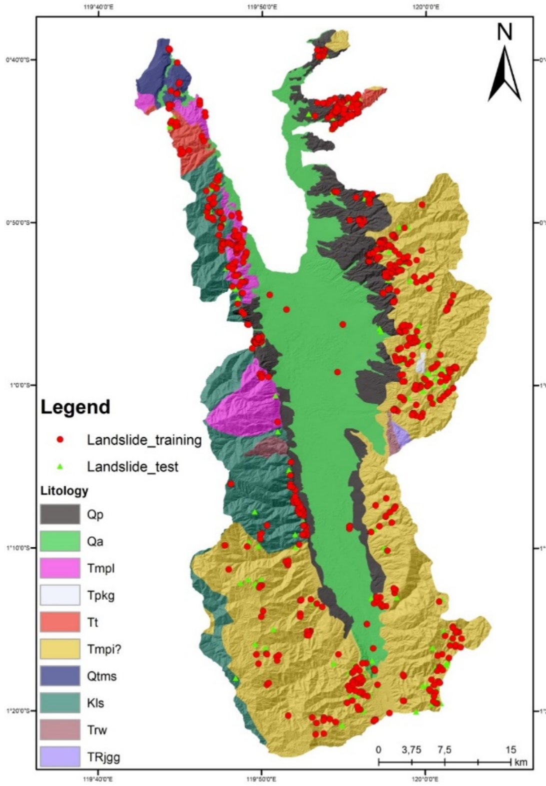
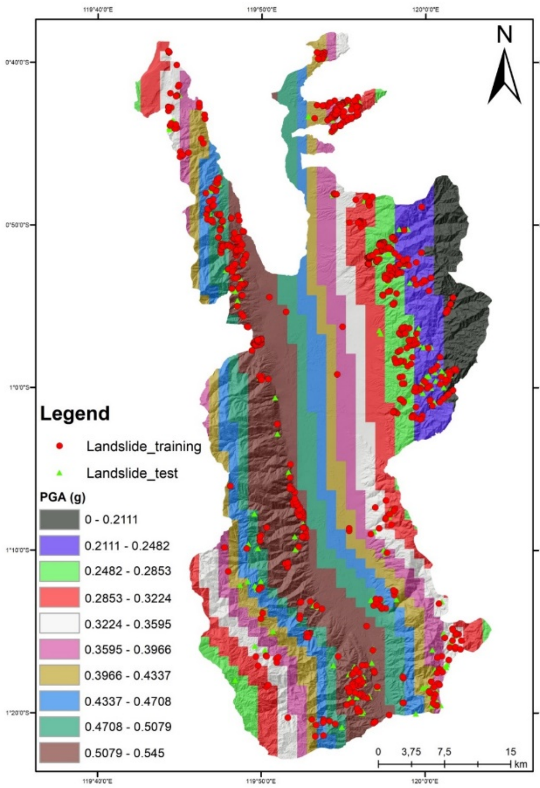


Figure 6-86 Lithology Map



Source: BG

Figure 6-87 PGA (Peak Ground Acceleration) Map

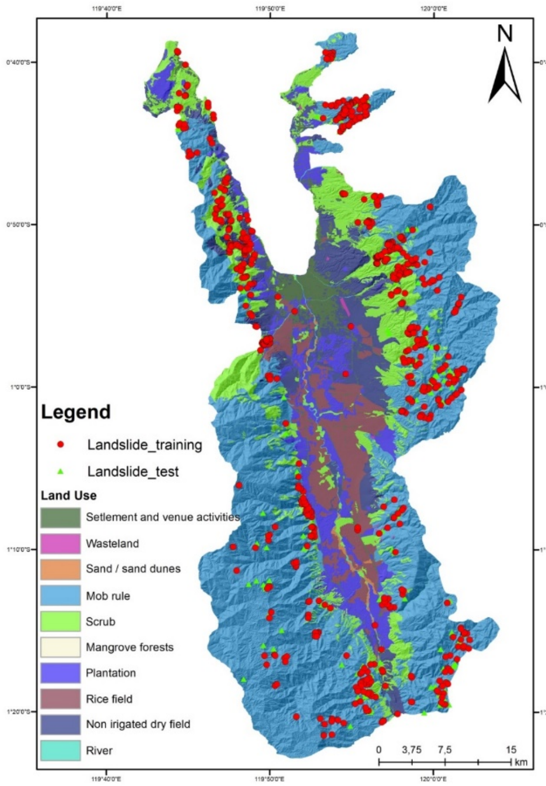


Figure 6-88 Land Use Map