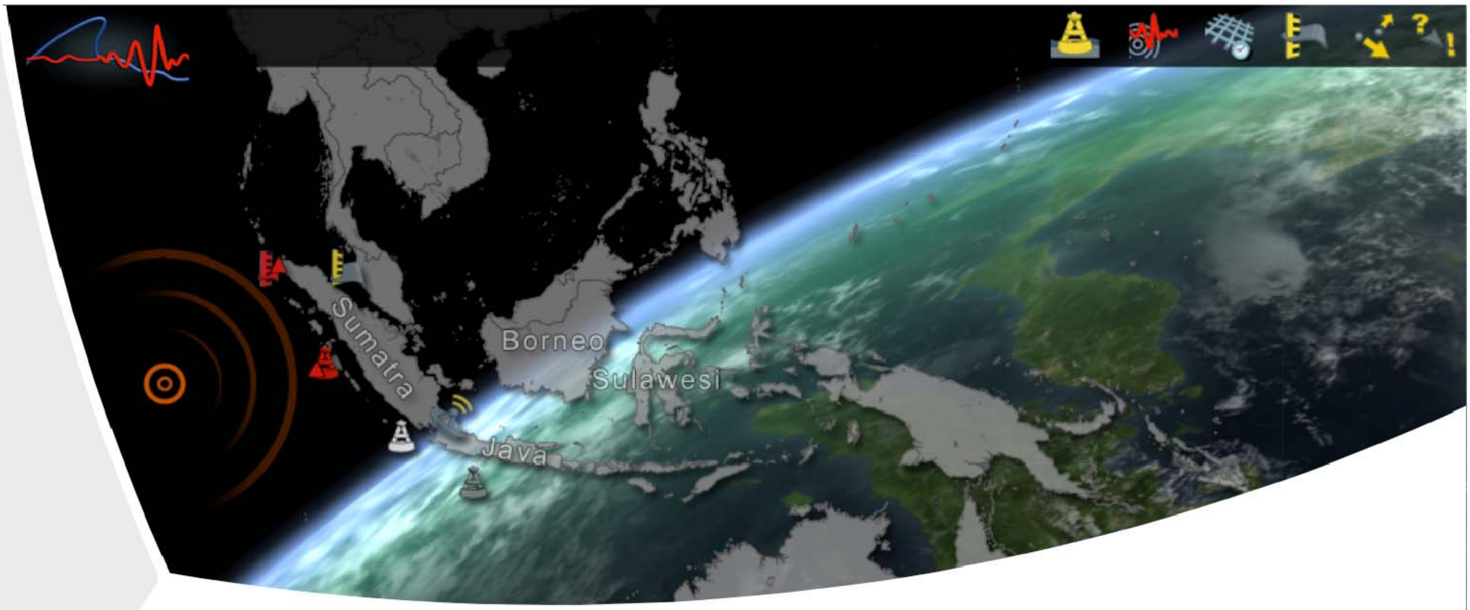

GUIDELINE FOR TSUNAMI RISK ASSESSMENT IN INDONESIA

SCIENTIFIC PROPOSAL
FOR PRACTITIONER AND END USERS

Indonesian – German Working Group on Tsunami Risk Assessment

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

LIPI

RISTEK

Bundesministerium
für Bildung
und Forschung

GITEWS

Product of the Joint Indonesian-German Working Group on Tsunami Risk Assessment

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Acknowledgments

This “Scientific proposal for practitioner and end users: Guideline for tsunami risk assessment in Indonesia” has been compiled by the joint Indonesian-German working group on Tsunami Risk Assessment. This joint working group was established in 2006 under the umbrella of the German Ministry of Education and Research (BMBF) in the frame of the GITEWS ((German-Indonesian Cooperation for a Tsunami Early Warning System) project and he State Ministry of Research and Technology of the Republic of Indonesia (RISTEK) in the frame of InaTEWS (Indonesian Tsunami Early Warning System). The working group was led by the Indonesian Institute of Sciences (Lembaga Ilmu Pengetahuan Indonesia, LIPI) at Indonesian side and the German Aerospace Center (DLR) at the German side supported by the United Nations University (UNU-EHS) and consisted of several research institutions, governmental authorities and Non-Governmental Organisations (NGO’s) in Indonesia and Germany. Furthermore the work was embedded in the UNESCO Intergovernmental Coordination Group (ICG) of the Indian Ocean Tsunami Warning and Mitigation System (IOTWS) context. Involved in the working group on Indonesian side were: DKP (Departemen Kelautan dan Perikanan - Department for Marine and Fisheries), LAPAN (Lembaga Penerbangan dan Antariksa Nasional - National Aeronautics and Space Institute), BAKOSURTANAL (Badan Koordinasi Survei dan Pemetaan Nasional - National Coordinating Body for Survey and Mapping), BNPB (Badan Nasional Penanggulangan Bencana - National Agency for Disaster Management), BMKG (Badan Metereologi dan Geofisika – National Agency for Meteorology, Climatology, and Geophysics), BPPT (Badan Pengkajian Dan Penerapan Teknologi - The Agency For the Assessment and Application Technology), ESDM (Kementerian Energi dan Sumber Daya Mineral – Ministry of Energy and Mineral Resources Republic Indonesia), BAPPENAS (Badan Perencanaan Pembangunan Nasional - National Planning Board), Public Works (Kementerian Pekerjaan Umum Republik Indonesia - Ministry of Public Works Republic Indonesia), UNAND (Andalas University, Padang), UGM (Gadjah Mada University Yogjakarta), ITB (Institut Teknologi Bandung – Bandung Institute of Technology), BAPPENDA (Badan Perencanaan Pembangunan Daerah-Local Planning Board), KOGAMI (Komunitas Siaga Tsunami – Tsunami Alert Community), PMI (Palang Merah Indonesia – Indonesian Red Cross), Bubati Kota Padang, and on German side the partners of the GITEWS consortium.

The German government supports the implementation of a tsunami early warning system in the Indian Ocean – especially in Indonesia – through the GITEWS project (German-Indonesian Cooperation for a Tsunami Early Warning System). The GITEWS project is carried out since 2005 through a large group of scientists and engineers from (GFZ) German Research Centre for Geosciences and its partners from the German Aerospace Centre (DLR), the Alfred Wegener Institute for Polar and Marine Research (AWI), the GKSS Research Centre, the German Marine Research Consortium (KDM), the Leibniz Institute for Marine Sciences (IFM-GEOMAR), the United Nations University (UNU), the Federal Institute for Geosciences and Natural Resources (BGR), the German Agency for Technical Cooperation (GTZ), as well as from Indonesian and other international partners. Funding is provided by the German Federal Ministry for Education and Research (BMBF), Grant 03TSU01. GITEWS is part of a bilateral cooperation between the governments of Indonesia and Germany, based on a joint agreement between BMBF and the Indonesian State Ministry of Research and Technology (RISTEK). The warning concept which was developed under the guidance of the Potsdam Geo Research Centre (GFZ) and in cooperation with national and international partners will significantly reduce warning times by making use of real-time data transfer, predetermined flooding scenarios in coastal regions, and direct warning reports. The two-year operational phase of German support for InaTEWS began in November 2008. The scope of this cooperation covers not only the technical aspects of the early warning system, but also hazard, vulnerability and risk assessment, production of maps for the project area, and capacity building. The German cooperation partner for hazard, vulnerability and risk assessments is the German Aerospace Centre (DLR).

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Part I of the guideline provides a comprehensive introduction into the risk and vulnerability assessment guideline. Thereby, the focus is to lay down the overall principles, structure, goals and target audience of the guideline at hand.

1 Preface

For disaster risk reduction, early warning systems play a key role: “If an effective tsunami early warning system had been in place in the Indian Ocean region, thousands of lives could have been saved” (ISDR 2006). In Bangladesh the establishment of an early warning system reduced the amount of cyclone victims in the period 1970-2007 from half a million to a few thousands (British Red Cross 2009). Although Indonesia had received a tsunami warning from the Pacific Tsunami Warning Centre on 26th December 2004 and in May 2007, the national administration was in lack of institutionalized early warning structures down to the local level to warn its population at risk in due time. The necessity to develop tsunami early warning and crisis management structures in Indonesia is inevitable considering the historical record and predicted probabilities of tsunami occurrence in the Indonesian archipelago. On average, every three years small and medium size tsunamis occur in this region causing damage and death (Hamzah et al. 2000). The new Indonesian law on Disaster Risk Management recognizes that the State of the Republic of Indonesia “has the responsibility of protecting all people of Indonesia […] (Republic of Indonesia 2007, p 1). Accordingly, UN Secretary General Ban-Ki-Moon stated in a recent essay in SpiegelOnline “that natural extreme events are not preventable but it is up to society to decide how to react to increasing disaster risk, thus whether its action in future increases or mitigates disaster risk” (SpiegelOnline 2008).

In the aftermath of the Indian Ocean Tsunami 2004, the German and Indonesian governments agreed on a joint cooperation to develop a People-centred End-to-End Early Warning System. Legally, Indonesia has now opted to go along the path of a paradigm shift, namely from disaster response to disaster prevention and preparedness. The paradigm shift is demonstrated by the institutional reform of the disaster management structures currently carried out and the establishment of a multi-hazard warning and mitigation centre, with tsunami early warning being an important first step.

One important consequence of the paradigm shift is the recognition of the need to anticipate risks and vulnerabilities related to threats of natural origin before they manifest. Therefore, scientific and stakeholder driven risk and vulnerability assessments are needed. The guideline at hand is an important step forward for Indonesia to identify and disseminate methods for risk and vulnerability assessment and to support end-users to build capacity in this field. As the major output of the Joint Indonesian – German Working Group on Tsunami Risk Assessment, a guideline for tsunami risk assessment in Indonesia as a scientific proposal for practitioner and end users is provided. The document at had is a proposal and it is intended to update this version after further discussions with interested parties to be the finally recognized and potentially adopted by the Disaster management Authority in Indonesia (BNPB).

The working group was coordinated and led by LIPI and DLR supported by the United Nations University (UNU-EHS) with contributions from other Indonesian and German organizations and carried out under the umbrella of the State Ministry of Research and Technology of the Republic of Indonesia (RISTEK) and the German Ministry of Education and Research (BMBF). Now, it is up to decision makers and practitioners to take up the work conducted adapt it and apply it within their territory of power.

2 Guideline Goals

InaTEWS does not only focus on the provision of the technology to detect tsunami events in due time to safe lives but also on the development of an Early Warning System (EWS) ensuring that warnings reach communities at risk and that these communities know how to respond adequately to warnings. Putting more emphasis on the last mile, meaning the efficiency of local response capabilities of organizations and the population at risk (e.g. warning decision and its dissemination, evacuation guidance and evacuation capability), has been promoted by UN/ISDR and has been identified as one of the priorities of the Hyogo Framework for Action (ISDR, 2005).

For the development of knowledge-based response capabilities of organizations and the population to increasing risks, vulnerability and risk assessment plays a key role. This guideline promotes risk and vulnerability assessment types that are tailored to specific risk management tasks structured according to the Disaster Risk Management (DRM) cycle. By providing the concept, methodology, results for risk and vulnerability analysis and implications hereof in the context of EWS an example is given. With the focus on EWS the risk and vulnerability analysis presented seeks to identify and make more transparent those weaknesses within societal and spatial structures that pose a threat to efficient warning and response structures, especially at the local level in both urban and rural areas.

The knowledge of vulnerability and risk contributes significantly to tsunami disaster risk reduction. The risk and vulnerability assessment framework developed within InaTEWS follows the logic that risk and vulnerability assessments are needed to provide knowledge-based decision support for the effective implementation of InaTEWS. Thereby, hazard and vulnerability assessments (generation of spatial and systemic knowledge of the "*weak points"* in the human and natural system) also aim to facilitate the process of identifying the best suitable EWS-risk management strategy. Thus, by enhancing risk communication amongst stakeholders, risk management can be negotiated knowledge-based.

Hence, this academic proposal aims at supporting the Indonesian Tsunami Disaster Risk Reduction Authority in producing a tsunami risk assessment guideline. This guideline in particular is objected to encourage also tsunami exposed local governments in Indonesia to conduct a related assessment together with the other institution in their area by using their own resources.

3 The InaTEWS Working Group on Tsunami Risk Assessment

The German government supports the implementation of a tsunami early warning system in Indonesia – through the GITEWS project (German-Indonesian Cooperation for a Tsunami Early Warning System). In this frame a joint Indonesian – German working group on Tsunami Risk Assessment was established. Its mandate was to develop Early Warning System specific risk assessment methodology and products with a strong involvement of relevant end-users in the assessment process and the application potential of risk products.

The working group's activities were carried out under the umbrella of the State Ministry of Research and Technology of the Republic of Indonesia (RISTEK) and the German Ministry of Education and Research (BMBF). Operationally, the working group was led by the Indonesian Institute of Sciences (LIPI) at Indonesian side and the German Aerospace Center (DLR) at the German side supported by the United Nations University (UNU-EHS) and consisted of several research institutions in Indonesia and German. The working group was established in 2006 at the first round table discussion by Indonesian and German scientists in Bandung, that attempted to define the process, concept and the framework of the assessment. The progress of the working group were discussed at the second, third and fourth workshops in Bandung and Jakarta as well as in the fifth to seventh workshops in the pilot areas accompanied by training and capacity building activities. In 2009 the final assessment step was implemented by the working group to provide tsunami risk information and data at the sub-national level and in three pilot areas. In 2010 it was agreed to launch a scientific proposal for tsunami risk assessment guideline for the Indonesian Board of Disaster Management (BNPB).

4 Guideline Target Audience

The target audience of this guideline is as diverse as stakeholders are involved in InaTEWS. This is due to the fact that the results of risk and vulnerability assessment are of utmost importance for the development of an effective InaTEWS. Decision makers and authorities involved in InaTEWS shall be able to acknowledge the importance and results of risk and vulnerability assessments. Risk managers at various administrative levels, who's duty is to establish InaTEWS, need to rely on the assessment results, and consider them as the bases for their risk management decisions.

But in fact, as this guideline not only presents assessment results but also provide the methodology, the most important target audience are experts from science and authorities whose mandate is to perform well in risk and vulnerability analysis and need to learn from concepts, approaches that have already been exercised.

It is necessary to outline that the process of risk and vulnerability assessment as well as risk management is inter-sectoral and crosscutting by nature, requiring the integration of data and management approaches inhabited by different sectors and authorities. Just to mention some, these are: spatial and land-use planning, environmental protection, education, public works, transport, social welfare and disaster management. Their expertise, data, data collection and analysis tools need to be acknowledged and integrated when risk and vulnerability assessments are conducted.

Hence, also a new type of risk and vulnerability assessment management process needs to be promoted. Strong coordination, communication and moderation skills by those taking the lead (e.g. risk management authority) are required, when different authorities, NGOs and the private sector collaborate during processes of data collected, processing, preparation and discussion of the risk and vulnerability assessment results.

In detail the following groups of stakeholders and end-users are suggested to learn more about methods for risk and vulnerability assessment:

- National authorities whose mandate is to develop and implement policies that increase institutional capacities for risk governance, including risk assessment, risk management and risk communication. Here, the guideline also provides insights into the technical skills that are required to replicate the assessment methods.

- Local authorities whose mandate is to implement risk and vulnerability assessments and transform the results into policy recommendation for practical risk management.

- National and international academia and scholars that seek for innovation and the further refinements of risk and vulnerability assessments from an applied science perspective.

5 Guideline Structure

This "scientific proposal for practitioners and end users: guideline for tsunami risk assessment in Indonesia" consists of four parts.

Part I of the guideline provides a comprehensive introduction into the risk and vulnerability assessment guideline. Thereby, the focus is to lay down the overall principles, structure, goals and target audience of the guideline at hand.

The guideline stresses the importance to develop risk and vulnerability assessment frameworks; methods and products tailored to specific risk management tasks. Thus, as the basis of the risk assessment **Part II** presents an in-depth description of the different risk and vulnerability management tasks and its risk assessment requirements for the ideal setup of an effective people-centred end-to-end tsunami EWS in Indonesia.

To set up InaTEWS effectively, risk and vulnerability assessment is a precondition and provides knowledge-based decision support. **Part III** of the guideline provides the methods and presents the risk and vulnerability products developed and tailored to user needs.

The **Technical Guideline** provides a detailed description of the technical implementation of the risk and vulnerability assessment. Based on this description users shall be enabled to understand and reproduce the different risk and vulnerability products. For this, end-users can in detail learn about the required input data, methods and techniques and the generation of products as they are summarized and discussed in the previous parts of the guideline.

Part II:

Risk Management and Assessment Requirements in the Context of Early Warning Systems

To define risk assessment methods and products for providing implementation and decision support for risk management requires defining desired risk management goals and options.

In order to understand the risk and vulnerability assessment developed by the joint Risk Assessment Working Group (Part III), it is necessary to understand the terns used in the guideline and to define specific risk management tasks for the ideal setup of an effective people-centred end-to-end tsunami EWS in Indonesia.

1 Introduction and Structure

Part II aims to provide an understanding on the key features and the functioning of EWS and its associated risk management tasks based on the warning and reaction scheme designed for Tsunami threat specifities in Indonesia. From this, the specific risk assessment requirements are deduced and risk assessment methods and products are developed.

Therefore, Part II of the guideline is can be summarized and is structured as follows:

- In **chapter 2** the concept of "risk assessment for risk management" is presented that is the basis for this guideline. The chapter starts right away with providing the core terminology of the guideline. The reader can return to this chapter if specific terms are unclear while reading the guideline.

- In **chapter 3** the "four elements of risk management within EWS" are presented that represent the internationally well-accepted framework by UN-ISDR for defining and conceptualizing EWS. Based on the ISDR concept of EWS, the InaTEWS reaction scheme and its sequences are defined, that takes into account specific challenges of tsunami threat in Indonesia. Then, for each sequence the specific risk management tasks and risk assessment requirements are deduced.

- In **chapter 4,** finally, a summary of the risk assessment topics and the key factors of risk and vulnerability in the context of InaTEWS is provided. Based on this, Part III of the guideline presents the risk assessment methods and products.

2 The Concept of Risk Assessment

In most countries around the globe risk management structures and capacities are not sufficiently developed to tackle the level of risk they face. This is largely due to the fact that they do not know their risks and vulnerabilities, thus leaving risk management structures ineffective. When risk and vulnerability assessments are successfully conducted and accepted by risk managers, their results can significantly contribute to the design and implementation of knowledge-based effective risk management.

Before presenting the methods and products of the risk and vulnerability assessment it is important to understand the concept and process of risk and vulnerability assessment followed in this guideline. The approach followed can be can be used as a template for any kind of risk assessment and for any kind of threat that requires to engage in risk reduction.

Chapter 2.1 provides broader definitions for risk and vulnerability that lay the foundation for understanding defining risk and vulnerability in the context of early warning and evacuation based on the reaction scheme. Thereby, the role of risk and vulnerability assessment for increasing the efficiency of InaTEWS is explained and the subsequent assessment framework is deduced.

Chapter 2.2 provides an understanding for the general process of developing risk and vulnerability assessment products, specifically designed to serve risk managers tasks to design an efficient Tsunami EWS.

Chapter 2.3 aims at showing the different domains of risk management that exist for achieving disaster risk reduction. Thereby, Early Warning Systems is one of the domains for which subsequent risk management tasks need to be defined.

2.1 Definition of Terms Used in the Guideline

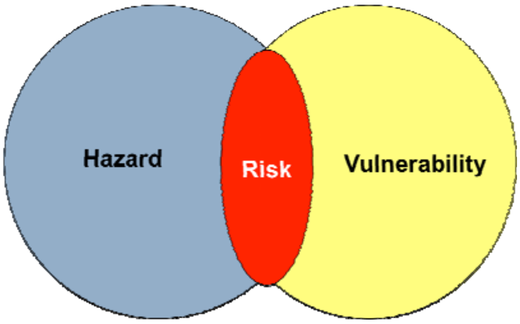
A variety of definitions and concepts of risk and vulnerability exists. The following broader definitions are published by UN-ISDR (2009) and constitute the foundation for the development of a definition that is specifically tailored to risk management tasks within the framework of a Tsunami-EWS in Indonesia.

Disaster Risk Reduction (DRM)

In the context of disaster risks of natural origin, DRM is conducted by the means of disaster risk reduction, since total risk avoidance is not possible (hazardous events of natural origin are not fully preventable). Thus, the focus is more on reducing the vulnerability of the risk absorbing system to the impacts of natural hazards, whereby the overall risk is brought closer to being acceptable (Renn 2008: 174).

Risk

Risk is in general terms regarded as the product of hazard and vulnerability which is defined in the following: The over all assessment builds on the well established rule that risk is a function of hazard and vulnerability.



Hazard

“A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.“ (UN-ISDR 2009)

Vulnerability

„The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management.“ (UN-ISDR 2009)

Risk Management

Risk Management refers to the creation and evaluation of options for initiating or changing human activities / structures with the objective of increasing the net benefit to human society and of preventing harm to humans and what they value (Renn 2008)

Thereby, risk management can be distinguished between hazard management / control and *vulnerability management.* Vulnerability management is not well recognized in literature but refers to the management of those factors that lead to the vulnerability of human, natural and physical elements to hazard impacts.

Risk Assessment

„A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.“ (UN-ISDR 2009)

Hazard Assessment

Hazard assessment refers to the quantification of hazard parameters such as their probability of occurrence, their impact area, intensities and their onset speed.

Vulnerability assessment

Identifying and measuring those factors in the human system that determines and can explain a specific expected impact pattern that a hazard has on exposed elements (population, economy, physical structures, and critical infrastructures and the environment).

Subjects of vulnerability analysis are people and households, physical and economic assets, environmental services and critical infrastructures. A crosscutting feature of risk and vulnerability analysis is the focus on the spatial relations of vulnerable elements with regard to the hazard characteristics and specific DRM challenges.

2.2 Risk Management Focused Risk Assessment

The guideline stresses the importance to link risk assessment with risk management to arrive at risk assessment products that are directly applicable for risk management in the area of spatial planning, education, engineering etc. Without specifying goals, tasks and tools for risk management, risk assessment remains illusive.

Figure 1 schematically illustrates the risk and vulnerability product development process followed in this guideline.

(1) Selection of the risk management domain.

(2) Definition of domain specific risk management tasks.

(3) Conceptualizing the risk and vulnerability assessment topics.

(4) Development of a risk assessment methodology.

(5) Finalization of risk and vulnerability assessment products to be utilized by risk managers.

Thereby, iterative processes of risk assessment product development include the validation of the assessment methods and products through multi-stakeholder dialogues and institutionalized feedback mechanisms on the basis on risk management experiences (compare Figure 1). This approach requires that hazard; vulnerability and risk assessors and managers need to engage in a dialogue to continuously improve the product development to also increase the efficiency of risk management.

End-user driven and risk management focused risk and vulnerability assessments not only aim at measuring the risk and vulnerability factors identified but on the other side process, assemble and transform the results into products (aggregated and disaggregated, mapped and documented) that are tailored to the different end-users needs and their capacities.

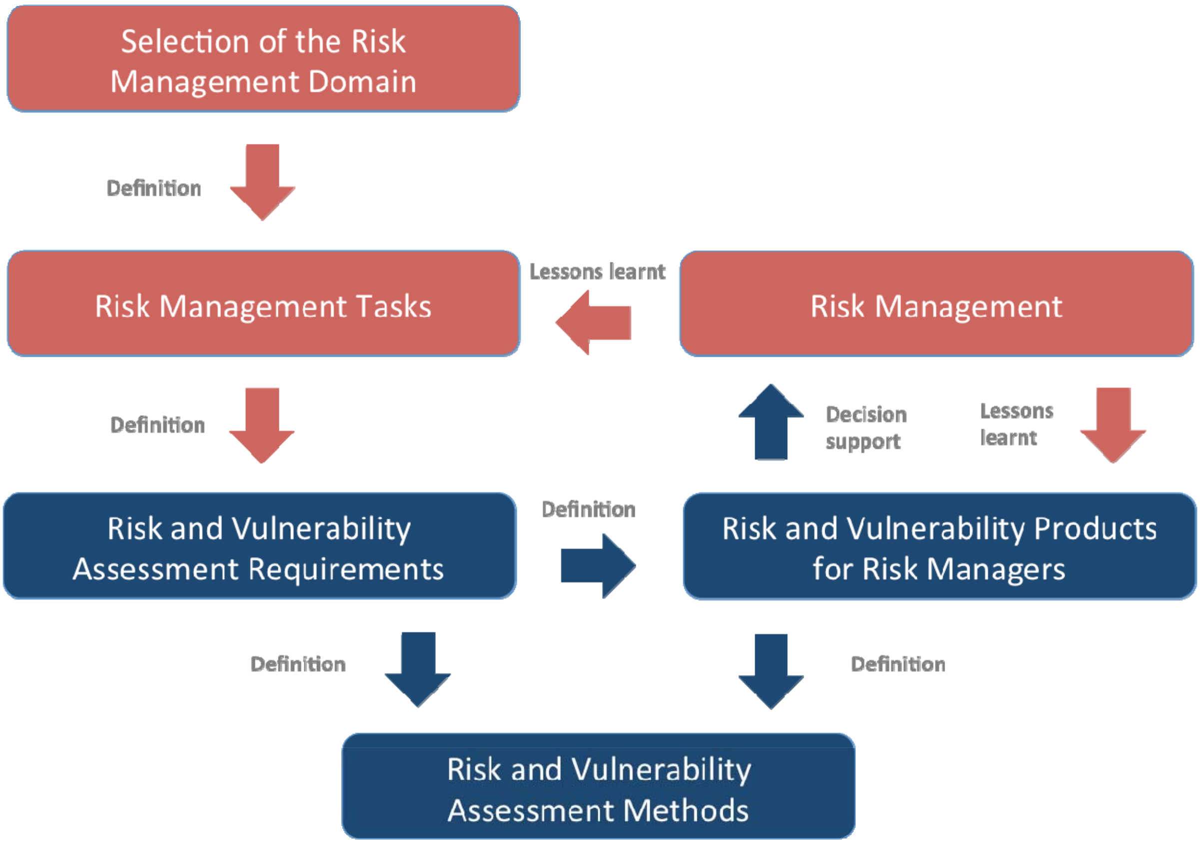


Figure 1: Process of risk and vulnerability product development

In order to define a vulnerability assessment approach suitable for risk management it is important to understand what risk management means and what the options and domains of risk management are.

In reality, risk management does not refer to the implementation of a single risk reducing measure, but to a diverse set of complementary risk management tasks that in their sum constitute risk management within a specific risk management domain (e.g. early warning, recovery, or long-term damage prevention). In order to provide implementation support for each of the specific risk management task also different kinds of risk and vulnerability information, products and tools are to be developed. Thus, the equation "risk = hazard x vulnerability" is guiding risk assessments by concept, but for assessing risk serving the implementation of risk management, risk information needs to be disaggregated according to user needs and specific risk management tasks. Thus, the goal of the risk assessment is not to present a methodology and a product for one specific risk component, might it be a single vulnerability, hazard or risk product, but to assemble risk and vulnerability information according to specific risk management tasks, related to e.g. spatial planning, education or engineering.

2.3 Domains of Risk Management

Based on the risk assessment and risk management approach laid down in the previous chapter, a first filter to define the overall context in which risk assessment takes place, is selecting the risk management domain that is best suited to realize sustainable and affordable risk reduction. Establishing EWS is one important domain of risk management but not the only one. According to the disaster risk management cycle other domains of risk management include the establishment of effective relief and sustainable recovery structures, but also the management of long-term exposure reduction (e.g. resettlement, building resistance or hazard control, compare Figure 2). For each DRM domain subsequent risk management tasks exist, which need to be defined and contextualized according to the specific characteristics of the threat.

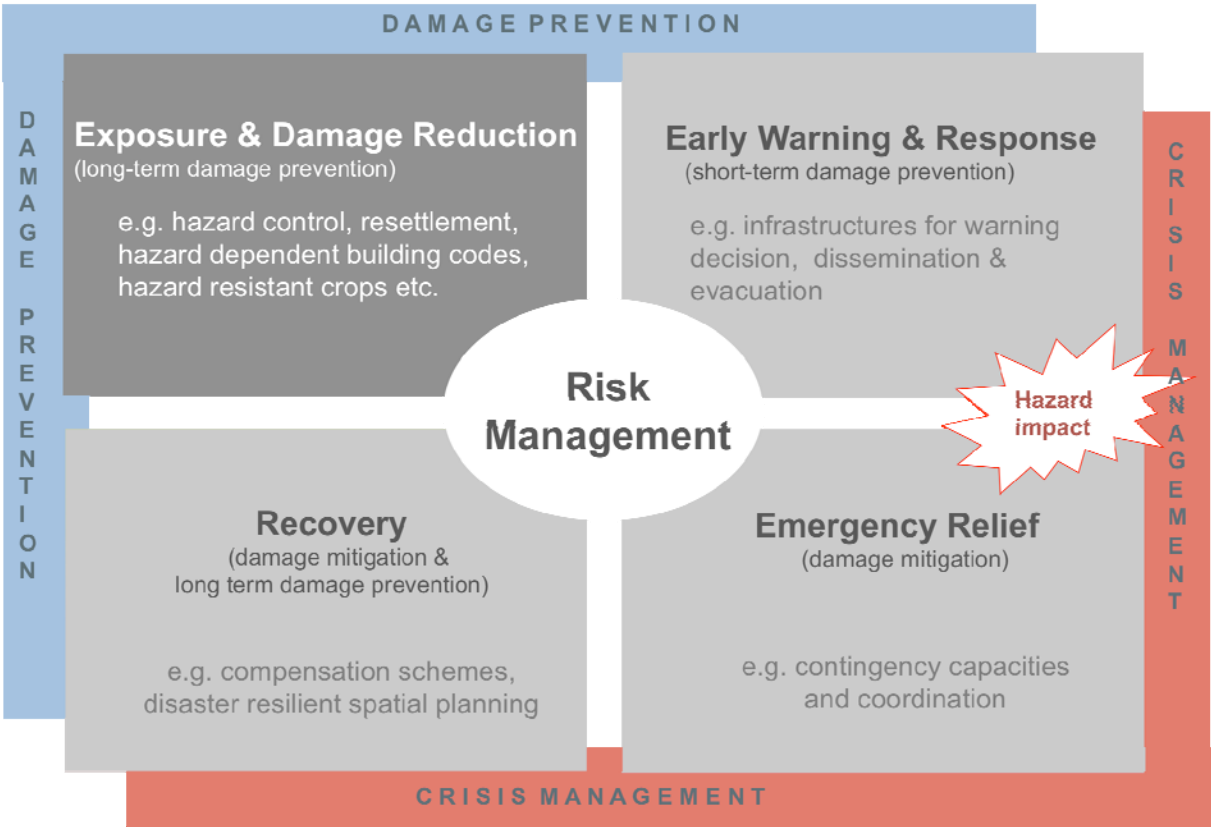


Figure 2: Domains of sustainable Disaster Risk Reduction

Ideally, when decisions on DRM options are made, all four domains of DRM shall not be played out against each other (e.g. absolute prevention is never possible, thus making crisis management inevitable), they are rather complementary, interdependent, and not substitutable. E.g. even though long-term exposure and impact reduction is achieved successfully for a specific hazard scenario; people are likely to be affected during a future much more extreme event requiring relief assistance or recovery support. It is the uncertainty in forecasting the magnitude and distribution of hazard events that requires sound crisis management.

But in reality decisions are made under conditions of limited resources available and interest priorities leading to trade-offs in achieving inclusiveness of DRM. Specific risk information can already support the decision on the choice of a specific risk management domain to engage in as priority. This is especially true for hazard probabilities and rough exposure estimations. For the case of tsunami risk in Indonesia, the government has chosen to rather establish an early warning system as a priority then promoting long-term exposure reduction. This is due to low tsunami occurrence probability at a specific coastal area und roughly high exposure levels, where long-term exposure reduction, e.g. through resettlement, is not realistic.

The focus of this guideline is on the risk management domain “Early Warning and Response” and the development of respective risk assessment methods and products to manage tsunami risk.

3 Risk Management and Assessment Requirements in the Context of Tsunami Early Warning Systems

This chapter defines the different risk management tasks and the respective risk assessment requirements for the establishment of an effective Tsunami Early Warning System. The definition and conceptualization of subsequent risk management tasks and risk assessment requirements for InaTEWS are based on internationally well accepted EWS-frameworks (e.g. UN-ISDR) and tsunami threat specificities in Indonesia.

Linked up, the authors of the guideline have developed the “InaTEWS reaction scheme” that schematically defines the sequence of actions needed to achieve full evacuation before a tsunami hits tsunami exposed people. The effective functioning of all sequences of actions in the reaction scheme is a requirement that decides upon death and survival in the course of a tsunami event when designing and implementing EWS in Indonesia.

For each sequence of action to be operational in case of tsunami occurrence specific risk management tasks are defined, from the development of capacities to detect a tsunami event to the provision of infrastructure for evacuation. To implement these risk management tasks effectively, risk assessment is crucial.

Following this rationale and to arrive at a risk management concept, respective methods and products, this chapter is structured as follows:

Chapter 3.1 provides the basis for defining the InaTEWS reaction scheme by summarizing the concept of early warning systems according to UN-ISDR. Thus, this guideline is based on an internationally well-recognized framework for Early Warning Systems.

Chapter 3.2 strives to adapt the ISDR framework by putting it in the context of fast and sudden onset hazards such as Tsunami in Indonesia. By defining the Ina-TEWS reaction scheme and its subsequent risk management tasks, for each reaction scheme component the risk assessment requirements are deduced.

3.1 Four Elements of EWS according to UN-ISDR

In a global survey on capacities and gaps for early warning systems prepared by the UN\ISDR Secretariat, “warning dissemination and preparedness to act” (response capability) were identified as the weakest elements (ISDR/PPEW 2006). The findings of the survey reflect the need to develop People-Centred Early Warning Systems, which ensure that warnings reach hazard prone communities who know how to respond to these warnings. Accordingly, UN\ISDR defined four elements of a people-centred EWS (figure 3) that poses specific governance challenges regarding vertical and horizontal institutional coordination as well as implementation in the last mile.

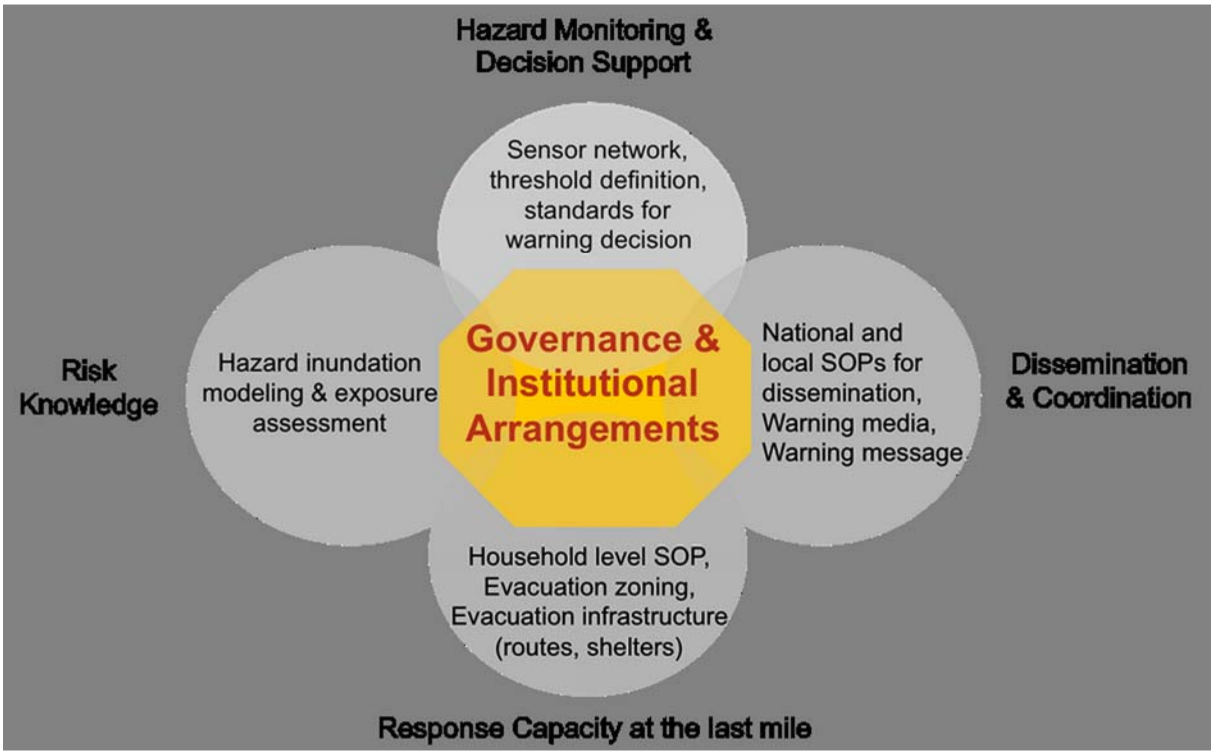


Figure 3: Four Elements of people centred EWS (UN\ISDR 2006)

3.1.1 Hazard Monitoring and Decision Support

This component relates to the development of the hazard detection infrastructure, which includes sensor networks (e.g. for the case of tsunami GPS stations, seismographs, Ocean Bottom Units) and a warning centre in which all the different data are compiled and processed to derive meaningful information on whether a tsunami is going to happen or not. If properly constructed and managed the event detection infrastructure provides real-time decision support for responsible stakeholders to decide whether to warn or not. The process of decision support provisions and warning decisions by stakeholders is subject to the development of Standing Operational Procedures (SOP) that clearly defines roles and responsibilities. In this respect also local authorities need to be engaged because they also share the responsibility with national stakeholders to warn their citizens. Risk information can significantly contribute to effective warning decision and SOP development.

3.1.2 Dissemination and Coordination

Once a warning is issued, it needs to be communicated to exposed populations in due time and in an understandable manner for a layperson. Therefore, also here national, regional and local

Standing Operational Procedures (SOP) are to be developed that define modes of warning dissemination amongst authorities and to the general public. Thereby, questions arise such as: How is the public media engaged in the process of warning? Are warnings communicated directly to the general public, or must they first pass through all levels of governance according to the institutional setup and power system? Who are the authorities that are engaged in the warning process, do they possess the capacities to provide 24-hour emergency services? Which devices are the most effective one to warn citizens in due time?

3.1.3 Response Capacities

Response capacities can be diverse depending on hazard specifications, such as hazard type, exposure levels and the time left from the moment of warning until the hazard occurs. E.g. for drought, if the warning is issued long time before drought occurs, there are a lot of measures that can be implemented to prevent or mitigate the damage (e.g. food aid to affected populations, setting up irrigation systems, prevention of fire outbreak etc). Whereas, for tsunamis in Indonesia that take on average 30 minutes to arrive at land after their detection, there is only one solution left for response: Quick evacuation of exposed populations.

Although there is only one solution, setting up evacuation capacities is complex to become effective. For the design of effective evacuation systems many tasks need to be accomplished that relates to household level preparedness activities and setting up evacuation infrastructure that, if the local spatial conditions are unfavourable, requires huge investments in evacuation and shelter infrastructure that pose a difficult challenge for spatial planning.

3.1.4 Risk Knowledge

Risk knowledge within this framework specifically refers to the knowledge of probabilities of hazard distribution on land and the question whether elements are exposed to the hazard. For the case of tsunami the knowledge of the area inundated by tsunami is necessary for defining the evacuation zone and the deployment of warning dissemination infrastructure, such as sirens. But risk knowledge is not limited to hazard and exposure assessment. As already defined, vulnerability assessment refers to analysing the underlying factors that determines the likelihood of damage and loss of life during and after an extreme event. In the view of the authors of this guideline, risk knowledge is important to increase also the effectiveness of the other elements of an EWS.

3.2 InaTEWS Reaction Scheme and Risk Assessment Requirements

The InaTEWS reaction scheme has been developed based on the four elements of EWS (UN/ISDR). It provides an overview of a sequence of hierarchical processes that need to be accomplished for saving lives within the time span from the detection of a tsunami event until the materialization of a tsunami at the coast. Especially, for the case of Indonesia, there is a need to develop quick institutionalized response mechanisms of organizations involved in the issuing of a tsunami warning, and of exposed populations to react to warnings and find a safe place before the first tsunami wave hits. This is due to the fact that the Estimated Time of Arrival (ETA) of a detected tsunami at the coastline in Indonesia facing the Sunda trench is very short (below one hour), which poses an extra ordinary challenge for the development of efficient warning as well as response structures (evacuation system).

Figure 4 schematically illustrates the reaction and time sequences of an early warning system (downstream component) from the moment of tsunami warning detection until the evacuation of the population at risk. It serves as the basis for the risk and vulnerability assessment approach presented in the following chapters.

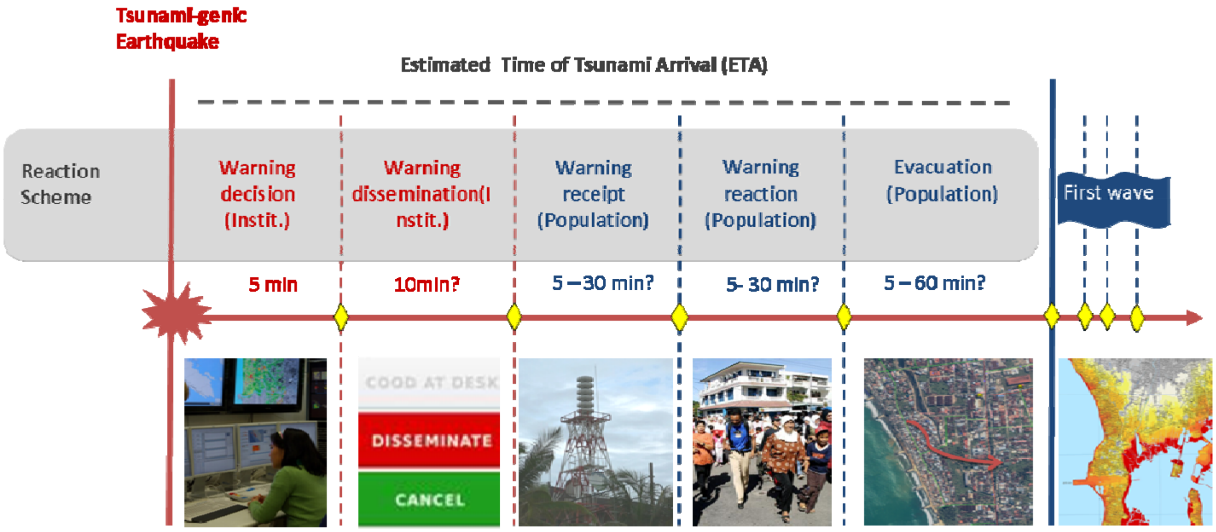


Figure 4: Reaction scheme of people centred early warning systems.

In detail, 5 subsequent components complete the reaction scheme:

- **Warning decision**
- **Warning dissemination**
- **Warning receipt by the population**
- **Warning reaction**
- **Evacuation**

If only one of the downstream components fails to be effective, the whole EWS does not function, causing loss of life during a tsunami event. Especially, in the case of Indonesia as being a large coastal country, the functioning of the different integrated components at different administrative levels and at every geographic area that is exposed to tsunami is a particular challenge.

In the following for each of the reaction scheme components, specific risk management tasks and accordingly the risk assessment requirements are presented.

3.2.1 Warning Decision

Risk management task: DSS event detection and SOP for warning decision

Warning systems commonly use information provided by networks of sensors able to monitor and detect impending disasters, aggregate and condense these information to provide reliable information to a decision maker whether to warn or not, disseminates the warning message and provide this information to people at risk. The ultimate aim of effective warning decision support is to enable those in danger to make decisions and to take action to safe their lives (evacuation). The use of risk knowledge in early warning most often is treated in a theoretical manner, yet less in an operational, practical sense.

Risk assessment requirements: Hazard, exposure, evacuation capabilities and fatalities

Dedicated risk information can contribute to an effective warning decision. Mainly the use of hazard and exposure related information can be used together with knowledge of the evacuation capability and time-dependent expected casualty information. Hence the integration of this information can be used to optimize (1) warning segment definition (spatial warning units), (2) warning level definition and (3) spatial differentiated warnings (different times to send out warnings to different warning segments). For example, currently almost all warning systems base their definition of warning levels purely on expected hazard intensity (e.g. expected tsunami wave height at the coast). But a tsunami wave height of e.g. 4 meter may cause at one location more damage and casualties than at another location. To overcome this, risk information can be used to enhance definition of warning levels. Hence, the integration and use of risk assessment information in the Decision Support System for Tsunami Early Warning is highly important.

Another important aspect in using risk information in warning decision is to integrate risk information to warning products for dissemination. And to have corresponding risk information (e.g. hazard maps relating hazard zones to warning product information) at the local level. This allows that at the local level people and decision makers can learn before an event on what warning information will lead to which affected area and design e.g. evacuation strategies correspondingly. Hence the use of risk information in the warning decision process at national level with corresponding risk information at the local level is the important tie between national level early warning with local level reaction and preparedness measures.

3.2.2 Warning Dissemination & Warning Receipt

Risk management task: 1: Linking national and local level warning dissemination SOPs

To ensure effective warning, stakeholders at national and the local level need to participate in the development of a warning dissemination strategy. Local stakeholders can tell national stakeholders about the most efficient way to reach their citizens, who live in rural or urban areas. Therefore, risk management tasks related to warning dissemination on the one side and warning receipt on the other side are strongly linked and require vertical administrative coordination.

Risk management task: 1: SOP for National Warning Dissemination & Technical Implementation

The International Early Warning Programme (IEWP) stresses as one of the four sub-domains of an effective people-centred early warning system the following question: “Do the warnings reach those at risk?” (IEWP 2004).

Warning dissemination mechanisms need to identify the most efficient way to reach tsunami-exposed populations in a very short time. At the national level institutions involved in the DSS and mass communication (in general the media) need to develop quick communication mechanisms when a warning alert is issued by BMKG.

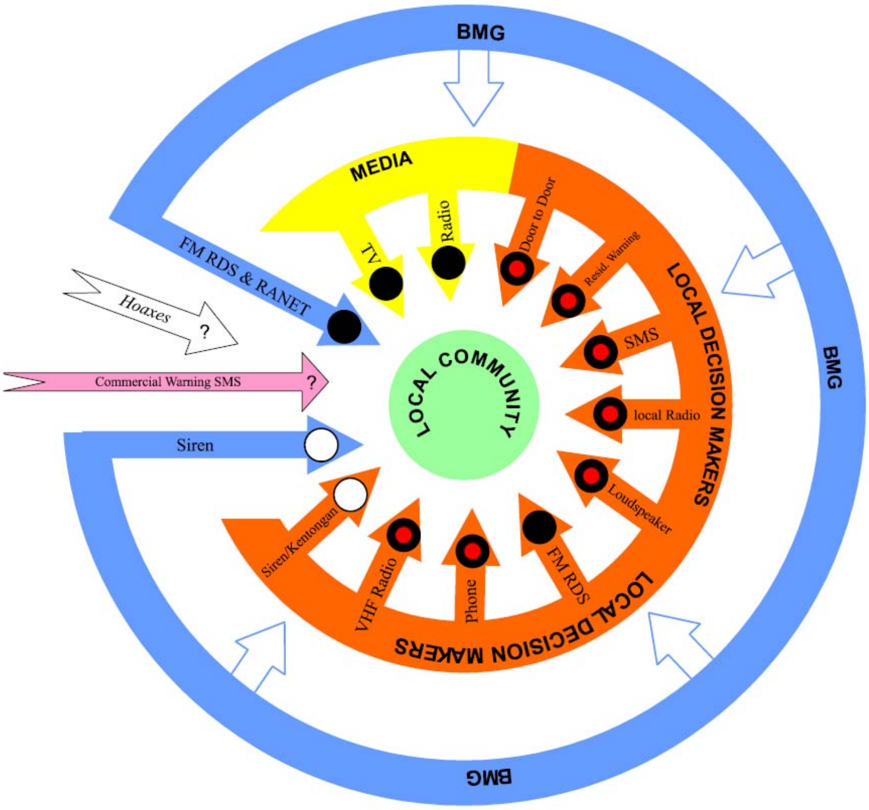


Figure 5: Origin, flow, and type of information and their respective dissemination technologies from a local perspective, Source: GTZ

As well, formats for tsunami event specifications dependent warning messages need to be defined and designed. Warning messages need to include information about location and extend of potential tsunami impact, and it's Estimated Time of Arrival (ETA).

Risk management task 2: Local warning SOP and Infrastructure

At the local level two factors are decisive for effective warnings that ensure exposed populations receive timely warnings:

(1) SOPs for local warning dissemination: A local warning dissemination strategy must ensure that also at the local level institutional arrangements for warning decisions and dissemination exist, that are capable to issue and disseminate warnings within a few minutes.

(2) Local infrastructure for warning dissemination: A local warning dissemination strategy must ensure that the majority of the population receives warnings. Especially where time is limited, full and timely access to warnings of the population is a prerequisite. This requires setting up extensive local warning infrastructure by taking into consideration local and cultural capacities for warning receipt and communication of the population. The efficiency of mass notification methods is a function of the following most important criteria: access of the population to

outdoor and indoor mass notification tools at different places day and night; informal warning communication; day and night households' communication device usage patterns; warning dissemination speed reliability of the different tools (e.g. during the occurrence of earthquakes); and the information value of the message that a specific device can provide.

Due to the ability of the mobile phone technology to disseminate warnings flexibly and selectively to those at risk (e.g. for a given region), mobile phones are one of the communication media considered suitable for use in Indonesia (GTZ 2007). However, other information dissemination tools such as TV and radio should be considered as well, due to their widespread accessibility even among the Indonesian rural population. Salamun (1993) stated that radio is the primary mass medium for much of rural Indonesia, and TV is regarded in general as the most effective means of reaching mass audiences (Sen & Hill 2000).

Risk assessment requirements: Deficiencies of population's access to warning infrastructure

Measuring and mapping the spatial variation of people's access to tsunami warning is specifically necessary to develop people-centred warning dissemination channels that are effective. Since the best strategy is to channel warnings through all kinds of different devices available in a country, it is still necessary to look closer at the deficiencies of recipients' access to outdoor (e.g. sirens, mosques) and indoor (mobile, TV, radio) mass notification infrastructure and to identify gaps that are of special concern and require specific solutions that enhance warning effectiveness. This kind of vulnerability information provides the knowledge base for the design of national and local level warning dissemination infrastructure systems and SOPs.

3.2.3 Warning Reaction

Risk management task: People's preparedness and SOP

In case people at risk do receive a tsunami warning and the evacuation infrastructure is in place the next question that arises is: "Are people prepared and ready to react to warnings?" Especially for the case of Indonesia where in some areas the average Estimated Time of Tsunami Arrival (ETA) is below one hour, its coastal population at risk has to decide individually and prompt to evacuate, whereas in other regions such as Hawaii, authorities have enough time to persuade their inhabitants to leave their place. Thus, for the case in Indonesia, a warning message needs to be understood directly by the recipients themselves first-hand in order to act. Are mechanisms and rules of procedures in place and internalized by the population that enhance effective evacuation (e.g. knowledge of evacuation place and routes, family based rules on meeting points, plans for the usage of vehicles, and support for the elderly)?

Thus, for immediate and appropriate evacuation, policy makers need to continuously raise awareness amongst citizens. Measures to enhance appropriate evacuation behaviour include awareness and socialization programmes, promoting household level SOPs for the case of a tsunami warning alert and visual support for evacuation routes and locations of shelters (signs, tables, maps, leaflets etc.).

Risk assessment requirements: Factors & degree of evacuation readiness

When warnings reach people at risk not everybody reacts to the warning in the same manner. Some people don't do anything, some want to confirm the tsunami occurrence before they run, some hassle to find their children, and some run on their own to higher ground. In the face of the very limited evacuation time available as is the case in Indonesia, inappropriate reactions to warnings are a vulnerability factor that can lead to the loss of life. In order to design appropriate awareness and socialization programmes, it is important to understand the underlying factors that shape warning response and evacuation readiness of tsunami-exposed populations.

3.2.4 Evacuation

Risk management task: Evacuation planning (SOP)

An evacuation plan needs to be developed by local stakeholders whose tasks are to ensure that their citizens manage save evacuation in due time. DRM tasks include defining the evacuation zone, developing evacuation infrastructure for horizontal and vertical evacuation and evacuation routes to shelters. In the following the different DRM tasks will be explained in detail.

Evacuation Plans describe activities and measures taken to ensure temporary evacuation of people from threatened locations before the disaster strikes. Plans identify affected and safe areas, difficult-to-evacuate areas, evacuation target points (horizontal and vertical areas) and evacuation routes.

The following information is necessary for evacuation planning:

Knowledge on location and capacities (people and basic needs provision) of evacuation target points

- Knowledge on emergency services capacities and locations (police, military, medical service)
- Knowledge on evacuation routes and evacuation bottlenecks
- Knowledge of areas with deficiencies in timely evacuation (difficult-to-evacuate areas)
- Amount of people in difficult evacuation areas and potential casualties
- Location of critical facilities needing special attention during evacuation (e.g. schools, hospitals)

Risk assessment requirements: Evacuation (failure) modelling

A comprehensive evacuation modelling approach developed for this reaction scheme component provides decisive information for local evacuation and contingency planning. In order to provide respective information, the following steps have to be undertaken:

1. Using hazard assessment to assign potential safe areas
2. Identification of potential evacuation target points for horizontal and vertical evacuation
3. Assessing detailed population distribution
4. Accessibility modelling
5. Evacuation modelling

Important evacuation target points and emergency services can be located and characterised using clearly defined criteria sets for vertical and horizontal evacuation. Accessibility modelling can show the fastest evacuation route from each point of a defined area to the nearest evacuation target point. Important evacuation bottlenecks and difficult-to-evacuate areas are obvious considering available evacuation times, shelter capacities, population density and main evacuation routes. Other evacuation alternatives can be identified by taking into consideration all passable land use classes. Furthermore through the assessment of people's evacuation capability, time-dependent expected casualties per administrative unit (e.g. desa/keluharan level) can be calculated. Based on this, recommendations for additional needed evacuation target points can be a crucial contribution for sustainable land management in tsunami risk areas and in reducing the risk of loss of lives.

3.2.5 Integrated Risk Assessment for Risk Management in the context of Early Warning

The assessment of the efficiency performance of the above mentioned components of the reaction scheme are methodologically combined to provide an integrated picture of tsunami risk. The result is a quantification of the spatial risk of loss-of-live and can be presented in form of maps or time-dependent casualty numbers per administrative unit.

Using this information the decision maker can intuitively see and evaluate areas possessing high risk. This consequently indicates a high probability of early warning and evacuation failure and hence a high probability of loss of lives. This integrated picture can strongly support decision for all disaster risk management aspects within the disaster cycle.

4 Summary: Definition and Factors of Risk and Vulnerability Based on the InaTEWS Reaction Scheme

This chapter provides first a definition of risk and vulnerability tailored to the context of the risk management domain: “Early Warning and Response”. Thereafter, an overview is provided that summarizes all the factors and criteria that play a role for the development of risk assessment methods and products presented in this guideline.

4.1 Definition of Risk and Risk Assessment in the Context of EWS

The broad and comprehensive definition of risk and vulnerability needs to be adapted to the specific risk and vulnerability context in the pre-tsunami-disaster phase, which is early warning and evacuation. Thus, Risk and vulnerability in the context of early warning and evacuation is defined as (...)

(...) *the conditions that increase the likelihood of the population being exposed to tsunamis, not being able to access tsunami warnings and adequately react to warnings, to find a safe place in due time and to suffer loss of life.*

Thus, the concept of risk is used but disaggregated and tailored to specific risk management tasks for the development of effective warning decision, warning dissemination, receipt and reaction and evacuation structures (see reaction scheme). Following this definition of risk, questions arise that try to point at the underlying factors that constitute problems in the tsunami warning and reaction scheme: Who are the exposed populations, where are they living and what are the reasons why they are less likely to be able to receive warnings? What determines people’s evacuation readiness and why do they fail to evacuate in due time?

Thus, **risk assessment** within InaTEWS is to identify those spatial and non-spatial factors that create effectiveness problems in the reaction scheme (warning dissemination and evacuation) causing loss of life during tsunami event. Thus, whether effective warning dissemination and evacuation capacities exist, under which conditions and how they can be increased, needs to be investigated by the means of risk and vulnerability assessment. Investigating on and measuring these factors of risks and vulnerabilities means identifying hazard parameters such as probabilities of occurrence, ETA and inundation as well as vulnerability parameters that point at the gaps and weaknesses of the spatial and social patterns of tsunami exposed social groups with regard to their access to warnings, their evacuation readiness, and their evacuation time needed.

4.2 Summary of Factors of Risk in the Context of EWS

For getting a quick overview of the risk and vulnerability criteria a summary is provided in Table 1, structured according to the different risk management tasks based on the reaction scheme.

Table 1: Vulnerability assessment criteria in the context of tsunami early warning and evacuation

Reaction scheme component	**Risk Management Tasks**	**Vulnerability criteria**
Warning decision	People affected	• Exposure of the population • Lack of capacity to evacuate
Warning dissemination % warning receipt	Access to tsunami warning infrastructure by the population	• Outdoor mass notification tools: Sirens and mosques • Indoor mass notification tools: Mobile phone, TV, Radio • Communication device usage profile during day and night • Informal notification / warning communication: community based warning, word of mouth • Availability of devices at different places during day and night • Reliability of the different tools (e.g. during the occurrence of earthquakes, blackouts) • Warning dissemination speed
Warning reaction	Evacuation preparedness & SOPs	• Clearness and preciseness of the warning message that a specific device can provide • Perception of risk (hazard knowledge, subjective exposure perception, cost-benefit of evacuation) • Beliefs and trust into warnings and authorities • Evacuation capability perception • Evacuation behaviour • Knowledge of safe place • Household structure and composition (age, gender, income)
Evacuation	Evacuation planning	• Environmental-physical and spatial factors: location of evacuation shelters and their carrying capacity, distance of people to shelters / safe areas, land use patterns and topography: slope, material, street network • Bio-physical factors (Age, gender)

In order to recognize also the common risk equation (risk = hazard x vulnerability), the risk criteria developed are structured according to their relation to the equation. Here, Figure 6 schematically summarizes how the concept of risk is operationalized in the context of tsunami early warning and response in Indonesia.

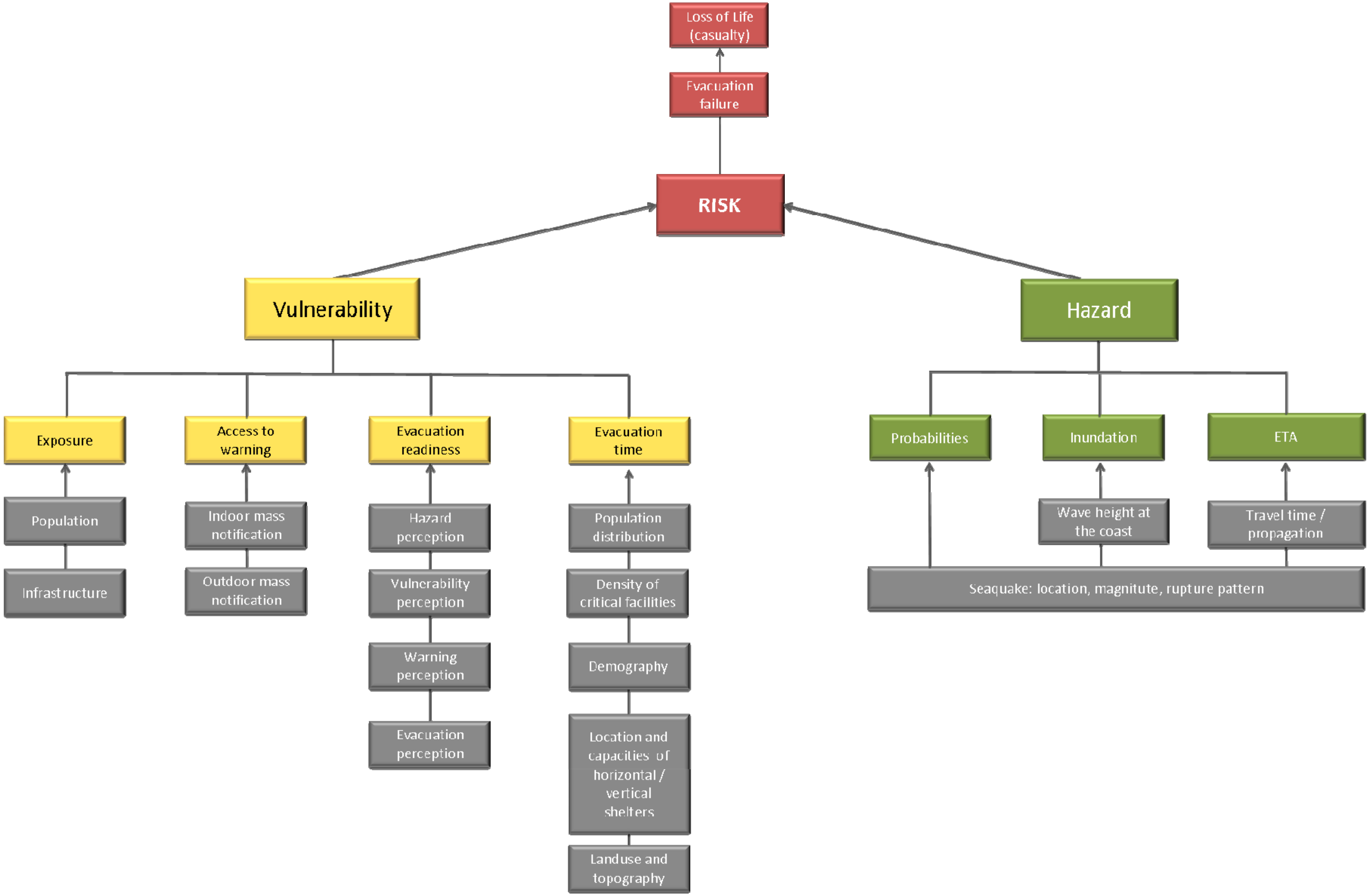


Figure 6: Components of risk in the context of InaTEWS

Part III:

Risk and Vulnerability Assessment: Products, Methods, and Recommendations

To set up InaTEWS effectively, risk and vulnerability assessment is a precondition and provides knowledge-based decision support. Part III of the guideline provides the concept, explains the methods and presents the risk and vulnerability products developed and tailored to user needs.

1 Introduction and Structure

Part III of the guideline is structured according to the following chapters:

- **Methods** for measuring components of risk (Chapter 2)
- **Products** of risk assessment based on the reaction scheme (Chapter 3)

Figure 7 serves as an overview and guide on which methods lead to which products and for which risk management component based on the reaction scheme they serve.

The **top row** of figure 7 shows the reaction scheme components. They were already described in Part II of this guideline. This separates the most important components in the time line of a tsunami disaster from its occurrence until the impact. This timeline is separated in the reaction scheme components Warning decision – Warning dissemination – Warning receipt – Warning reaction – Evacuation (see figure 7, top row).

In the **second row** from the top the specific risk management tasks are shown. To fulfill the given tasks a risk assessment has to be conducted in order to provide the respective data and knowledge for risk management.

Hence, the **bottom row** labeled “2. Risk Assessment Methods” and “3. Products national and local level (Pilot areas)” are the chapters that guide through the respective methods and products generated in order to provide the relevant information to do the specific risk management tasks.

The methods developed and implemented for risk assessment follow the assessment of hazard, vulnerability and risk – as is depicted in figure 7 and described in chapters 2.1, 2.2 and 2.3 respectively. The generated results and products link directly to the reaction scheme components and the risk management tasks. This is described in chapter 3.

For example, for the risk management task “evacuation planning” the following products were developed:

- “Hazard map – detailed” (green box),
- “Exposure map – detailed” (yellow box),
- “Evacuation time map – detailed” (yellow box) and
- “Risk of evacuation failure map” (red box in figure 7).

Going left from these boxes in figure 7 under the “2. Risk assessment methods” section, the respective methods leading to the respective products can be found together with the respective chapter in this guideline. Hence the product “evacuation time map” is methodologically described in the Vulnerability section of chapter 2 and there in chapter 2.2.4 evacuation time.

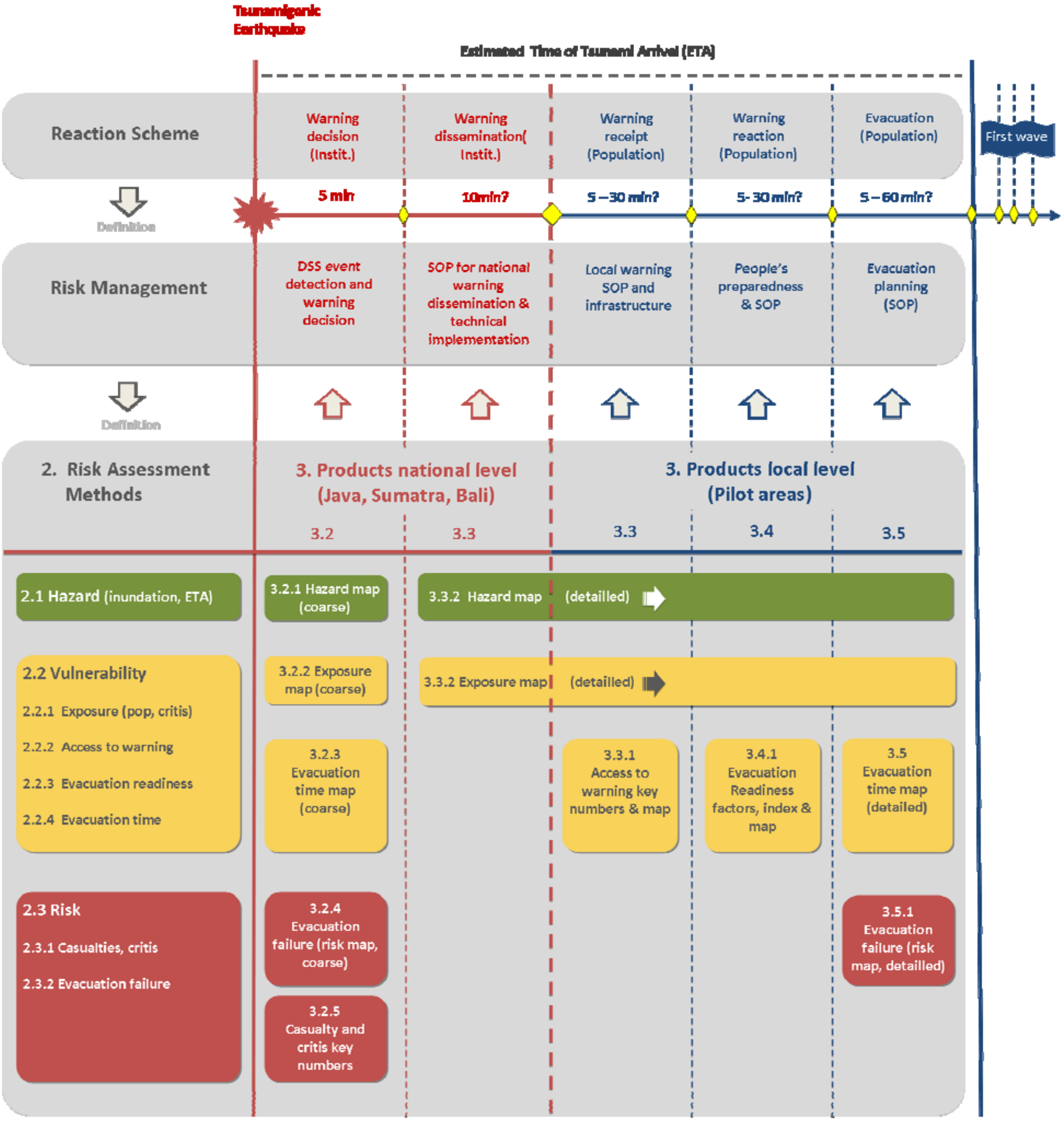


Figure 7: Overall structure of risk products (bottom row in figure, horizontal alignment) provided for specific risk management tasks (second top row in figure) and reaction scheme components (top row in figure) and their methodological base laid down in the risk assessment methods section (bottom row in figure, vertical alignment). The bottom row provides an overview in which chapter the methodological description is located for which product (e.g. hazard map products are described in chapter 3.2.1 and 3.3.2 whereas the methodological description is given in chapter 2.1 Hazard).

Description of Figure 7:

Warning decision takes place at the national level and needs risk information covering the entire area of responsibility of the Warning Center. The risk information for warning decision then has to link and relate with the risk properties at the local level and to appropriate local level reactions. Consequently, risk information needs to be given on a coarse level (coverage of entire nation) and on local level. This is taken into account in the overall risk assessment strategy. Therefore products are provided on national and on local level – as required through the respective risk management tasks and reaction scheme components (see figure 7 Products).

The following chapters outline and describe first the concept of risk and vulnerability, second the developed and deployed methods and third the hereof derived products and their implementation.

2 Methods: Measuring Components of Risk

Risk assessment is a logical outcome of the processes involved in the tsunami hazard and vulnerability assessment. The hazard assessments have to define the exposure parameters relating to the specific tsunami scenario and the probability of that scenario. The vulnerability assessment encompasses the identification and assessment of the vulnerability of the population exposed. Risk information aim at identifying the capacities and resources available to address or manage tsunami threats. In the following all components of risk assessment as conducted within GITEWS will be presented.

2.1 Hazard Assessment

The hypothetic question for all elements of the hazard assessment can be summarized by: How is the degree of impact on land? Different methods can be used to answer this question, depending on available knowledge and access to data in a certain community. Table 2 gives an overview about different assessment methods.

Table 2: Overview on three principle tsunami hazard assessment methods (1) using historical tsunami event information, (2) based on one worst-case or most credible scenario and (3) based on many pre-computed scenarios.

Source of Information	Derived parameter	Assessment information
Historical tsunami events	Maximum tsunami height and inundation	Distance and elevation zones with different probabilities to be affected by a tsunami
Inundation modelling results		
- based on one worst-case (most credible scenario	Flow depth, Flow velocity, Maximum inundation	Tsunami impact zones based on flow depth, maximum inundation and/ or flow velocity
- based on many scenarios	Flow depth, Flow velocity, Maximum inundation, Probability of occurrence	Tsunami impact zones based on flow depth, flow velocity, maximum inundation, probability of occurrence

2.1.1 Historical experiences

A basic way to come to a hazard zoning is to use local knowledge and observations of historical tsunami events which occurred in the respective area. This determines an area which already had been affected by a tsunami as a first classification of a tsunami exposed area and can be used to select an elevation based on a prior tsunami. This can be the maximum height of a large historical tsunami in the community or be based on geological evidence of pre-historic tsunamis.

Simple method – Influence of distance and height to tsunami impact

Historical information can be further amended by a simple method considering the correlation between the altitude and distance to the coast and the relating tsunami impact.

It is quite evident that there is a correlation between the distance to the coast and the degree of tsunami impact. For a classification of distance zones with different probabilities to be affected by a tsunami, diverse databases of historical tsunami events are available (e.g. NGDC). By discrete measurements of the maximum inundations in a certain area (see Figure 8), one can derive zones with a different frequency of an event. For example the inundation zones of more than 60 % of all tsunami events were less than 100 m inland. This information could be used as input for the definition of tsunami prone areas.

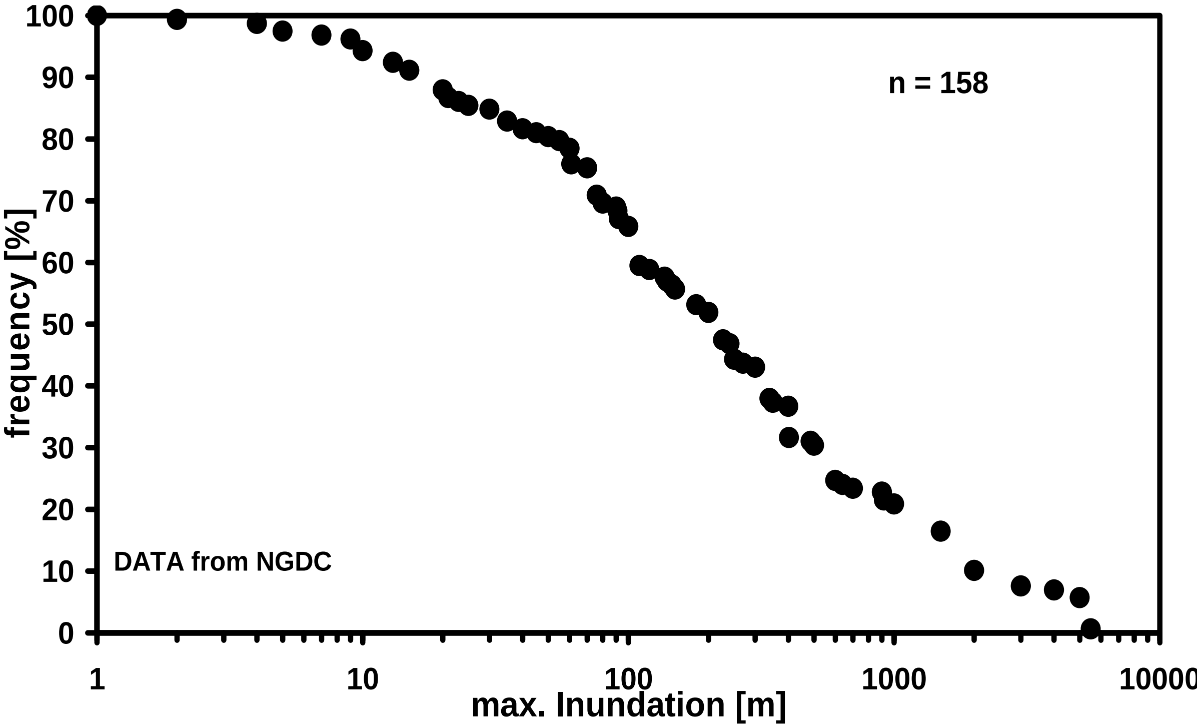


Figure 8: Discrete maximum inundation data of historical events (from NGDC, 2007).

A further crucial parameter influencing tsunami inundation is the elevation. The spatial distribution of the elevation (topography) along the coast can be derived from Digital Elevation Models (DEMs) or from topographic maps. This classification is strongly depending on the resolution of the available base data. Elevation information is most commonly available in order to divide into 10 m elevation steps as most tsunamis have serious impacts only at elevations lower than ten meters above sea level, although it is possible for very large tsunamis to be destructive above this elevation. Hence, e.g. the first zone with a very high probability of being affected by a tsunami reaches from 0 to 10 m above sea level. The zonation also takes into account river valleys, where the tsunami can run further inland. These valleys are highly exposed zones. The following figure gives an example of relative frequency of tsunami impact dependent on terrain elevation above sea level. This uses information of the NGDC data base, 2007 (Tsunami world wide, accessible at http://www.ngdc.noaa.gov).

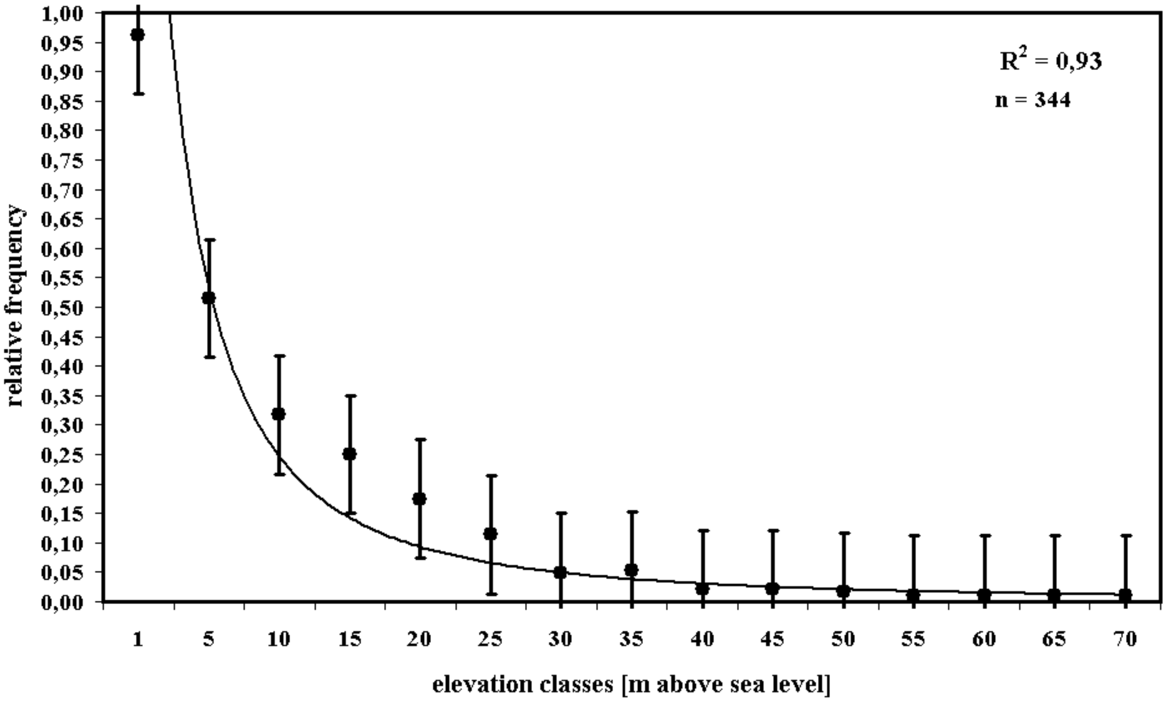


Figure 9: Relative tsunami frequency depending on elevation above sea level derived from historical tsunami impacts worldwide as documented in the NGDC data base, 2007 (Tsunami world wide, accessible at http://www.ngdc.noaa.gov).

2.1.2 Using tsunami modeling results

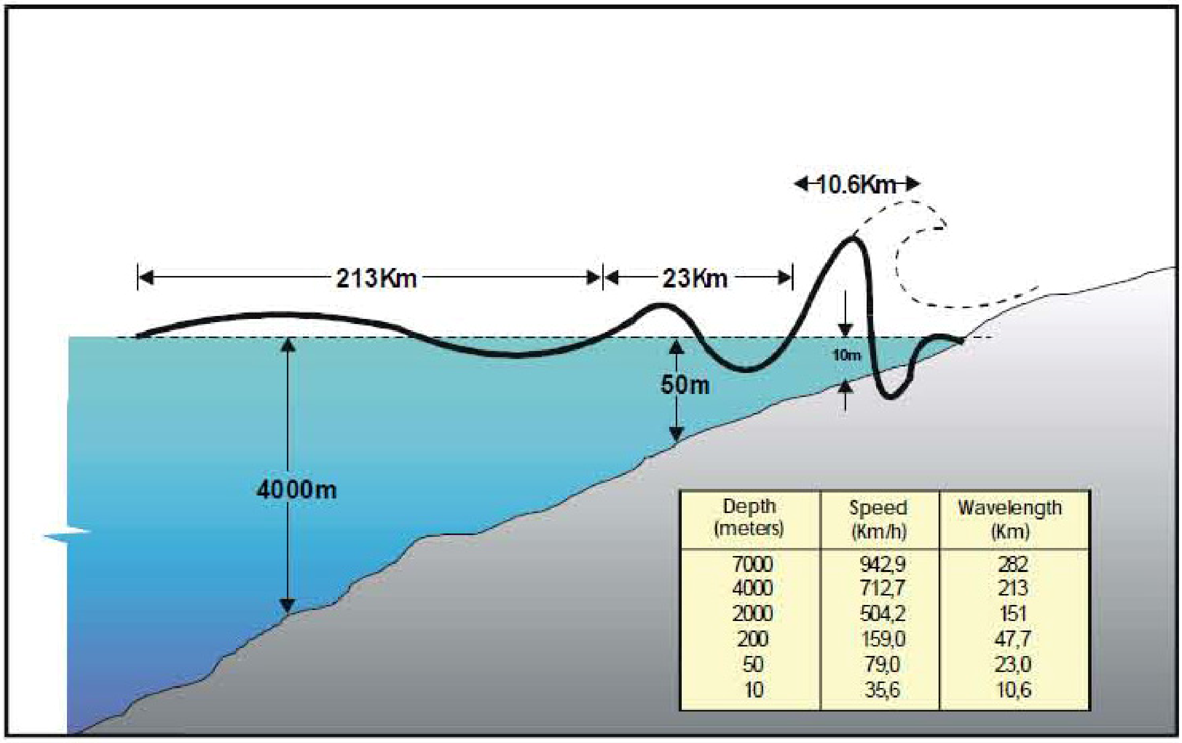
For estimating tsunami impacts on land, the hazard assessment is often conducted by using numerical inundation modelling results, based on a presumed geological framework. This analysis requires high resolution topography and bathymetry data (elevation data on land and underwater, respectively), and information about potential regional tsunami sources. The outcomes of tsunami inundation modeling are to identify areas that could be flooded and to estimate water depths, current strengths, wave heights, and wave arrival times.

The calculated results yield a probability for the intensity distribution of a tsunami at the coast (or run up) and the spatial distribution of the maximum inundation area depending on the location of the source.

a) based on one scenario – worst case or most credible

Here one tsunami modelling result considering a worst case or most credible scenario for a certain region is used to derive hazard impact zones expected.

The hazard impact zones can be derived by using the modeling results water depth above land surface (flow depth) and the water velocity. In the simplest way the flow depth can be used as criteria generating impact zones, e.g. by proposing hazard zones labelled as high, moderate and low with certain thresholds. In a more complex way, the water flux, as a function of flow depth and flow velocity, can be used to estimate the force impacting people, buildings or other objects. There might be the case that a lower flow depth inhibits higher water flux than a higher flow depth. Hence the force of a tsunami wave is different and by using flow depth as only criteria may not be able to distinguish this fact. The described water flux can be used incorporating characteristic thresholds to come to an impact zoning.



Depth (meters)	Speed (Km/h)	Wavelength (Km)
7000	942,9	282
4000	712,7	213
2000	504,2	151
200	159,0	47,7
50	79,0	23,0
10	35,6	10,6

Figure 10: The effect of water depth on wave height and velocity. Source: Tsunami Glosssary, UNESCO 2006

b) based on many scenarios – GITEWS multi- scenario approach

This approach, as used within GITEWS, analyses the likelihood of tsunamis of various sizes (based on many scenarios) that can then be simplified into tsunami hazard zones.

Tsunami modelling

The database for this approach consists of the results of the tsunami modelling performed by GITEWS partner AWI (Alfred Wegener Institute) at epicentre locations (source grid) for tsunami scenarios provided by GFZ (German Research Centre for Geosciences, 2008). The area modelled covers the south coasts of Sumatra, Java and Bali. The datasets used are global coverage GEBCO data (bathymetry data) and global coverage SRTM data (topography data). The results of the tsunami modelling based on these global datasets provide a level of detail usable only for maps of a scale of 1 : 100,000 or below. Hence, based on these datasets, only hazard maps with a scale of 1 : 100 000 were produced.

The method used to produce detailed hazard maps for the GITEWS pilot areas is the same as for the 1:100 000 hazard map series, but the used database is more detailed. For detailed inundation modelling the MIKE21 FM model from DHI-Wasy GmbH was used, and run-up modelling was performed by GKSS and DHI-Wasy. Initial bottom deformation and sea surface height as well as time series of water level elevation at the open boundaries were provided by AWI and GFZ in the frame of the GITEWS project. Spatial resolution used in modelling is between several hundreds of meters to ten meters, allowing for representation at a map scale of 1 : 25,000. Several thousand tsunami inundation scenarios were used, with moment magnitudes of 7.5, 7.7, 8.0, 8.2, 8.5, 8.7 and 9.0. The bathymetry is based on GEBCO data, C-Map data and echosounder measurements performed by BPPT and DHI-Wasy. The topography is based on digital surface model, street and building data, provided by DLR, and differential GPS measurements performed by DHI-Wasy.

Tsunami hazard mapping

The approach used for the tsunami hazard map production is a combination of probabilistic analyses and multi-scenario tsunami modeling results. Along the Sunda trench a large number of realistic tsunami scenarios with different tsunami source locations and earthquake magnitudes have been calculated. All scenarios together cover the south coast of Sumatera, Java and Bali. These scenarios are used as input data for the hazard maps. The approach is based on an “event tree technique” with different steps and takes into account the different warning levels which are issued from the Tsunami Warning Center. The warning levels are specified by INA-TEWS (BMKG 2008) and are defined as follows:

Table 3: Defined Warning levels in INA-TEWS (BMKG 2008)

Tsunami Category	**Warning Level**	**Wave Height (WH) Range [m]**
<none>	**<none>**	**0,0 = WH < 0,1**
Minor Tsunami	**Advisory**	**0,1 = WH < 0,5**
Tsunami	**Warning**	**0,5 = WH <3,0**
Major Tsunami	**Major Warning**	**WH ≥ 3,0**

The “Advisory Level” causes only a very small inundation area or no inundation at the coast. Hence in this hazard mapping approach the “Advisory Level” and the “Warning Level” are used in combination. The mapping approach for a comprehensive tsunami hazard probability map follows six steps, see below:

Step 1: Determine the Tsunami scenarios affecting the area of Interest:

As first step all the scenarios which affect the area of interest are chosen form the Tsunami Scenario database. This is realized by a spatial data query and selects all scenarios which at least inundate one point on land of the area of interest (e.g. a map sheet). The selected scenarios represent the basis for the further assessment.

Step 2: Classification of the scenarios depending on the warning levels:

As second step all available scenarios are grouped into the two warning level classes. Therefore a database query “Which scenarios generating a wave height at coast over 3 m” is performed. By defining the outline of the consolidated inundation of the classes you can get a first map showing the maximum inundation areas for the warning levels (see Figure 11). For the final hazard map product only the zone which is generated by the class “wave heights at coast smaller or equal 3 m” is displayed (red zone in Figure 11). The other zone is substituted by a calculation of continuous tsunami impact probabilities, which is described in the next steps.

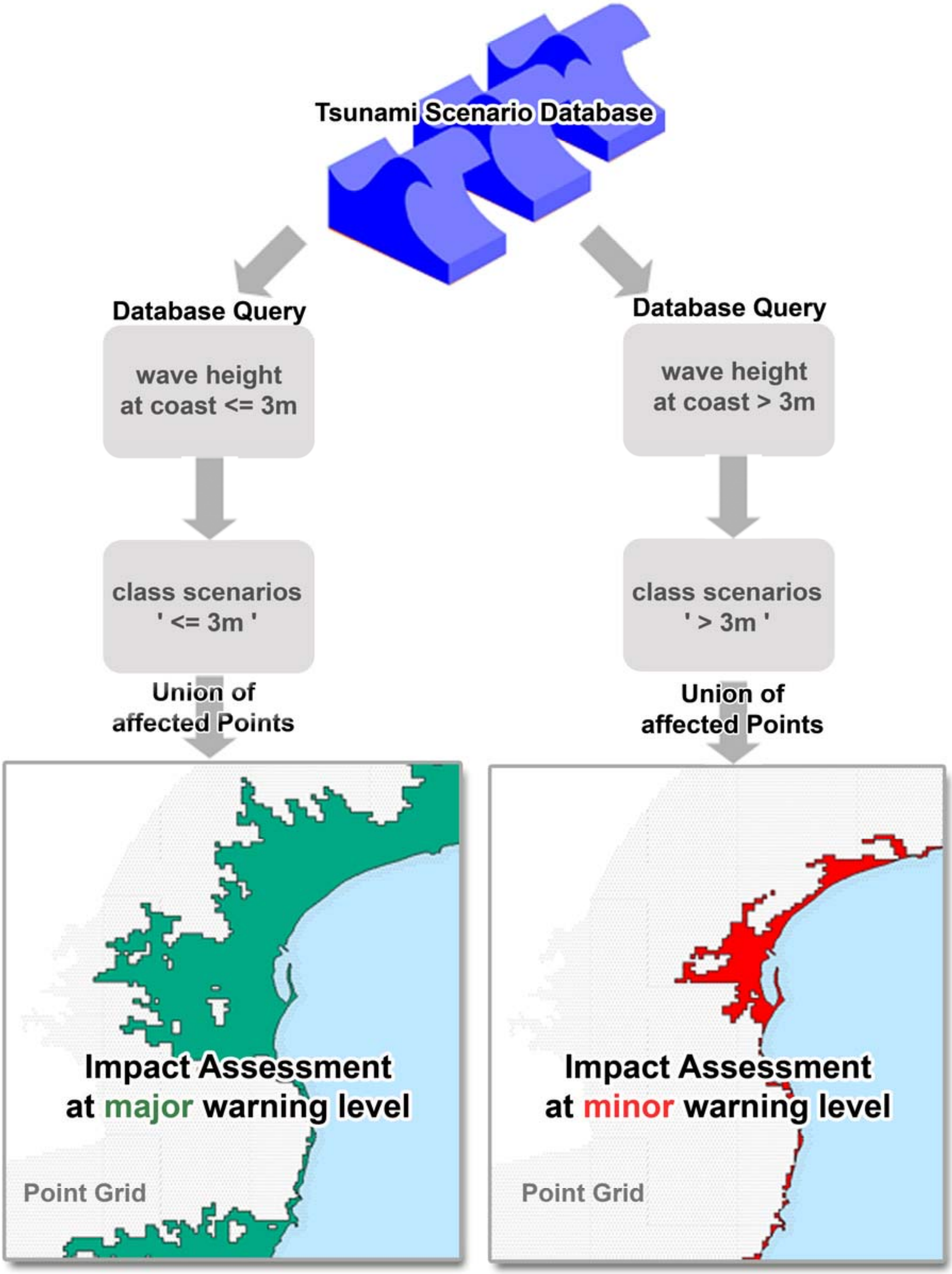


Figure 11: Multi-scenario aggregation taking into account the different tsunami warning levels

Step 3: Estimation of the spatial distributed probability for an earthquake with a specific magnitude along the Sunda Trench:

Since submarine earthquakes with high magnitudes occur more infrequent as earthquakes with lower magnitudes the scenarios with higher earthquake magnitudes (Moment magnitude: Mw) must be considered with a lower occurrence probability in the analysis. Similarly some regions along the Sunda Trench show a higher seismic activity as other regions and some spots are characterized by special geologic conditions – like a strong coupling of the plates at the subduction zone - which leads there to a higher occurrence probability for earthquakes with a high magnitude. This means that an area on land will be inundated by a tsunami event caused by an earthquake with a high magnitude at a region with low seismic activity is more unlikely as by an event with lower magnitudes at a earthquake “hot spot”-area. Therefore an assessment of the earthquake occurrence probability must be done.

This analysis is divided into two calculation steps. First the Sunda Trench region is zoned into three smaller regions which are showing different seismic activities (this is frequently published, e.g. Latief, Puspito& Imamura 2000, and can be also determined by a statistical analysis of historical earthquake data). At this zones the probability for an annually recurrence of every used Mw are estimated using the historical earthquake data (NEIC). To improve this assessment topical investigations like deterministic models are considered by a weighting of the occurrence probabilities between 1 (for determined hot spots with a high probability for an occurrence of a strong earthquake) and 0.1 (for determined more or less “inactive” spots). Figure 12 displays an example for the results of a weighted earthquake occurrence probability for a specific Mw. Thus every used tsunamigenic source has an individual occurrence probability (please notice: the probability that an earthquake also generates a significant Tsunami is covered by the numerical Tsunami model approach).

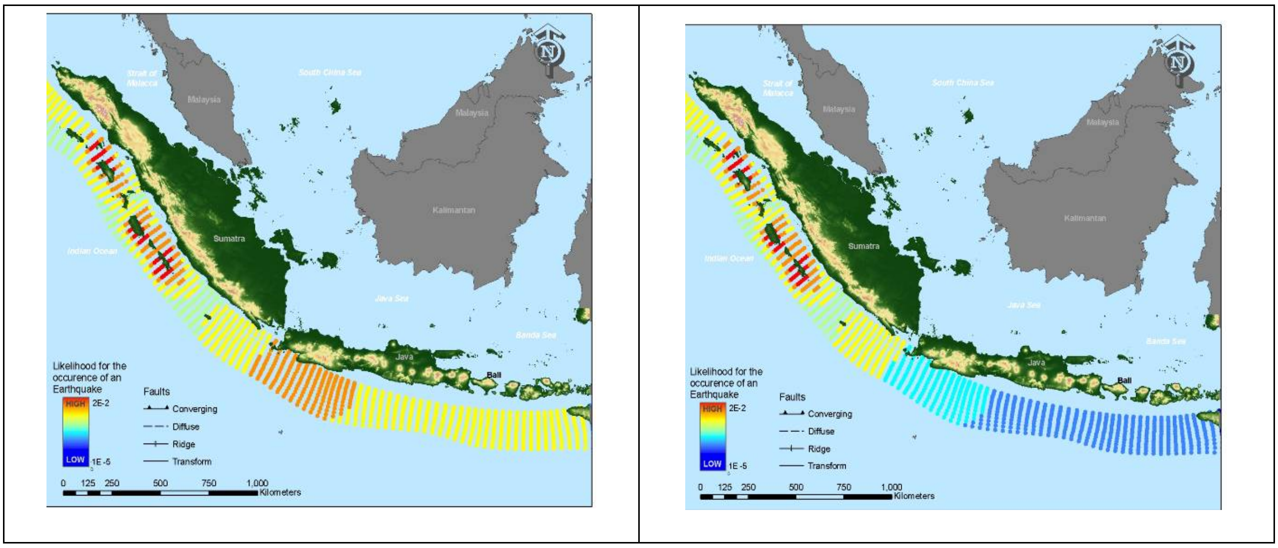
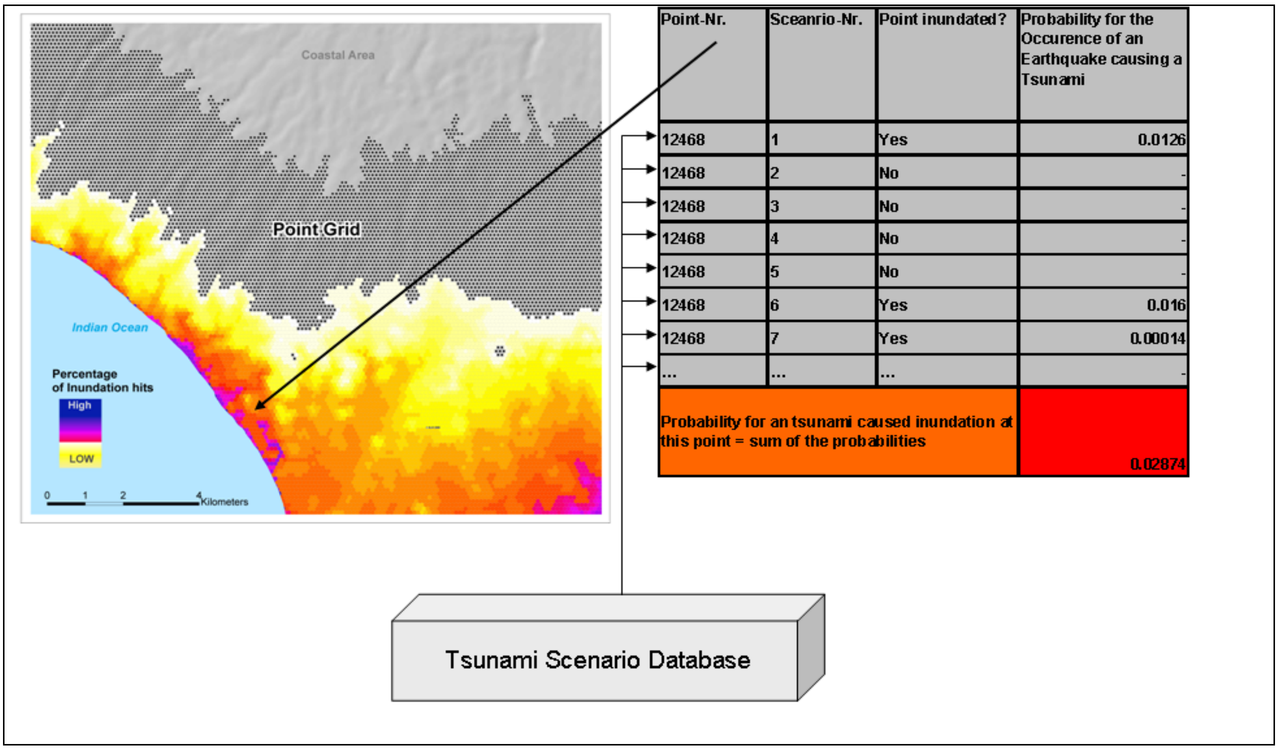


Figure 12: Assessment of the spatially differentiated likelihoods for the occurrence of an earthquake with a specific magnitude along the Sunda Trench (left: Mw 8.0, right: Mw 9.0).

Step 4: Determine a spatially distributed inundation probability:

In the next step a spatial differentiation for the possibility that a coastal area will be inundated is specified (spatial inundation likelihood). The results of the modeled tsunami scenarios include the impact on land, i.e. the area on land which will be inundated from a tsunami with a specific location and magnitude. The single impact areas from the different scenarios can, of course, overlap each other (because the tsunami source locations are not so far away from each other or the location is the same and the scenarios differ only by the magnitude of the submarine earthquake). Hence every point on land can be inundated several times by different scenarios. As a general example a point near the coast will be normally more often inundated as a point far away from the coast. For the calculation of the inundation likelihood the regarded coastal area is represented by a point grid with a grid extend of about 100 m. So for every point on the grid (every 100 m inland along the whole coast) the scenarios are selected which hit this point. For these selected scenarios the occurrence probabilities of their tsunami source (estimated in step 3) are summed up and divided by the amount of used scenarios. Hence the occurrence probability represents the probability that this point will be hit by a Tsunami within a year. Figure 13 shows the query of the relevant scenarios and the total of the probabilities at one point on land. For the display in a hazard map the discrete points on land are interpolated.



Point-Nr.	Sceanrio-Nr.	Point inundated?	Probability for the Occurence of an Earthquake causing a Tsunami
12468	1	Yes	0.0126
12468	2	No	-
12468	3	No	-
12468	4	No	-
12468	5	No	-
12468	6	Yes	0.016
12468	7	Yes	0.00014
...	...	...	-
Probability for an tsunami caused inundation at this point = sum of the probabilities			0.02874

Figure 13: Schematic representation of the determination of inundation frequency on land. Point hits by each per-calculated scenario are summed up and divided through the amount of scenarios for every location.

Figure 14 shows the basic procedure of this approach. In principle, this method derives from the probability of occurrence for different earthquake magnitudes at different geographic locations, the probability of occurrence for a specific wave height at the coast and the probability for every point on land to get hit by a tsunami. These values are combined and quantified by a logical tree technique. Detailed on the technical implementation are described in “Technical Guideline”

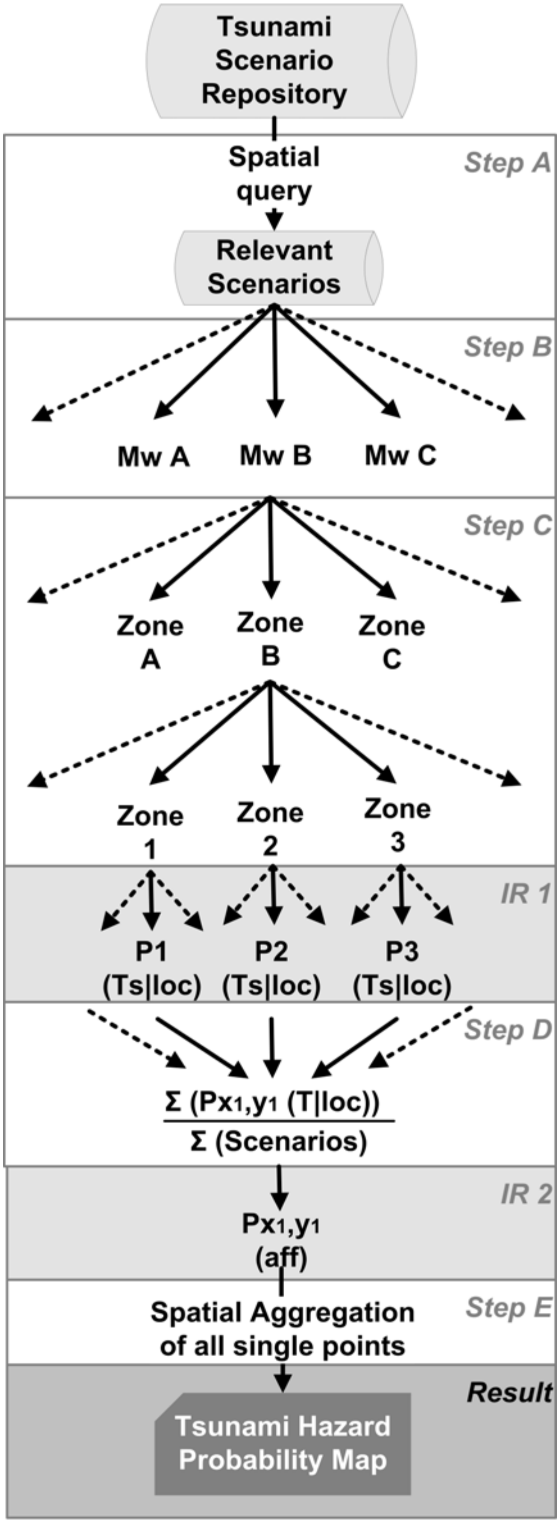


Figure 14: Principle scheme for the aggregation of various scenarios and their probabilities in the multi-scenario approach

Using this approach continuous hazard probability quantification is obtained. For the hazard map display we only show the probabilities for the major warning zone (moderate to low probability). The area which will be affected by a warning level situation is displayed in the hazard maps as red zone summarizing quantified tsunami probabilities to high tsunami probability. The zone is derived as described in Step 2.

Step 5: Combine the continuous probability with the "warning level" zone:

As next step the continuous Tsunami impact probability is overlaid by the derived "warning level" zone from step 2 in the hazard map.

Step 6: Adding additional parameters to the map:

Supplementary to the information about the inundation area the hazard map contains more parameters which characterize the potential tsunami danger of a coastal area. Every modeled scenario comprises an Estimated Time of Arrival (ETA) of the first disastrous Tsunami wave hitting the coast. The ETA can vary to a great extent for the various scenarios depending generally on the distance from the coast to the tsunamigenic source and the earthquake magnitude. To derive a valid value for the ETA from all available scenarios, two values are shown in the hazard map. The Min. ETA represents the minimum ETA which was found in all available scenarios. This is the worst case for the displayed point in the map. But this can be also a very rare event, so the Med. ETA is added to the point in the map. This value is the Median (50%-value) of the ETAs of all relevant scenarios for the regarded region. These values can be taken as estimation for the time to react which is left after the earthquake event happened (see Figure 15).

Figure 15: Example for the ETA values displayed in the hazard maps.

Furthermore, the relevant tsunamigenic sources for the regarded region are shown in a small display on the hazard map. It is indicated which tsunamigenic sources cause a dangerous tsunami for the region on the map. They are divided into sources with a high magnitude (which are widely dispersed along the Sunda trench) and sources with a lower magnitude (which are in general nearer to the regarded area). This illustration can be used to assess whether an earthquake will probably affect the regarded area by a tsunami (see Figure 16).

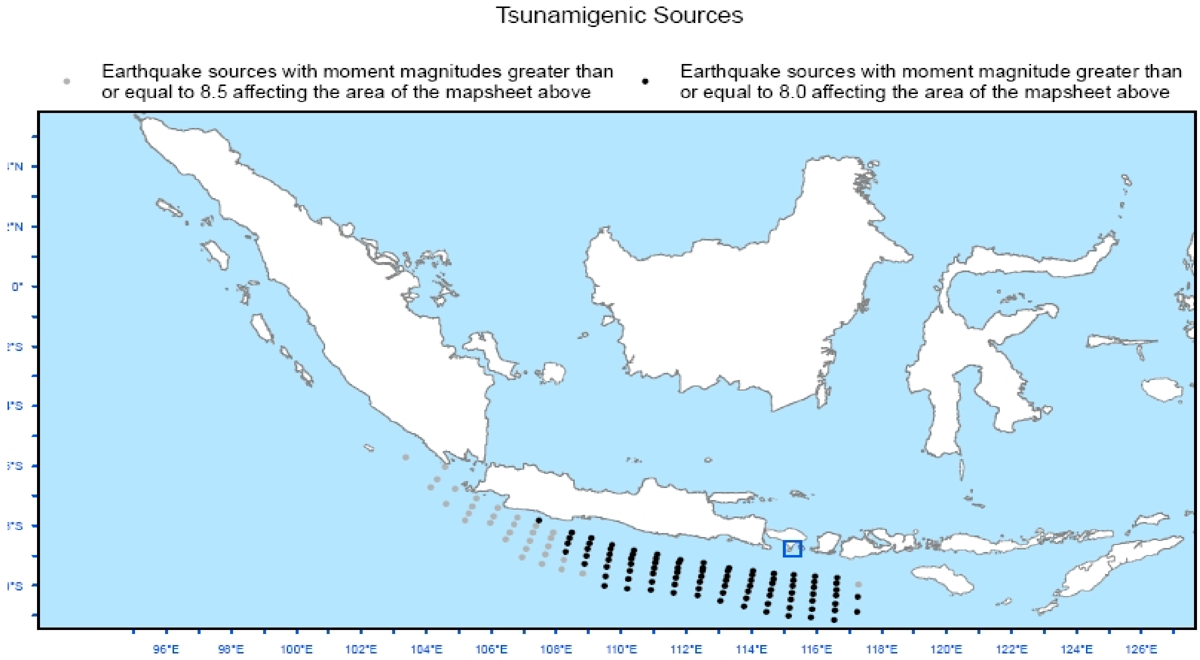


Figure 16: Example of tsunamigenic sources displayed in the map.

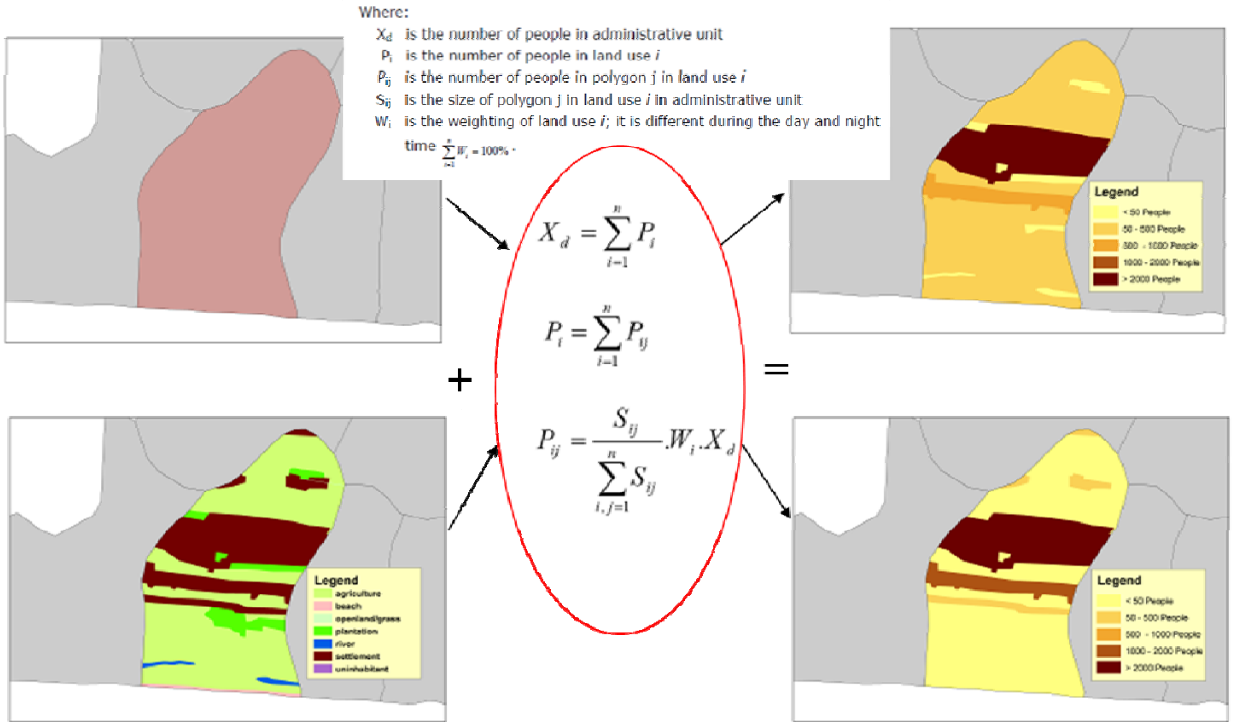
2.2 Vulnerability Assessment

2.2.1 Exposure

In case of a tsunami the decision whether a region should be warned requires sound information on the spatial distribution of exposed population, critical facilities and lifelines in order to prevent false alarms and to prioritize tsunami warnings. In addition, providing information about exposed population, critical facilities and lifelines (schools, hospitals etc.) is important for a national disaster management institution in order to be able to define local / sub-national “hotspots” for early warning and evacuation.

Population

The available information on population distribution is mostly based on statistical data and is related to administrative boundaries, like village, municipal, district, province, or national borders. In most countries of the world and also in Indonesia population distribution data are available for villages as smallest administrative level provided by the national statistical agency. The number of people is assumed to be distributed homogenously within each unit area, even in the part of uninhabited areas e.g. lakes, forest, swamps, and areas with high slopes. The resulting people distribution derived from census data on this level is not consistent with reality and hence too coarse for the usage for early warning purposes. To improve the spatial resolution of population data, a method to disaggregate population information from available datasets to land use classes (Figure 17) is presented in the following.



$$X_d = \sum_{i=1}^{n} P_i$$

$$P_i = \sum_{j=1}^{n} P_{ij}$$

$$P_{ij} = \frac{S_{ij}}{\sum_{i,j=1}^{n} S_{ij}} . W_i . X_d$$

Where:

X_d is the number of people in administrative unit
P_i is the number of people in land use *i*
P_{ij} is the number of people in polygon j in land use *i*
S_{ij} is the size of polygon j in land use *i* in administrative unit
W_i is the weighting of land use *i*; it is different during the day and night time $\sum_{i=1}^{n} W_i = 100\%$.

Figure 17: Concept of population distribution modeling

Statistical analysis of people's activities is used to allocate weights for the disaggregation whereby the determination of weighting factors that distribute the population to land use classes during day- and night-time is crucial. There are two sources of statistical data in Indonesia that provide information about people's activities at village level that can be used for the derivation of weighting factors: a complete enumeration of village data throughout Indonesia (PODES) and census data provided by BPS - Statistics Indonesia. The PODES data set contains information on the main income sources of the population in a community and the number of workers and non-workers. Additionally, the census data provide information on the percentage of employment in different sectors in each community. These parameters provide an indication of the type, volume and locality of human activities, and can be used to calculate the potential number of people engaged in different land use activities at various times of the day. During night-time, almost all people stay in the settlement area while during the daytime people are widely spread to different land use areas depending on the professional activity. Based on this information a more detailed and time-specific population distribution within a certain village can be stated. Figure 18 shows the methodological workflow.

The result of the population distribution modeling is an enhanced population density map (day and night distributions) at different scales, depending on available input data: maps at a scale of 1 : 100 000 are available for the entire coast of Sumatra, Java and Bali, more detailed maps at a scale of 1 : 25 000 are available for the GITEWS pilot areas. For further details on used input data and processing steps, please refer to the Technical Guideline. The map products are presented in Chapter 3.

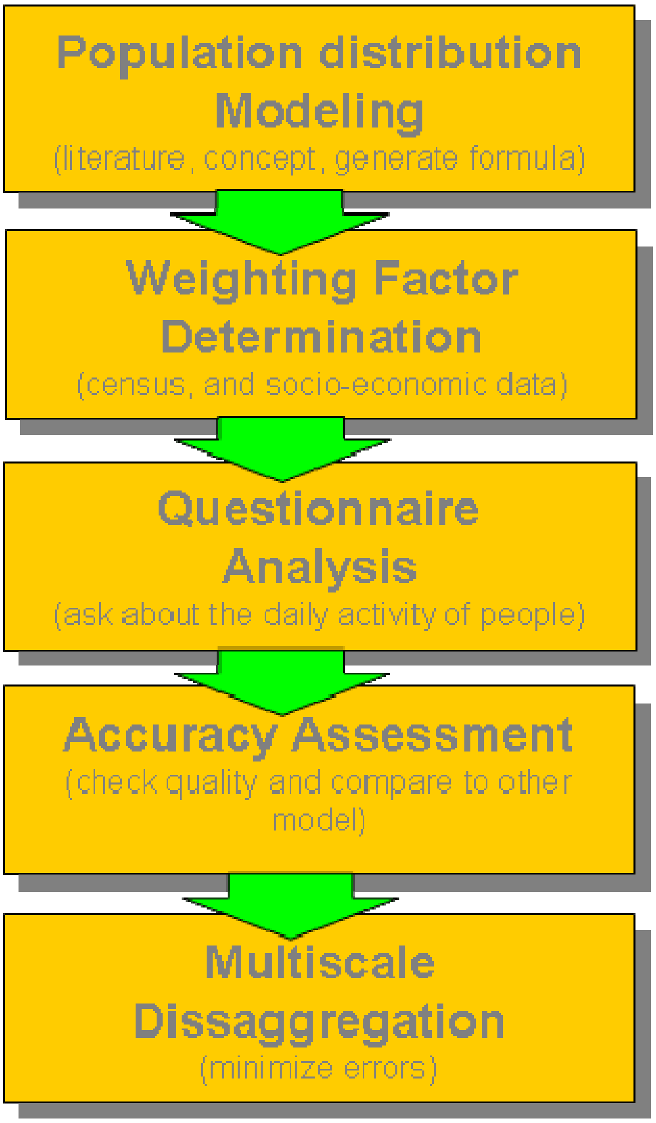


Figure 18: Methodological workflow of population distribution modelling.

Critical facilities and lifelines

Following a definition issued by the German Ministry of the Interior, critical infrastructures are organizations and facilities having high relevance for the national community whose disturbance or failure would have lasting effects on supply, considerable disruptions of public safety, or other significant adverse impacts (e.g. high rate of loss of life).

This definition corresponds to the Indonesian terminology of SARANA and PRASARANA, i.e. a classification into critical facilities and lifelines. Using this differentiation of critical infrastructures, the classes can be further subdivided into:

1) SARANA – critical facilities

All critical facilities are characterized by their importance for an efficient society and by their high exposure to a tsunami. They are further subdivided to:

- essential facilities

  Facilities featuring particularly endangered people (young, old, ill, disabled)

- supply facilities

  Facilities which are important in providing supply functions

- high loss facilities
- Facilities with high danger in causing negative effects for people and environment (secondary hazards like fire, oil spill).

2) PRASARANA – Lifelines

- Transportation Systems

  Lifelines having transportation characteristics like roads, railways, etc.

- Utility systems

  Lifelines used for resource provision, e.g. water pipes, electricity network, communication

Providing information on critical facilities and lifelines for early warning purposes at the sub-national level needs at least data on the amount of facilities per administrative unit (preferably desa). Naturally knowledge of the precise location improves the quality of early warning information. Considering this fact, for the early warning case the critical facilities shown in Table 4 can be regarded as valuable.

Table 4: Inventory of critical facilities to be considered for assessment

Critical facilities - Sarana		
Essential facilities	**Supply facilities**	**High loss facilities**
Hospitals	Airports	Industry
Kindergardens	Harbors/ports	Power plants
Primary schools	Police stations	Oil tanks
Residential homes for the elderly	Fire brigade	Refineries, Oil industry
Residential homes for the disabled	Military	Nuclear power plants

For the pilot area assessment spatial representation and respective function of critical facilities and lifelines are represented in more detail. This means that in contrast to the objective considered for the coarse analysis, namely exposure of critical infrastructure, the following objectives are relevant for the pilot areas:

1. Assess the exposure of the infrastructure **and** the people inside the infrastructure
2. Assess the vulnerability according to the early warning chain
3. Assess the feasibility of utilizing the building as a vertical evacuation place structural (area, height), SOPs, willingness to accommodate refugees, accessibility (open at night?)
4. Assess the suitability to provide emergency services

Table 5: Inventory of critical facilities to be considered for the pilot area assessment

Critical facilities - Sarana		
Essential facilities	**Supply facilities**	**High loss facilities**
Hospitals	Airports	Industry
Public and private education (schools, universities, kindergartens)	Harbors/ports	Power plants
Primary schools	Police stations	Oil tanks
Residential homes for the elderly	Fire brigade	Refineries, Oil industry
Residential homes for disabled	Military	Nuclear power plants
	Sports stadium	Big size industry
	Markets (etc. traditional, fish)	
	Bus terminal	
	Shopping mall	
	Hotels	
	Mosques / Church / Temple	

In addressing these objectives it is crucial to provide a clear definition which critical facilities and lifelines are investigated. An inventory of critical facilities and lifelines to be considered has been established in Table 5 and Table 6.

Table 6: Inventory of lifelines to be considered for the pilot area assessment

Lifelines - Prasarana	
Transportation Systems	**Utility Systems**
Road network	Water supply
Railway network	Electricity supply
	Telecommunication

All used information for critical facilities and lifelines are based on data from BPS-Statistics Indonesia. For further details on the used input data and processing steps, please refer to the Technical Guideline.

2.2.2 Access to Warning

Measuring and mapping the spatial variation of people's access to tsunami warning is specifically necessary to develop people-centred warning dissemination channels that are effective. Since the best strategy is to channel warnings through all kinds of different devices available in a country, it is still necessary to look closer at the deficiencies of recipients' access to outdoor (e.g. sirens, mosques) and indoor (mobile, TV, radio) mass notification infrastructure and to identify gaps that are of special concern and require specific solutions that enhance warning dissemination effectiveness.

(1) Method overview

Figure 19 presents the key steps for mapping the access of exposed populations to tsunami warnings.

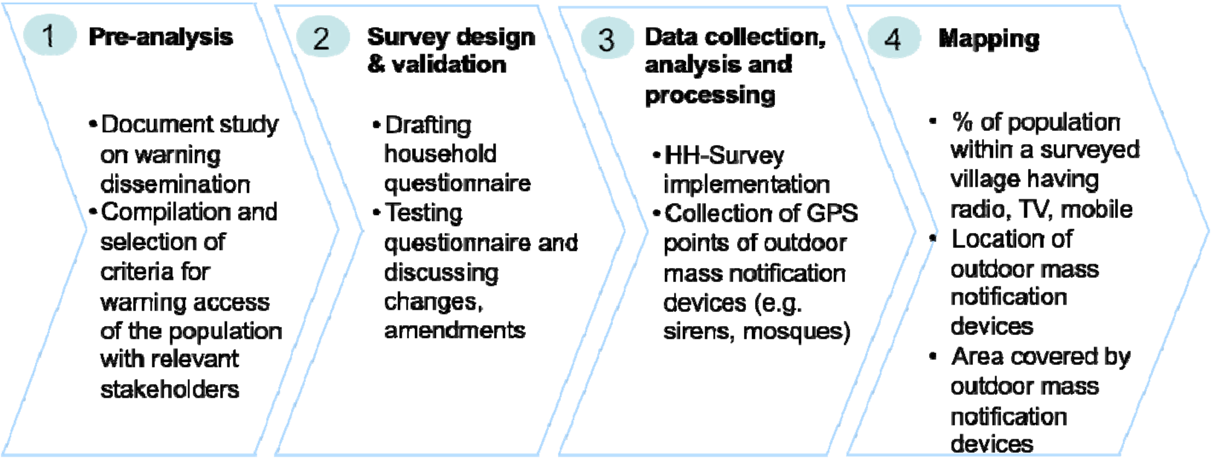


Figure 19: Process of mapping access to tsunami warnings by the population

Criteria selection

Access to tsunami warnings is the function of the following criteria, structured according to “physical” and “social” criteria that determine tsunami exposed population’s access to indoor and outdoor mass notification devices:

Physical criteria for access to warning devices:

- Outdoor mass notification tools: Sirens and mosques
- Indoor mass notification tools: Mobile phone, TV, Radio
- Reliability of the tools (e.g. risk of blackouts due to earthquake)

Social criteria for access to warnings:

- Communication device usage profile of households and individuals during day and night.
- Informal notification / warning communication: community based warning, word of mouth.

Social and physical criteria for access to warnings:

- Availability of devices at different places during day and night.

The following assessment example only focuses on measuring existing indoor and outdoor warning infrastructure.

Calculation

(1) Distribution of indoor mass notification devices among households

- Single device availability: The share of households in a village possessing a radio, or a TV or a mobile phone (in %), Method: descriptive analysis aggregated at the village level (desa) as the reference unit for deriving relative values (%).
- Device diversity: Share of households (%) in a village having no, one, two and all three devices.

(2) Spatial coverage of outdoor notification devices (sirens, mosques)

Two information layers were calculated that assess the current status of communities equipped with outdoor mass notification infrastructure:

a) Area in a village covered by sirens (only Bali and Padang);
b) Area in a village covered by mosque loudspeaker (only Cilacap and Padang). Utilizing mosques as warning dissemination channels has been discussed in various areas, amongst them in Padang and Cilacap.

Two criteria determine by concept the size of the area covered by a mosque speaker, sirens or other forms of outdoor mass notification.

a) Average city noise: Sound level (measured in db) at which a siren cannot be heard anymore: This is 80db (Federal Signal Cooperation, 2005)
b) Output level of the speaker of a siren / mosque / any other system.

Thereby, the term "area covered" relates to the area where not only sound can be noticed, but where also e.g. guidance messages can still be understood.

Two steps need to be followed for calculating coverage areas of mass notification systems:

(1) System's inventory: Compiling GPS information for of all locations of mass notification speakers from any kind of mass notification system that exists within the tsunami exposed area.

(2) Estimation of the area that notifications disseminated through a speaker and can be heard by exposed populations: The geometric form applied for calculating siren and mosque speaker spatial coverage are circles. For mapping them in the urban and rural environment in the three pilot areas the buffer function in ArcGIS9.3 has been applied.

It shall be noticed that any kind of mass notification system to be installed can be assessed using the same methodology.

Siren coverage calculation

Estimations of the area that exposed populations can properly hear a specific siren are based on sound projection measurements published by the Federal Signal Cooperation (2005). Figure 20 illustrates the maximum radius for sirens in an urban environment. The data tell that sirens become ineffective at 80db (average surrounding noise level).

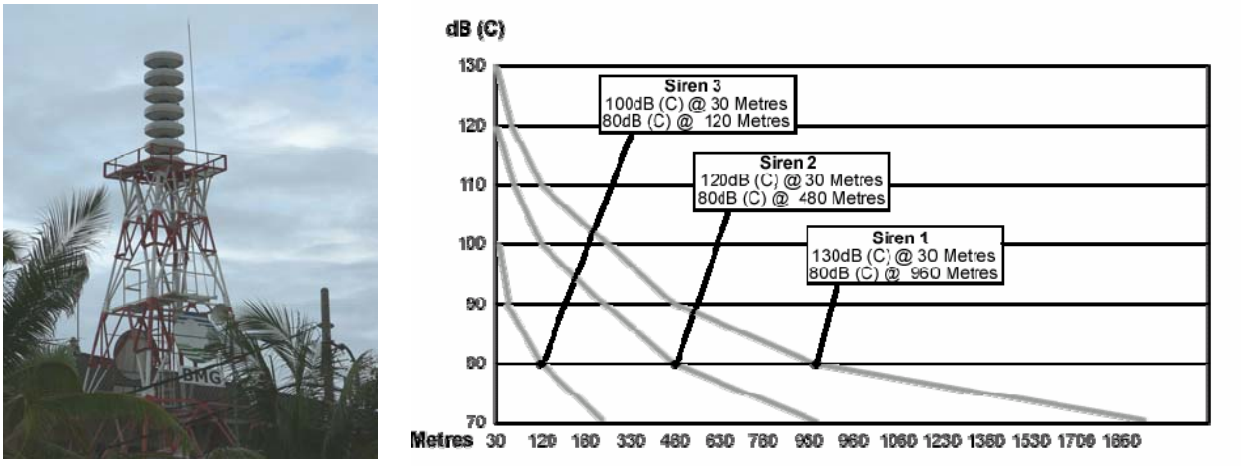


Figure 20: Sound projection for three sirens with different output power. Source: Federal Signal Corporation (2005): Modular Series Speaker Arrays. Illinois

Respectively, by using different siren output levels, three categories of siren coverage radius can be estimated and mapped:

- 100dB siren output = 120m coverage radius;
- 120dB siren output = 480m coverage radius;
- 130dB siren output = 960m coverage radius.

Mosque coverage calculation

If authorities regard mosques as a suitable warning dissemination system mapping their coverage area is needed. Inventories of mosques exist already in many statistics. Also data on GPS exists in some areas. When they are missing they have to be compiled. This is also true for measuring mosque speakers' output levels. Each mosque loudspeaker has different output levels, which could not be assessed. Instead a 150 m radius has been used and mapped for each mosque surveyed using the *Buffer* technique in ArcGIS 9.3, explained above.

(3) Exposure assessment: Merging night and day time population distribution

Census data on the desa/keluharan level are disaggregated to land use classes using weighting factors. The method to calculate population densities at day and night time is based on land use and population data is described in chapter 2.2.1. For the access to warning infrastructure map, night and day population densities are merged. This has been done by comparing the population density data values at day and night for each land use polygon and selecting only the higher value as the basis for the day and night exposure mapping. This step is important, because decisions on warning dissemination infrastructure investments shall not take into account day and night exposure levels, but for highest levels throughout 24 hours. In order to derive an exposure information layer, hazard inundation distribution information needs to be overlaid with the population distribution data to derive population distribution information for specific hazard areas. For methods of hazard inundation modelling please compare chapter 2.1. For this map, the maximum inundation area calculated is used.

Data source

a) Indoor mass notification devices:

Household survey data were collected in 2008 in three districts. The survey included questions on whether the household / respondent possess a radio, TV and mobile phone:

Padang:	1000 households
Cilacap:	500 households
Bali:	500 households

b) Outdoor mass notification devices:

- GPS points from mosques and sirens taken in the study area
- Expert judgment on mosque speaker spatial coverage

c) Exposure information:

The original database for the population distribution modeling is provided by BPS Census 2000 data which contains the population density per desa/kelurahan. For assessing precise population distribution, the land use information from BAKOSURTANAL and LAPAN were utilized. Compare chapter 2.2.1 for further details.

2.2.3 Warning reaction: Evacuation Readiness

When warnings reach people at risk not everybody reacts to the warning in the same manner. Some people don't do anything, some want to confirm the tsunami occurrence before they run, some hassle to find their children, and some run on their own to higher ground. Due to very limited evacuation time available as is the case in Indonesia, inappropriate reactions to warnings are a vulnerability factor that can lead to the loss of life. In order to design appropriate awareness and socialization programmes, it is important to understand the underlying factors that shape warning response and evacuation readiness of tsunami-exposed populations.

Anticipating actors warning response behaviour is challenging because it deals with identifying and estimating psychological and cognitive factors of individuals and groups. Conducting research in this field of vulnerability requires conducting integrated qualitative and quantitative research. Studying evacuation readiness requires research on the household level by the means questionnaire based data collection. Figure 21 shows the general methodological steps of the development of the Evacuation Readiness Index and its mapping. The overall methodological challenge was to identify the psychological (perception) and awareness (knowledge) factors that determine people's response to warnings and their evacuation readiness. The purpose of calculating an Index is to provide end – users with an easy tool to communicate and discuss the factors of evacuation readiness.

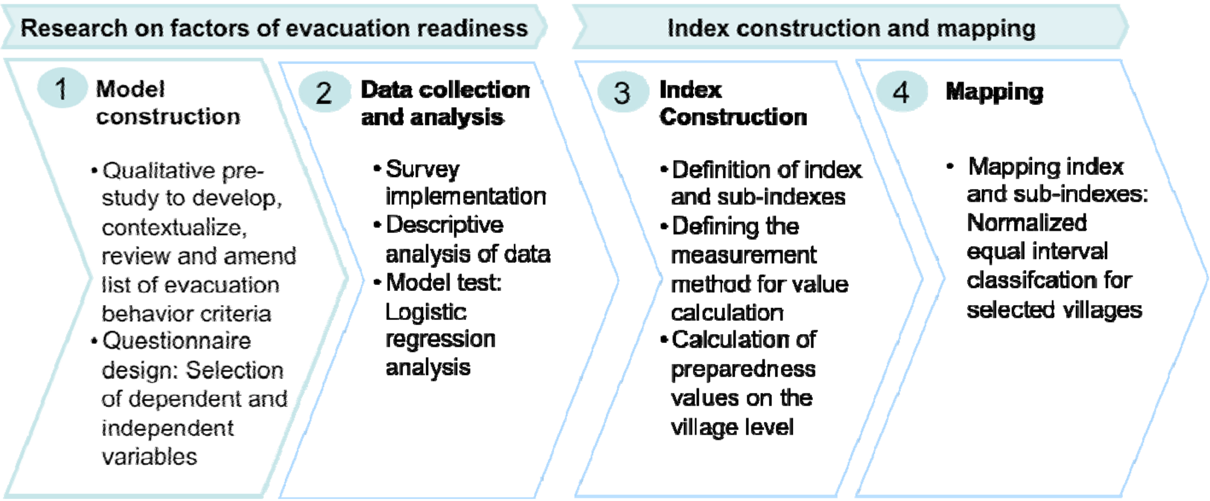


Figure 21: Methodological flowchart for constructing and mapping the evacuation readiness index

Option: For decision makers who aim assess the evacuation readiness of the population it is not absolutely necessary to identify the factors of evacuation readiness by complex statistical methods. Rather it would be important to measure the degree of evacuation readiness of exposed populations by utilizing the index parameters identified in the regression analysis as input parameters for the design of a household questionnaire. Then, measuring the degree of evacuation preparedness is a matter of designing questionnaire metrics and processing compiled survey data to arrive with a set of quantitative evacuation preparedness index values.

Identification of factors of evacuation readiness

This chapter explains the methods applied to identify those factors that shape individuals evacuation readiness. Thus, conducting a social science based analysis of evacuation readiness factors includes the following steps:

- Construction of a multivariate statistical analysis model (example here is given for the logistic regression);
- Household questionnaire design;
- Data collection;
- Data analysis: Regression analysis;
- Results interpretation (Model fit measures and variable discussion).

(1) Logistic Regression Model construction

For this research the logistic regression analysis tool has been the method identified to be most appropriate because it is designed to predict the probability of the occurrence of an event (anticipated evacuation yes, or no) by fitting data (set of variables influencing evacuation preparedness) to a logic curve. This means the model aims at discovering those key factors (independent variables) that according to theory, qualitative analysis and expert judgement are assumed to influence individuals' decision and speed to commence evacuation after receiving a tsunami warning. The logistic regression is a generalized linear model applied for binominal regression (binominal dependent variables). Like many forms of regression analysis, it makes use of several predictor variables that may be either numerical or / and categorical (Buehl, A. and P. Zoefel: 2002). Constructing a social science based model for logistic regression includes the following steps:

Selection and preparation of a dependent variable

In order to apply the logistic regression, binominal / categorical dependent variables (0 and 1) need to be developed. The questionnaire provides the basic set of variables for the development of the dependent variables: *"What would you do in the case you receive a tsunami warning?"*

Eight response options were provided in the questionnaire that shall allow respondents to precisely reflect on, imagine and judge on their hypothetical *anticipated action after receipt of a tsunami warning alert*. In order to use these variables for the as dependent variables in the logistic regression analysis they were transformed / recoded into a “quick” and “slow / no” warning alert response variable.

Selection and preparation of a set of independent / predictor variables

What are the variables that are assumed to influence / predict people’s response behaviour to tsunami alerts? The variables included in the quantitative questionnaire were developed and selected based on the following analytical steps:

- Pre-selection of variables based on theory: The theoretical background for the preliminary variable selection is the Protective Motivation Theory from Rogers (1983) that assumes that cognitive processes are mediating individual and collective behavior;
- Qualitative pre-study; contextualization of theory based variables:
    - Defining evacuation behaviour requirements according to threat and EWS specifications in Indonesia;
    - Semi-Structured Interviews (SSI) with exposed households and stakeholder consultations (workshops of the Indonesian - German Working Group on Tsunami Risk Assessment);

Finally, 35 predictor variables (independent variables) were selected for the logistic regression that are assumed to represent those cognitive processes that shape individuals response to tsunami warnings for the case of Indonesia.

(2) Household questionnaire design

Quantitative household surveys are the key instrument for data collection. It is advised to develop and manage household surveys in close cooperation with universities to insure quality control and representative results. Also BPS has a significant competence to assist. BPS can also provide guidelines on questionnaire design, including layout. According to the research topic and data needs, questionnaires differ in terms of questions and variable metrics and size of the questionnaire.

Three types of data sets shall be included in the quantitative household questionnaire, if a multivariate analysis is desired:

1) Baseline socio-economic parameters of households and individuals: age, gender, household size, income, employment sector, education etc.
2) Independent variables: How at best can anticipated and hypothetical reaction to warning alerts be captured, what are the variables? Here, it was chosen to design parameters

and question that respondents can easily associate with, when dealing with options after receiving a tsunami warning alert.

3) Dependent variables: All possible and by theory assumed variables shall be included in the questionnaire. In the statistical analysis some of them may turn out to be not significant and thus not suitable to be used for logistic regression.

Option: If multivariate analysis is not required only the set of variables need to be included in the questionnaire that highly impact individuals’ evacuation readiness (compare chapter 3.4.1)

(3) Data collection and survey sampling

To define the survey sample locations and size it is necessary to define the product goal and output desired. Here, measuring evacuation readiness and developing decision support products for awareness rising and sensitization aims at developing indicators whose values are representative for decision makers’ geographic territory of political power.

Thus, the survey sampling definition is based on the following steps:

1. Definition of the representative unit of analysis
2. Sample size selection
3. Sample location selection
4. Household selection

The household survey data were collected in 2008 in three districts (total 2000 households, in 20 villages). The data were collected jointly with Andalas University (Padang) and Ghajah Mada University (Yogyakarta).

Sampling method, sample size and the selection of villages to survey need to be defined according to the surveys goals. Since it is indented to develop an Evacuation Readiness Index, the following choices have been made:

Definition of the representative unit of analysis

The guideline presents the evacuation readiness assessment results representative at the village level. This scale has been chosen because it allows for a spatial analysis of evacuation readiness at different exposure levels. In addition, it allows for prioritizing and designing village specific socialization campaigns, depending on the level of evacuation readiness within a village.

Option: It is up do decision makers to choose the scale. If decision makers involved in awareness and socialization campaigns want to know the degree of evacuation readiness in different places in their territory of power to prioritize intervention activities (e.g. district), the village level is the suitable representative unit of assessment. If the respective programme only tempts to have a general overview of the degree of evacuation readiness e.g. in a district, the representative unit would be the district level.

Sample size

For the assessment to be representative at the village level, the sample size needs to be selected according to the social structure and its heterogeneity within a village. Generally speaking, the higher the heterogeneity the higher the sample size. In this case the sample size for each village ranges from 60 – 90 households. Depending on how many villages shall be selected the total sample size varies. Here in total 2000 households have been surveyed in 24 villages.

Option: If the village level shall not be the representative unit of the assessment, the sample size can be much smaller, which also lowers the resources necessary. But also defining the sample size e.g. to be representative for the district level, shall take into account the social structure of the population. Enough samples shall be generated for each social group, e.g. defined according to gender, age and income.

Household Selection: Stratified sampling

Due to the lack of precise socio-economic sampling data for different villages / city wards, the household samples were selected based on remote sensing analysis of the physical urban structure of residential areas (building type, density and size, rural/urban area). Thereby, it is assumed that the physical structure corresponds with the socio-economic structure of the household entities residing in the respective building. Thus, in order to include all sub-groups of the population an equal share of the different residential building types that exist within a village was selected randomly. The precise remote-sensing based pre-selection of single households was only possible in urban Padang and Cilacap due to the availability of high-resolution Ikonos satellite imagery. For the more rural areas and for Badung (Bali) simple random sampling has been conducted.

Options: Depending on the available information of the social structure of an area other means of stratified sampling is possible. E.g. the census block information from BPS can be used, and can be obtained in the local BPS office.

Village Selection

Due to limited financial resources of the research in this guideline only a few villages in the pilot areas could be covered. Therefore, also the product developed shall act as an example how evacuation readiness can be measured. For the product developed in this guideline the criteria 'coastal / hazard exposed' and 'regional / developmental difference' were the two main criteria applied for selecting the villages of interest for the study.

Option: To get a full picture of the degree of evacuation readiness of all coastal villages more villages need to be covered. Based on hazard inundation maps exposed villages can identified and entirely surveyed.

(4) Data analysis: Logistic regression

The data analysis is at best conducted with SPSS (Statistical Package for Social Science). Before conducting the multivariate analysis, descriptive analysis of the data is important. With such information at hand, one can judge whether the data are good enough to be utilized for further analysis.

Nowadays it is easy to conduct complex statistical analysis using computer software such as SPSS. The real challenge is then to interpret the results, e.g. the modelfit measures. Applying the logistic regression the dependent variable must be "nominal" the independents: "nominal" and / or "scale". In this analysis both scales were used. The models were performed separately for each pilot area (Cilacap, Bali and Padang) considering the fact that those variables showing strong influence do not have to be the same ones because of location specific differences (compare Technical Guideline).

Index construction

To derive aggregated information about the degree of evacuation readiness of the population that can be used by decision makers, the factors identified in the regression analysis were grouped into sub-indexes and labelled according to their logic association. Finally, an aggregated Evacuation Readiness Index has been created (Figure 22).

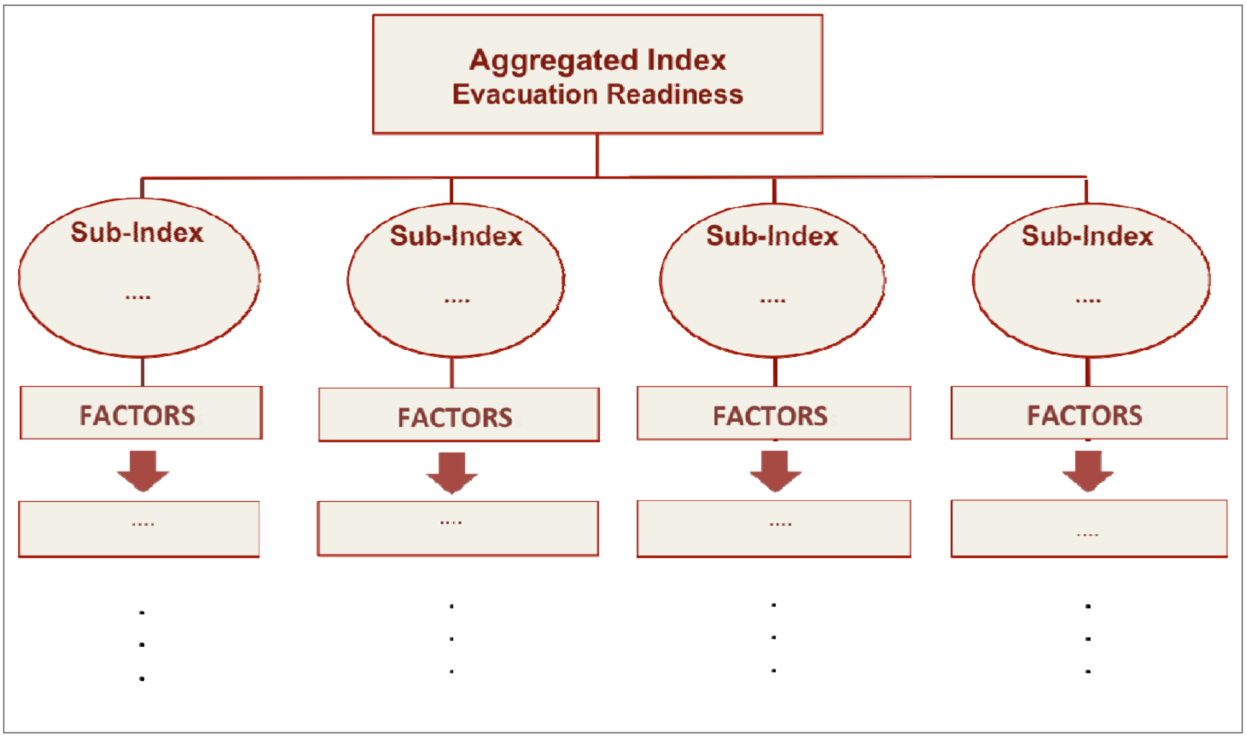


Figure 22: Evacuation readiness sub-indexes and aggregated index

Index calculation

To measure the degree of evacuation readiness and its sub-indexes at the village level the following steps were conducted (compare Figure 22: Evacuation readiness sub-indexes and aggregated index).

1. Scoring system development: Recoding the case values of each variable into 0, 0.5; and 1. The higher the value the more likely the specific factor contributes to overall evacuation readiness.
2. Aggregation by calculating mean values: All case values of variables belonging to the same village were aggregated.
3. Sub-(index) calculation: To derive sub-index values, village level mean values of the variables belonging to a sub-index were calculated. The same procedure was applied to derive evacuation readiness index values.
4. Grouping of the index values: The index values were grouped into four levels of evacuation readiness using the equal interval method: very low, low, high, very high.

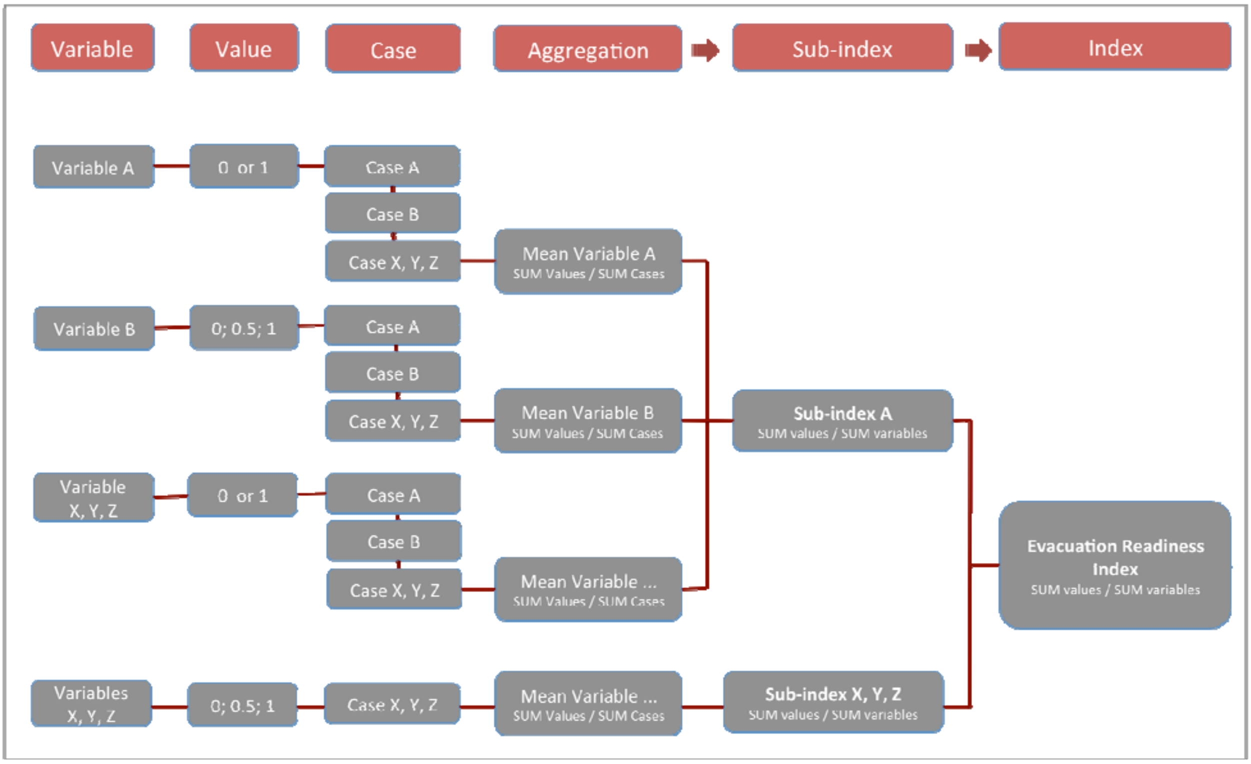


Figure 23: Evacuation readiness Index construction

Index Mapping

Finally, the index and sub-index results were mapped for each surveyed village in the three pilot areas. In order to be able to distinguish between very low, low, high and very high levels of evacuation readiness at the village level, an equal intervals classification scheme was employed.

2.2.4 Evacuation Time

The central factor in quantifying peoples' evacuation capability is time. Knowledge of tsunami warning response properties in the sense of (1) "how much time do people need to rescue themselves?" (here defined as Evacuation time - ET) versus (2) "how much time do they actually have?" (here defined as Response time - RsT), is a crucial information in the early warning process and disaster management. Consequently, the central aim of this part of the vulnerability assessment is to describe a methodological framework which contextualizes the key components and underlying processes in quantifying peoples' evacuation capability.

Generally, peoples' evacuation capability can then be estimated on the basis of the relationship between ET and RsT. For RsT>=ET people in the respective areas are able to rescue themselves by reaching a safe area. Critical areas possess RsT<=ET values because people within these areas will be directly impacted by a tsunami.

In the following the process steps for the production of an "evacuation time map" ,showing peoples' evacuation capability to a tsunami disaster, will be explained. Evacuation capability is expressed as the time (in minutes) needed to reach the closest evacuation target point.

Evacuation time

The ability to respond properly to a tsunami warning message, i.e. evacuate on time, depends on (1) location of tsunami safe areas and their properties, (2) land cover, (3) topography (slope), (4) population density, (5) age and gender distribution and (6) density of critical facilities (primary schools, hospitals). The location of safe areas determines the distance an evacuee has to cover. Land cover and slope alters the evacuee's movement and speed (ADPC, 2007). Related to demographic factors it has been found in several studies that age and gender distributions significantly impact fatality rates due to contributions to longer evacuation times. In evacuation modeling studies, the impact of population density and evacuation properties of different group sizes are accounted for. The larger the group and the higher the population density the slower the evacuation process (Klüpfel, 2003). The existence of critical facilities such as schools and hospitals result in reduced response capabilities due to the presence of people needing special attention during an evacuation (Johnson, 2006). Obviously physical and mental disabilities are limiting factors for individuals to cope during a disaster.

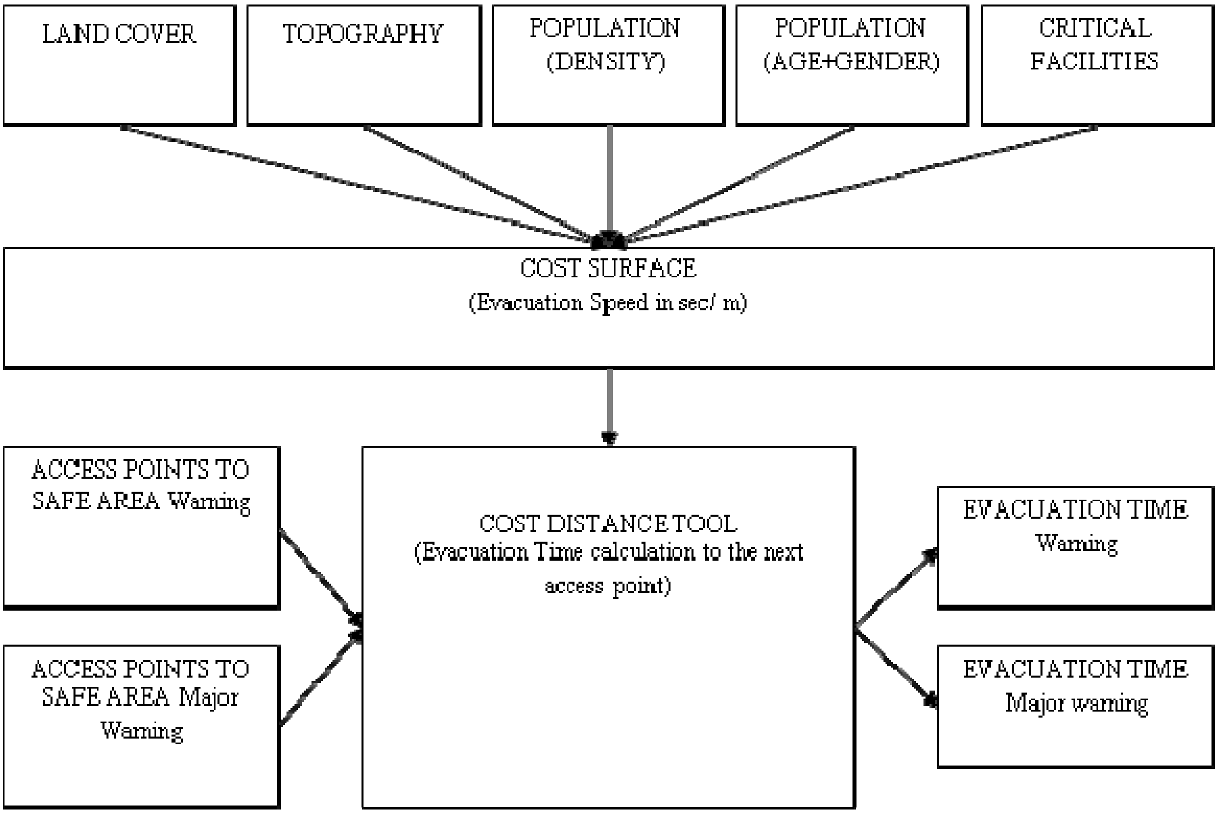


Figure 24: Workflow to calculate evacuation time (ET) based on key determinants and a cost distance weighting approach.

The basic principle for the quantification of evacuation time is a GIS analysis to define the fastest path (best evacuation route) from a given point to the safe area. Using the determined credible evacuation area (both “warning” and “major warning” cases, see chapter 3.1), so called access points to safe areas can be assigned. First characteristics of a safe area referred as temporary shelter areas for evacuation are determined. The temporary shelter areas have to be outside the evacuation area and have to feature a suitable land use/cover and topography (slope) beside a minimum area of 10 000 m^2 ensuring sufficient space for temporarily gathering of evacuees. A measure of travel costs is used which can be considered as travel time (evacuation time) needed when approaching the next safe area. In this concept, the accessibility to a safe area is calculated on a cost surface which consists of a regular two-dimensional grid where each cell value represents the cost to travel through it depending on costs introduced by land cover, population density, slope, critical facility density, age and gender distribution (Figure 24). Using the cost weighted distance approach (ESRI, 2001) the time needed from each location (raster cell) within the credible evacuation area to the next safe area is calculated using the ArcGIS cost distance algorithm (ESRI, 2001). For further details on the used input data and processing steps, please refer to the Technical Guideline.

Response Time

Response time is not a static value since some determinants can not be quantified or defined precisely. However, the determinants itself are known and can be summarized as follows:

Response Time (RsT) = Estimated Time of Arrival (ETA) – Reception time of Tsunami warning (ToNW) – Reaction Time (RT)

One parameter in the tsunami scenario database is the estimated minimum time of arrival of the tsunami (ETA) per scenario and for predefined coastal locations. Quantification of representative ETA is based on a set of tsunami scenarios covering the range of potentially possible tsunami events along distributed tsunami sources zones (along the Sunda Arc) provided by the German Research Centre for Geosciences (GFZ Potsdam) within the GITEWS project. For each coastal location the median value (50th percentile of ETA distribution at the respective location) is calculated. The values of the coastal locations are then aggregated on warning segments using again the median value of the obtained distribution. Warning segments are pre-defined spatial entities within the Tsunami Early Warning Centre related to district (Kota/Kabupaten) administrative boundaries in Indonesia. For this spatial unit the median ETA is used as representative value for anticipated time of arrival of a tsunami.

Calculation of the evacuation speed

The evacuation speed is created on the basis of different parameters (as already mentioned above) which influence the people’s evacuation speed:

1) Land use and Slope

Each land use and slope class of the dataset got a new value, describing their capability to modify the speed of a walking person. The new values represent how much the average speed will be conserved on the different land use types and its respective slope. Based on a value of 100 (100% speed conservation), for example, a value of 80 means that the speed will be reduced of 20%. Due to the fact that not every class of the dataset is a passable one, like water bodies or slope values above 45 degree, a suitable filter had to be set. For further analyses all classes had to be retained, therefore relatively inaccessible classes got the value 1 or 5, good evacuation routes receive the value 100.

2) Area around critical facilities

Critical facilities, like hospitals and schools, are characterized by their high exposure to a tsunami. In case of an evacuation there will be a lot of activities around these facilities because people inside (young, old or disabled) are usually not able to evacuate themselves and therefore need support from emergency medical services or people around.

Within a buffer of 100 meter around these facilities a speed reduction of 50% is assumed to meet the situation during an evacuation.

3) Population density and demographic population index

It is assumed that the population density influences the evacuation speed significantly as moving alone will be much faster than moving in a crowd.

Studies about average evacuation walking speed show values in the range of 0.7 to 1.5 m/s (Klüpfel 2003). For the calculation of the evacuation speed an average speed of 1.2 m/s is used for a medium population density area. Further population density classes and respective speed values are based on studies about population density vulnerability assessment and further expert knowledge.

Additionally, a second speed parameter was used based on social and demographic factors like age and gender. Average walking and maximum running speeds are different according to age and according to gender in the productive age, whereby gender does not make a difference for children and elderly.

For the evacuation speed calculation, the mean value of those two different speed values (due to population density and due to demographic parameters) was taken.

The evacuation speed is calculated with the formula below, as a combination of all parameters which have an effect on the evacuation speed. The result is an inverse speed value, expressing the walking time in sec/m. Figure 25 shows an example of a possible result. High speed values with low speed impedance (e.g. streets) are displayed in yellow, low speed values with high speed impedance (e.g. mangroves) are displayed in brown.

$$\frac{1}{\frac{\cos ts\_landuse}{100} * \frac{\cos ts\_slope}{100} * \frac{\cos ts\_criticalfacilities}{100} * \left(\frac{speed_{populationdensity} + speed_{populationindex}}{2}\right)}$$

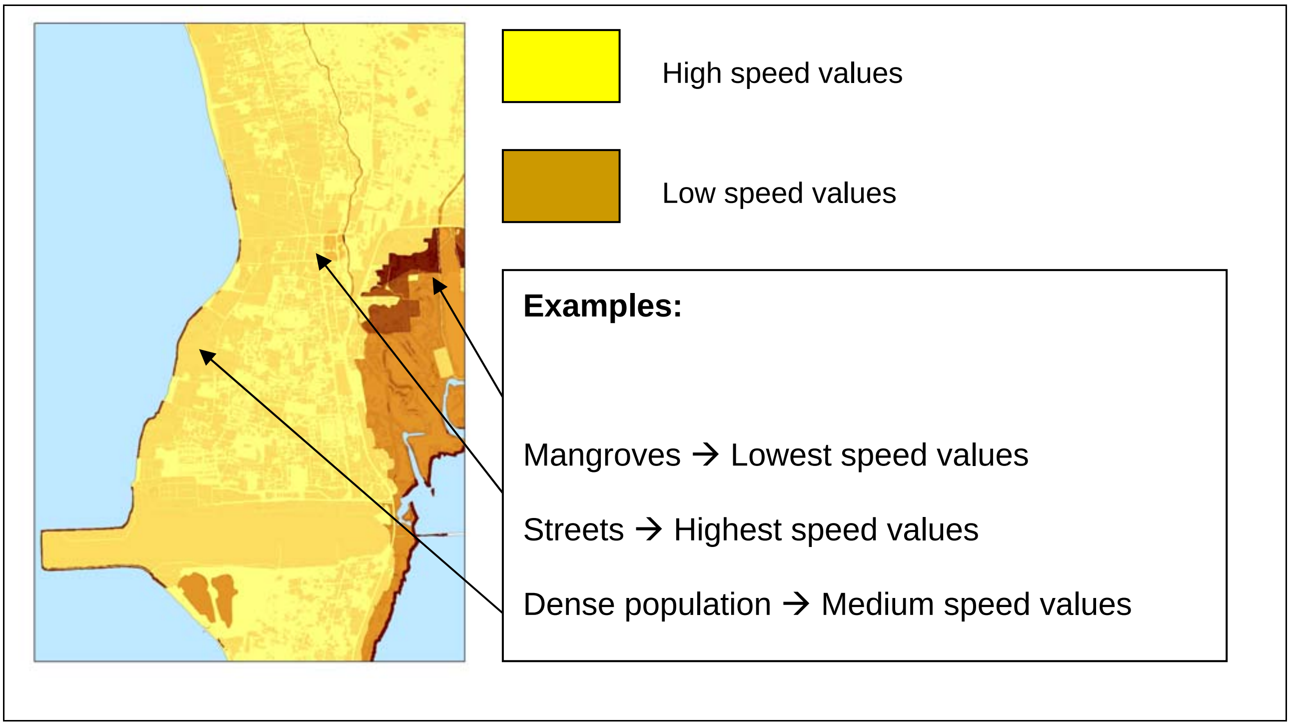


Figure 25: Evacuation speed as basis for the evacuation time map

Evacuation shelter access points

Evacuation shelter access points represent an access possibility to an evacuation target point. For horizontal evacuation areas, the access points are placed along the border of the hazard zone (maximum inundation line) accessible through the street network. For evacuation shelter buildings (vertical evacuation) the access points are placed on the top of the building.

To define buildings suitable for vertical evacuation, a decision tree for a building vulnerability assessment was developed (Figure 26). Buildings that can be used for vertical evacuation have to fulfill the criteria of different main components (defined by a threshold value) which is shown as YES and NO in Figure 26. The component order of the structure is not random but chosen regarding the importance of each component. That means, for example, if a building is reaching the total threshold value of the “Structural stability component”, “Tsunami component” and “Liquefaction component” but not for the “Accessibility component”, the building only reach the requirements of Class C and is therefore not suitable for vertical evacuation. Only buildings fulfilling the criteria of all four components are reaching the threshold value for Class VE.

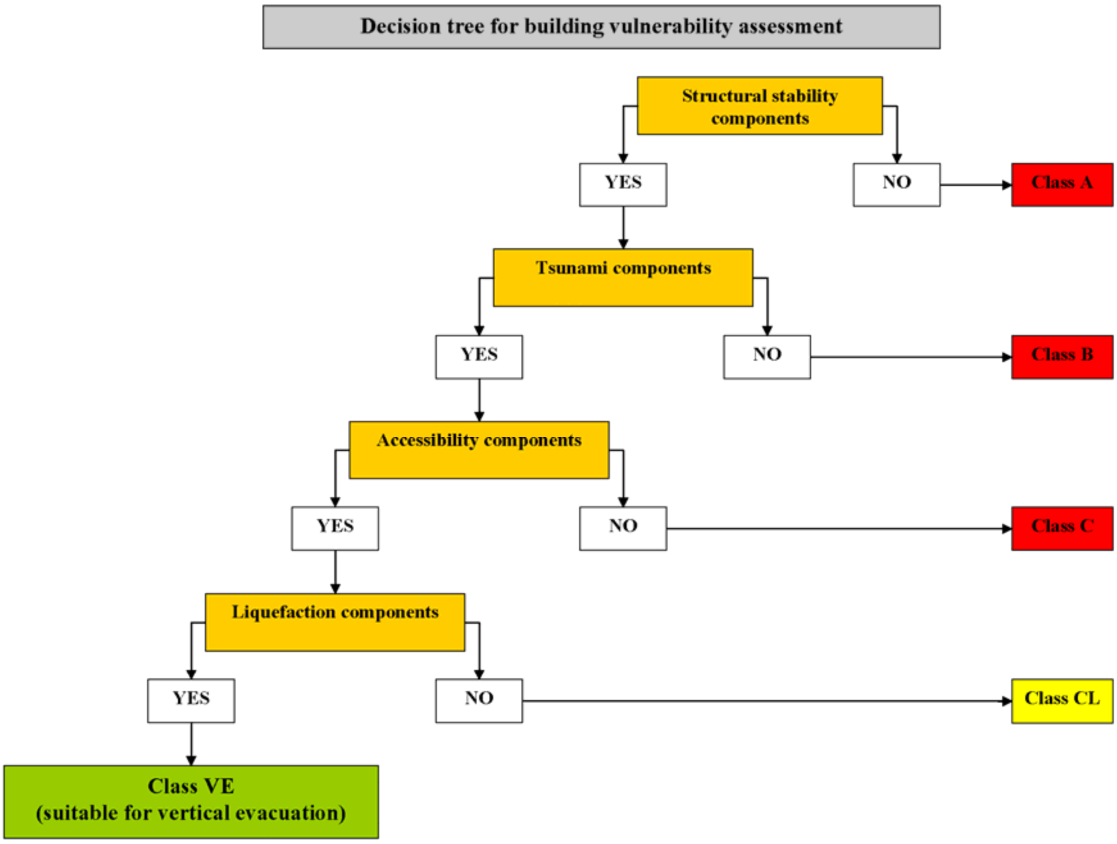


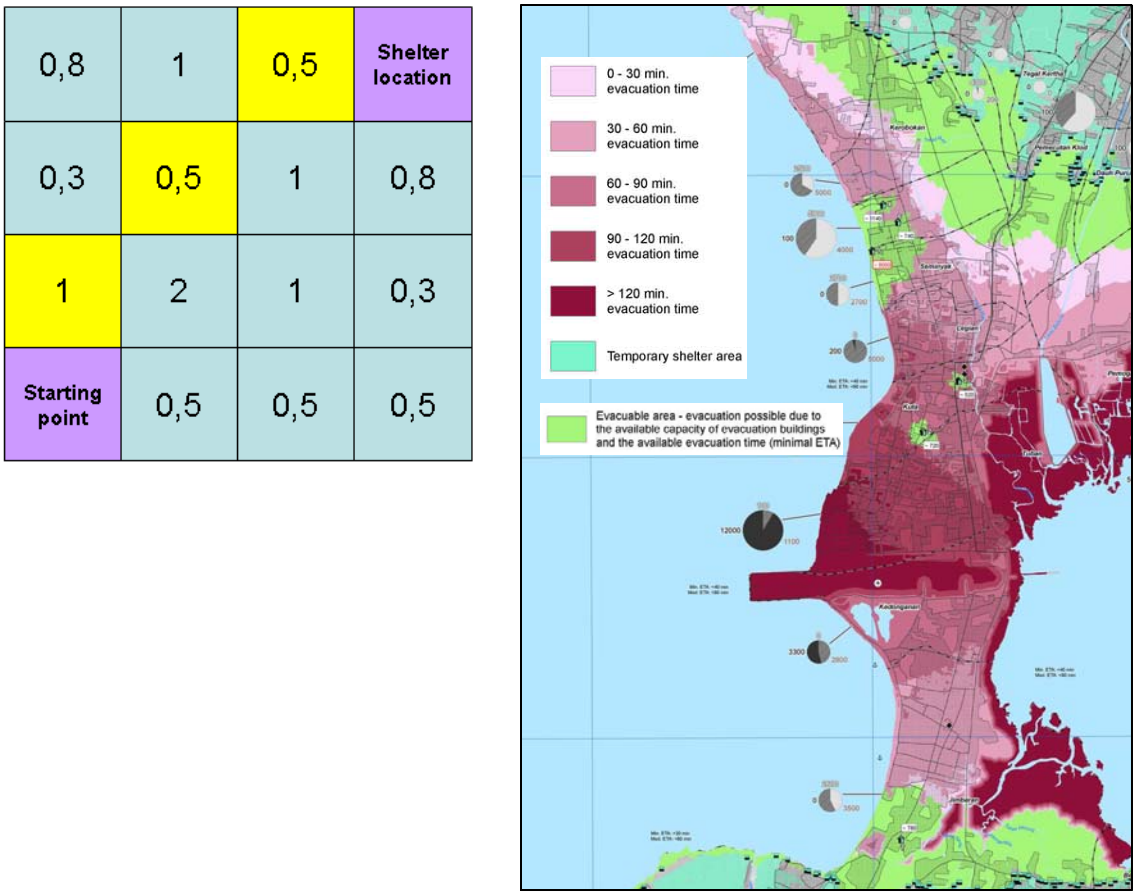
Figure 26: Decision tree for building vulnerability assessment

For further details on the used input data and processing steps for building vulnerability, please refer to the Technical Guideline.

Evacuation time map

On the basis of the calculated evacuation speed and starting from each of the placed access points the evacuation time map can be generated. In this map, the value of each cell represents the cost (in terms of time) necessary to go from there to the "costless" shelter following the fastest path (Figure 27). The output of this calculation is an Evacuation Time Map (Figure 27), dividing the evacuation area into time steps (red colour grading), visualizing people's evacuation capability in a certain area and evacuable areas within a specific time (green colour).

For further details on the used input data and processing steps for the Evacuation Time map, please refer to the Technical Guideline document. The map results are presented and described in detail in Chapter 3 of this guideline document.



0,8	1	0,5	**Shelter location**
0,3	0,5	1	0,8
1	2	1	0,3
Starting point	0,5	0,5	0,5

Figure 27: Left: Fastest evacuation path between a starting point and the related shelter location. Right: Evacuation time map showing the time needed to evacuate to the nearest evacuation shelter (red colour grading) and the evacuable area (green colour).

Evacuation shelter capacity

The evacuation time map provides information on the time someone needs from a certain location to reach an evacuation target point and about the area where people are able to evacuate to the nearest shelter in a certain time following the fastest path.

A further crucial constraint during an evacuation is the shelter capacity. For horizontal evacuation the decisive factor is only the time, because horizontal shelter areas are not limited in terms of capacity. Only evacuation buildings are limited in their carrying capacity. Buildings suitable for vertical evacuation can have different primary functions (hotels, governmental facilities, schools, etc.) and therefore available space for evacuation is varying.

Hence for vertical evacuation two constraints are decisive:

1) Evacuation time

2) Building capacity

As illustrated in Figure 28 below, during an evacuation the area surrounding a tsunami evacuation building is defined by either Evacuation time (L1) or Capacity range (L2) constraints.

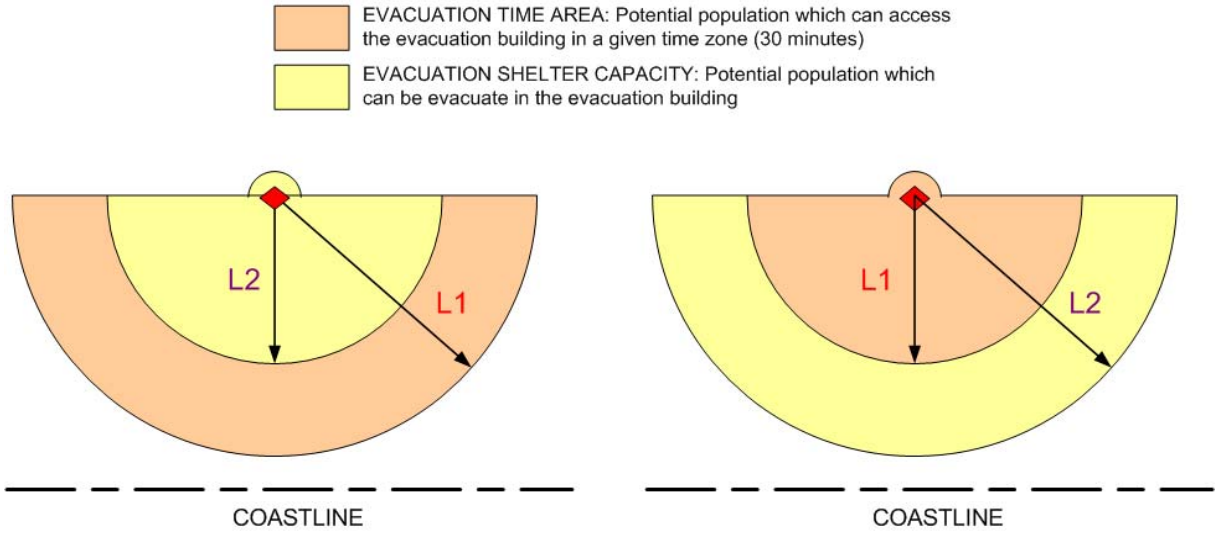


Figure 28: Evacuation time and Building capacity as decisive evacuation constraints

For further details on the used input data and processing steps for the building capacity, please refer to the Technical Guideline document. Application examples are presented and described in detail in Chapter 3 in this document.

2.3 Risk Assessment

2.3.1 Risk of evacuation failure

As risk is conventionally expressed by the equation Risk = Hazard × Vulnerability, risk assessment is a logical outcome of the hazard and vulnerability assessments as described in the previous Chapters. Main objectives of the risk assessment methodology developed within the GITEWS project was the identification of areas of high tsunami risk in terms of potential loss of life. Where high risk areas are identified, there is an urgent need for action by the local authorities to improve the response capability of the population, thus reducing the risk. The identification of high risk areas raises the awareness of vulnerable "hotspots" and provides information vital to the support of emergency decision making. The official activities of planning and implementing risk reduction measures, like the construction of tsunami shelters, the governance of construction activities, the signposting of evacuation routes, or the installation of structural and natural coastal protection measures, need to be prioritized.

Risk maps within GITEWS were produced on two assessment levels. In principal, the assessment methodology is the same for both scales, except differences in the used input parameters as shown below in Table 7.

Table 7: Overview of input parameter for the coarse and detail level assessment

Coarse assessment level (1 : 100 000)	**Detail assessment level (1 : 25 000)**
Input parameter: → Evacuation capability → Hazard probability → Population density	Input parameter: → Evacuation capability → Hazard probability → Hazard intensity (flux velocity) → Population density

The degree of risk is determined by a decision tree method (see Figure 29) where the combination of different risk parameters is evaluated and risk classes are disclosed accordingly.

Criteria to determine the degree of risk are as follows:

1) Is the location in an area of high hazard probability? (see chapter 2.1)

2) Is the location in an area of high hazard intensity? (only used for the detail assessment, see chapter 2.1)

3) Is it a densely populated area? (see chapter 2.2)

4) Is it possible to reach an evacuation target point in time? (see Chapter 2.2)

Depending on this analysis an area is classified into one of 14 risk classes, ranging from very low to very high risk. In order to retain the readability of the map product, the large number of risk classes as displayed in Figure 29 were aggregated to six classes ranging from *very low* (dark green) to *very high* (red).

Figure 29: Decision tree for determination of risk classes

For further details on the used input data and processing steps, please refer to the Technical Guideline.

One core product of the GITEWS project is the Decision Support System (DSS), based on a combination of sensor systems in a flexible and extensible observation and simulation framework which provide input for information fusion in order to make situation assessments and generate decision proposals. The system also contains risk and vulnerability information which was designed with the far end of the warning chain in mind – it enables the decision maker to base his acceptance (or refusal) of the supported decision also on regionally differentiated risk and vulnerability information.

Risk information implemented in the DSS are visible as (1) maps and (2) tabular data. To be displayed as maps, the risk information has to be prepared in three different scales for both warning and major warning case. Depending on the respective zoom level, risk information are displayed on (i) detailed scale (1 : 100 000), (ii) aggregated to desa level (1 : 1 000 000) and (iii) aggregated to warning segment level (1 : 3 000 000).

The tabular data of risk contains the degree of risk in a warning segment depending on the currently announced warning level for each segment. By the combination of input parameter for estimating the potential tsunami risk, each warning segment is benchmarked with a certain risk, divided into low, moderate or high risk (see Table 8). The based risk assessment methodology is based on the assessment for the tsunami risk maps as explained above.

Table 8: Categorization in low (1), moderate (2) and high (3) of the components response, hazard probability (hazprob), population density (popdens) and assignment of the degree of risk (values 1 to 14) with a final generalization in three risk classes

response	hazprob	popdens	Degree of risk	Generalized for map
1	1 / 2 / 3	1 / 2 / 3	1	low
2 / 3	1	1 / 2 / 3	2	low
2	2	1	3	low
2	3	1	4	low
2	2	2	5	low
2	3	2	6	low
2	2	3	7	moderate
2	3	3	8	moderate
3	2	1	9	moderate
3	3	1	10	moderate
3	2	2	11	high
3	3	2	12	high
3	2	3	13	high
3	3	3	14	high

2.3.2 Calculation of time dependant casualties

The calculation of time dependent casualties builds on the methods described in chapter 2.1 Hazard assessment, 2.2.1 Exposure and 2.2.4 Evacuation time. The calculation requires the estimated time of arrival (ETA), population distribution and the calculated evacuation time.

Recalling the definition of the response time, given through:

Response Time (RsT) = Estimated Time of Arrival (ETA) – Reception time of Tsunami warning (ToNW) – Reaction Time (RT)

it can be stated, that the response time by the population to start and conduct evacuation is constrained by the ETA. Hence the maximum response time in a region is equal to the estimate time of tsunami arrival (ETA). The minimum response time equals to zero. In this case the tsunami hits the coast and an unprepared population which did not start an evacuation at all.

Using the evacuation time (ET) results, which provide for each tsunami endangered location on land the time necessary for evacuation to a safe area, it is now possible to calculate the amount of people not able to evacuate in the given (response) time and consequently the potential casualties in a defined area. This can be performed for different response times. For example, assuming that the minimum ETA is 40 minutes, the response time can vary between 40 minutes (direct start of evacuation when feeling the earthquake) up to 0 minutes (no evacuation at all). Hence the time dependent casualty calculation can be performed e.g. for 5 minute intervals. For each time interval, I, of 5 minutes the following relationships are calculated:

IF $ET < RsT\_opt + I$ = evacuation possible, for $I = 0$ minutes to ETA_{median} (eq. 1)

IF $ET > RsT\_opt + I$ = evacuation failure, for $I = 0$ minutes to ETA_{median} (eq. 2)

According to these equations the area corresponding to the case “evacuation possible” (eq. 1) and corresponding to the “case evacuation failure” (eq. 2) can be assigned for each time interval. The following figure provides an example. For a given tsunami affected area, the area where evacuation is possible (figure 30, green) and the area with evacuation failure (figure 30, red) can be assigned using the evacuation time calculation results (see chapter 2.2.4).

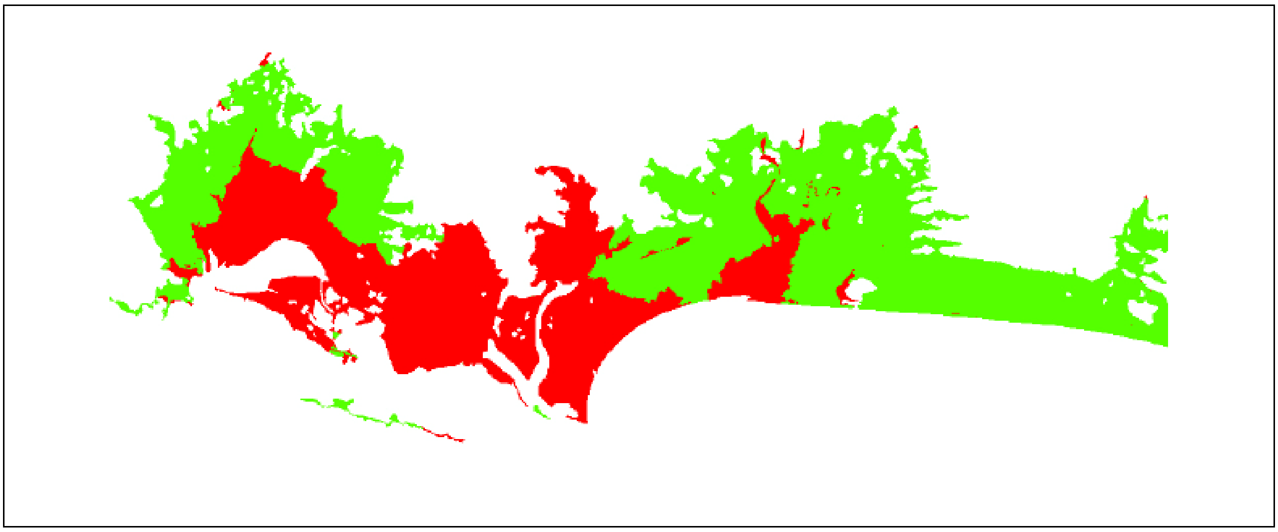


Figure 30: Areal discrimination of “evacuation possible” (green colour) and “evacuation failure” (red colour) area based on a defined response time and using evacuation time calculation results

It is then further assumed that people located within the area of evacuation failure will not be able to reach a safe area in time and will become a casualty of a tsunami. People being located within the “evacuation possible” area will potentially be able to reach a safe area in time but are then displaced by a tsunami. Casualties and the number of people being displaced can be dynamically calculated assuming the time slices defined by the interval I. This is done by summarizing the amount of people using the population distribution information (see chapter 2.2.1) for each of the areas (evacuation possible, evacuation failure area).

This can then be further specified and calculated for different spatial aggregation levels, for example for the desa / keluharan administrative unit.

The standard information related to time dependent casualties integrated in the evacuation time map (see chapter 3.5) are numbers of casualties per desa / keluharan level and for response times defined by the median and minimum estimated time of arrival (ETA, for calculation see chapter 2.1).

3 Risk and Vulnerability Products Based on the Reaction Scheme

The overall goal of the risk and vulnerability assessment is to develop products in such a way that they are of use by end-users who are involved in InaTEWS on the national to the local level. The presentation of the risk and vulnerability results and products are structured according the different risk management tasks based on the reaction scheme of InaTEWS (see Figure 31). Risk managers can select the product of interest according to their role and mandate in the early warning risk governance process. Products include maps, figures, statistics or qualitative information. Each product is commented regarding its specific utility for risk management and its replication and improvement requirements.

In this chapter the core products of the GITEWS risk and vulnerability assessment will be presented and described in detail concerning content and application possibilities in terms of early warning and disaster management. A sample map sheet is used in each chapter in order to describe the map content and to explain application possibilities of the respective map.

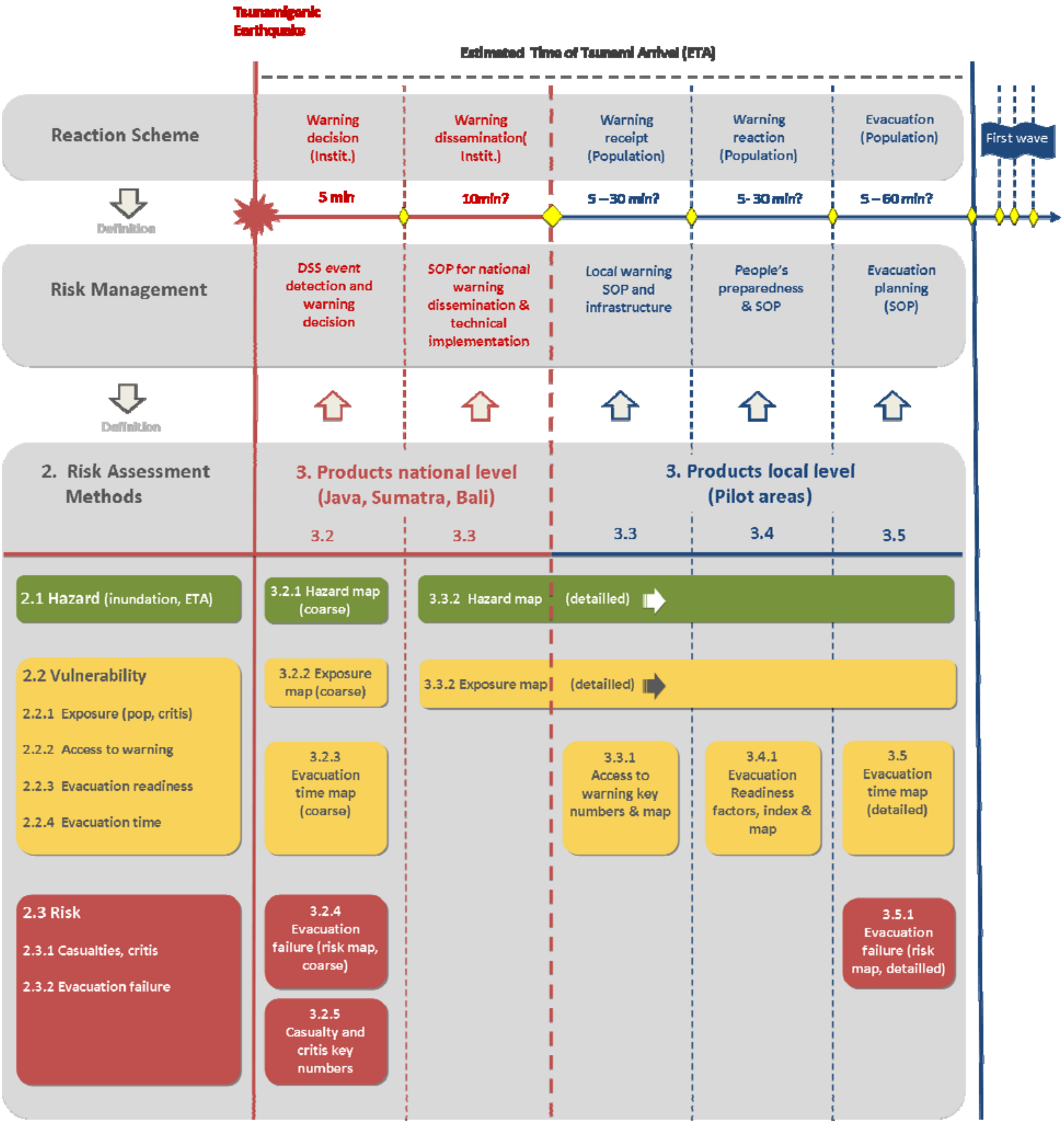


Figure 31: Overall structure of risk products (bottom row in figure, horizontal alignment) provided for specific risk management tasks (second top row in figure) and reaction scheme components (top row in figure) and their methodological base laid down in the risk assessment methods section (bottom row in figure, vertical alignment on the left). The bottom row provides an overview in which chapter the methodological description is located for which product (e.g. hazard map products are described in chapter 3.2.1 and 3.3.2 whereas the methodological description is given in chapter 2.1 Hazard).

3.1 Overview of Assessment Products

The National Tsunami Warning Centre requires risk and vulnerability products that can be generated for the whole Indonesian coastline at risk. Only then, usable decision support can be provided. Whereas, at the local level, where authorities are involved in the development of effective warning dissemination and evacuation structures ("last mile"), locally contextualized and spatially more precise risk and vulnerability products are required. The development of these products are sometimes cost intensive. The guideline provides only a showcase how the products at local level developed in the three pilot areas can look like but does not ensure full spatial coverage. It is up to the local decision makers to provide funds and infrastructure to produce valuable risk and vulnerability products for their territory of power.

Table 9 provides an overview about what kind of outputs can be expected and how the risk and vulnerability information can be used for accomplishing the different risk management tasks within InaTEWS.

Table 9: Overview of the utilization of risk and vulnerability products according to DRM tasks of EWS.

InaTEWS Reaction scheme	**DRM Tasks within InaTEWS**	**Responsible Authorities / NGOs**	**Decision support needs to increase efficiency of InaTEWS**	**Output of risk and vulnerability assessment**	**Use of risk and vulnerability assessment results for DRM within EWS**
Warning decision	**Event detection and warning decision**	National BMKG	Event detection	Hazard parameter / scenarios: Probability, Intensity, ETA, inundation area	Even if the event detection signals are difficult to interpret on tsunami occurrence, the risk and vulnerability information can facilitate the decision process.
			Anticipated tsunami impacts as a function of warning decision time.	Number of people that might loose their life, the more time is needed for deciding whether to issue a tsunami warning or not	
Warning dissemination and receipt	**SOP for national warning dissemination & technical implementation** **Local warning SOP and infrastructure**	National BMKG and mass media enterprises Local authorities, e.g. BMKG, religious organizations, CBO's	Knowledge of people's capacity to receive tsunami warnings timely.	Maps displaying warning infrastructure distribution and spatial warning coverage amongst settlement areas and social groups.	Disseminate warnings through devices that are widespread amongst citizens. Identification and promoting alternative ways for warning dissemination where needed. Setting up warning infrastructure in areas where they lack, such as sirens
Warning reaction	**Programmes supporting awareness, household level SOPs and preparedness**	Local authorities & NGOs involved in education	Knowledge of people's potential reaction to warnings and degree of their evacuation readiness.	Identification of relevant social and psychological factors that shape people's warning reaction and evacuation readiness.	Designing awareness materials (e.g. schoolbooks, radio shows, signs) that focus on the identified factors of evacuation readiness.
				Maps showing place specific degree of evacuation readiness.	Prioritize areas of intervention, especially in areas where evacuation readiness is low.
Evacuation	**Evacuation planning: Zoning, infrastructure development and SOPs**	Local authorities involved in infrastructure planning and DRM	Knowledge of the impact zone and shelter areas	Maps showing the hazard inundation zone.	Definition of the evacuation zone.
			Knowledge of the areas where evacuation is problematic: lack of shelters, lack of evacuation routes	Maps showing locations where the population will not be able to manage timely evacuation Maps showing locations where new shelters are needed and with what capacity. Maps showing the safe / shelter areas that exist	Identification of locations and capacities for shelters, safe places, and evacuation routes.

Assessment scales

Risk assessment is conducted at two scales: at the national and local level, each fulfilling a certain purpose. While the district level assessment provides products in the context of early warning (Crisis products, for entire exposed coastal zone), the local level assessment aims at contributing to the development of local specific disaster preparedness, adaptation and mitigation strategies (e.g. urban planning and evacuation planning, for priority areas). Figure 32 gives an overview about the coverage of all provided map products, depending on the respective assessment level.

Map sheets on a scale of 1 : 100 000 are available for the entire coast of Sumatra, Java and Bali. These cover the products hazard, exposure, evacuation and tsunami risk. Furthermore specific risk map layers and key numbers were generated and incorporated in the decision support system of the Warning Center on this level of detail. Details on this are described in chapter 3.2. For the three GITEWS pilot areas Padang, Cilacap and Bali, detailed map sheets on a scale of 1 : 25 000 are also available. They cover in greater detail the products hazard, exposure, access to warning, evacuation readiness, evacuation and tsunami risk.

In order to enable an efficient update of the maps, the map frame is designed according to the official topographic maps of Indonesia provided by the National Mapping Agency BAKOSURTANAL. This allows for a convenient update of the maps if e.g. the content of the topographic maps is updated.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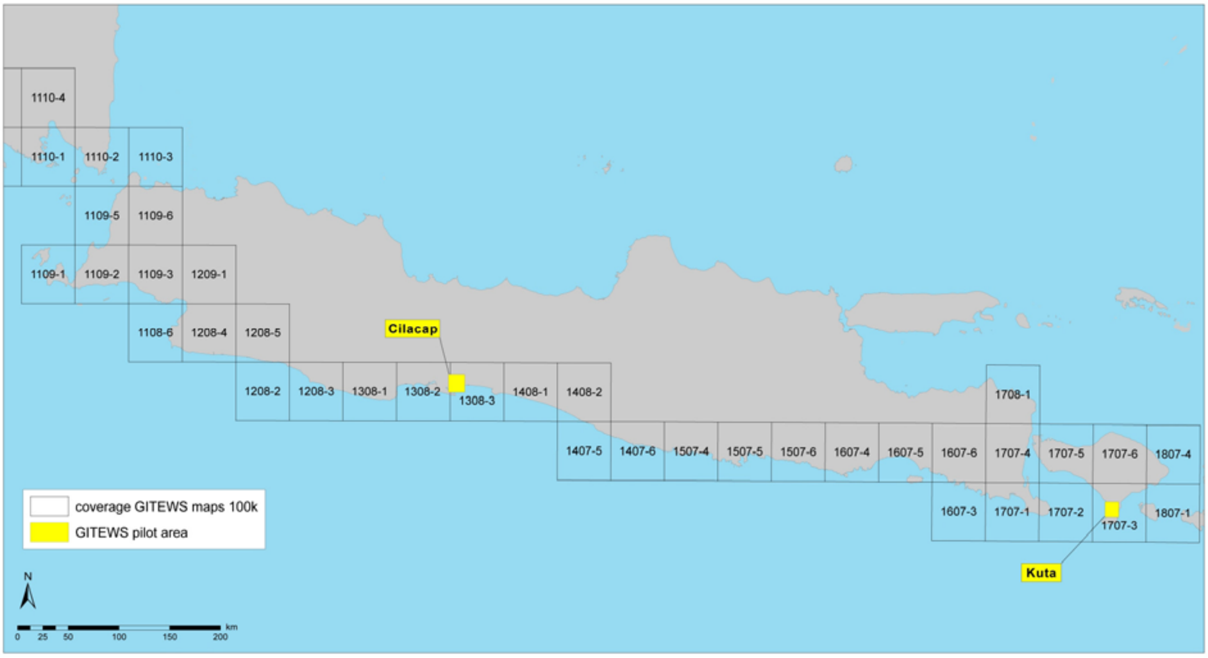


Figure 32: Overview on risk and vulnerability information available on a scale of 1 : 100 000 and 1 : 25 000

3.2 Warning Decision

Risk information can contribute to an effective warning decision. Mainly the use of hazard and exposure related information can be used together with knowledge of the evacuation capability. Combining hazard and vulnerability information, a risk map allows valuating specific tsunami risk for the coastal areas. Relevant products for the warning decision phase within the warning reaction scheme (see figure 31) are the coarse ‘tsunami hazard map’, the coarse ‘exposure map’, the coarse ‘evacuation time map’ and the coarse ‘tsunami risk map’ as well as risk information in the DSS. The information is available at a map scale of 1 : 100 000.

3.2.1 Hazard assessment products (coarse)

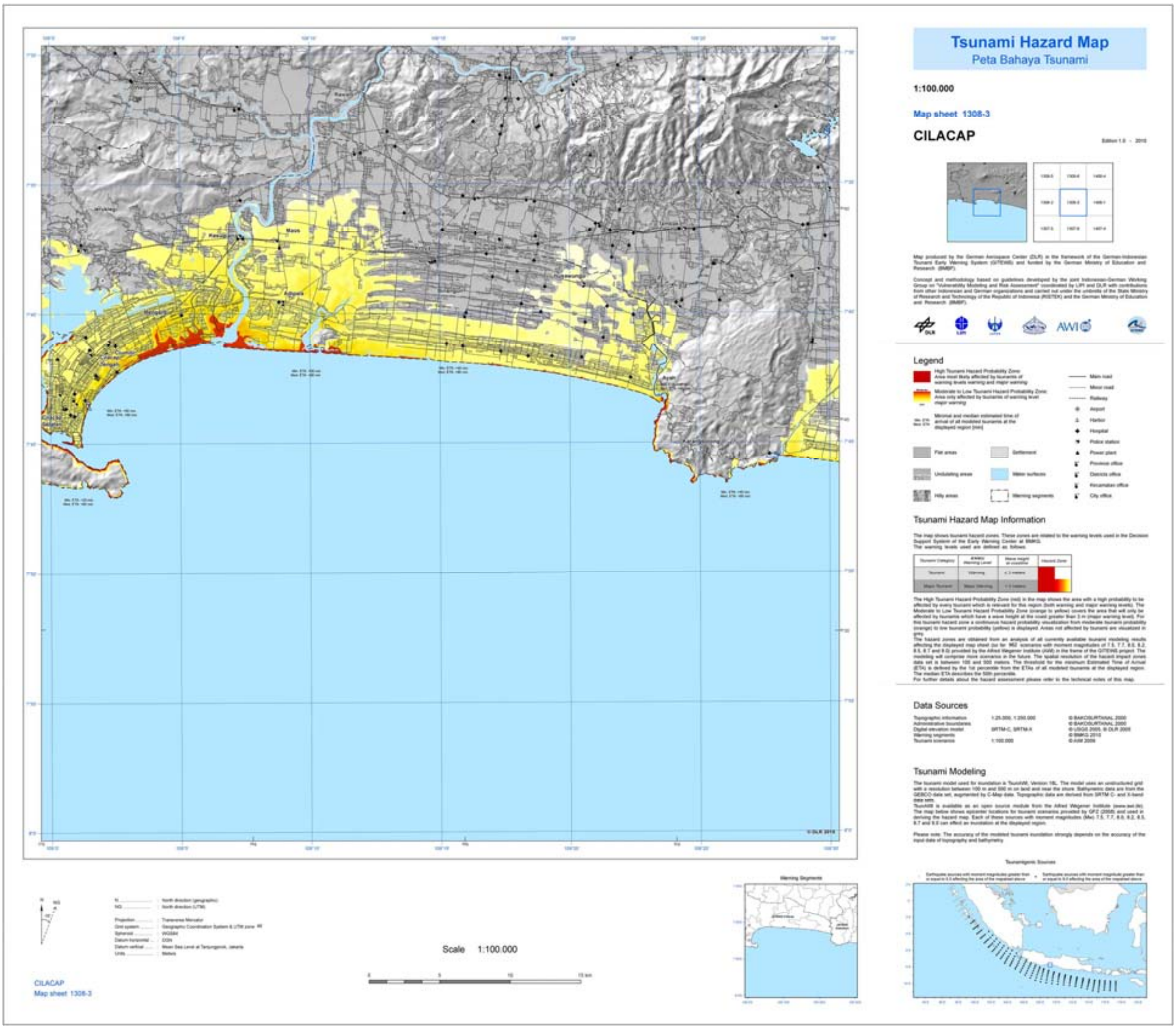
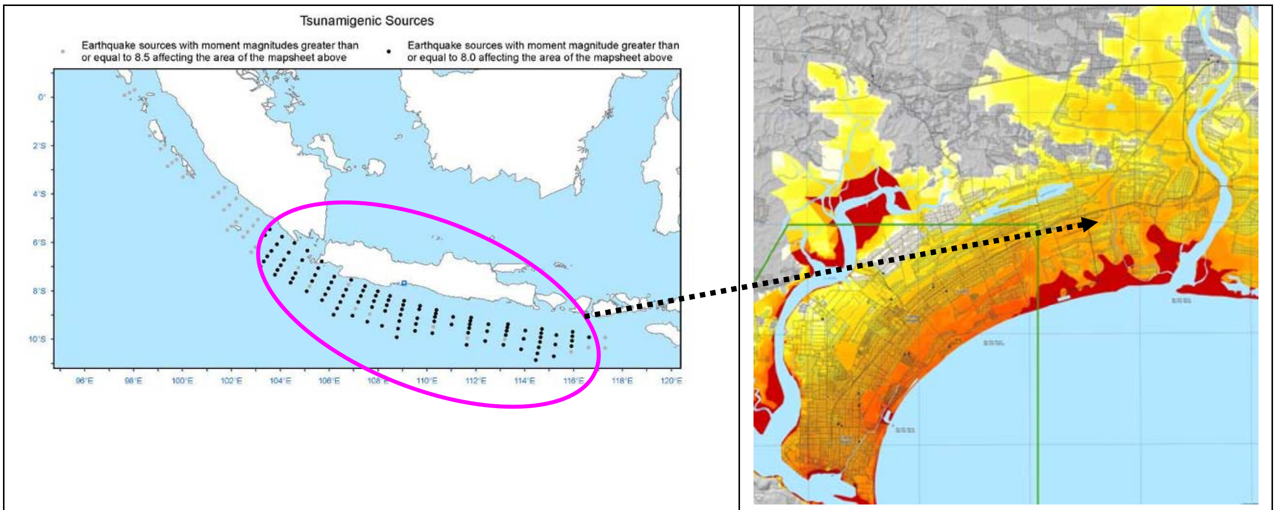


Figure 33: Tsunami hazard map of Cilacap (sample map sheet) at a scale of 1 : 100 000

Map description and results

The coarse hazard assessment was based on scenarios provided by the Alfred Wegener Institute (AWI). The available modeling results comprise currently about 1300 scenarios of moment magnitudes 7.5, 7.7., 8.0, 8.2, 8.5, 8.7 and 9.0 with a spatial resolution between 100 and 500 m.

The GITEWS tsunami hazard map is a multi-scenario map based on tsunami modeling. It visualizes the impacts on the coastline of a large number of potential tsunamis caused by earthquakes of various magnitudes and originating from various locations within the subduction zone (see Figure 34)

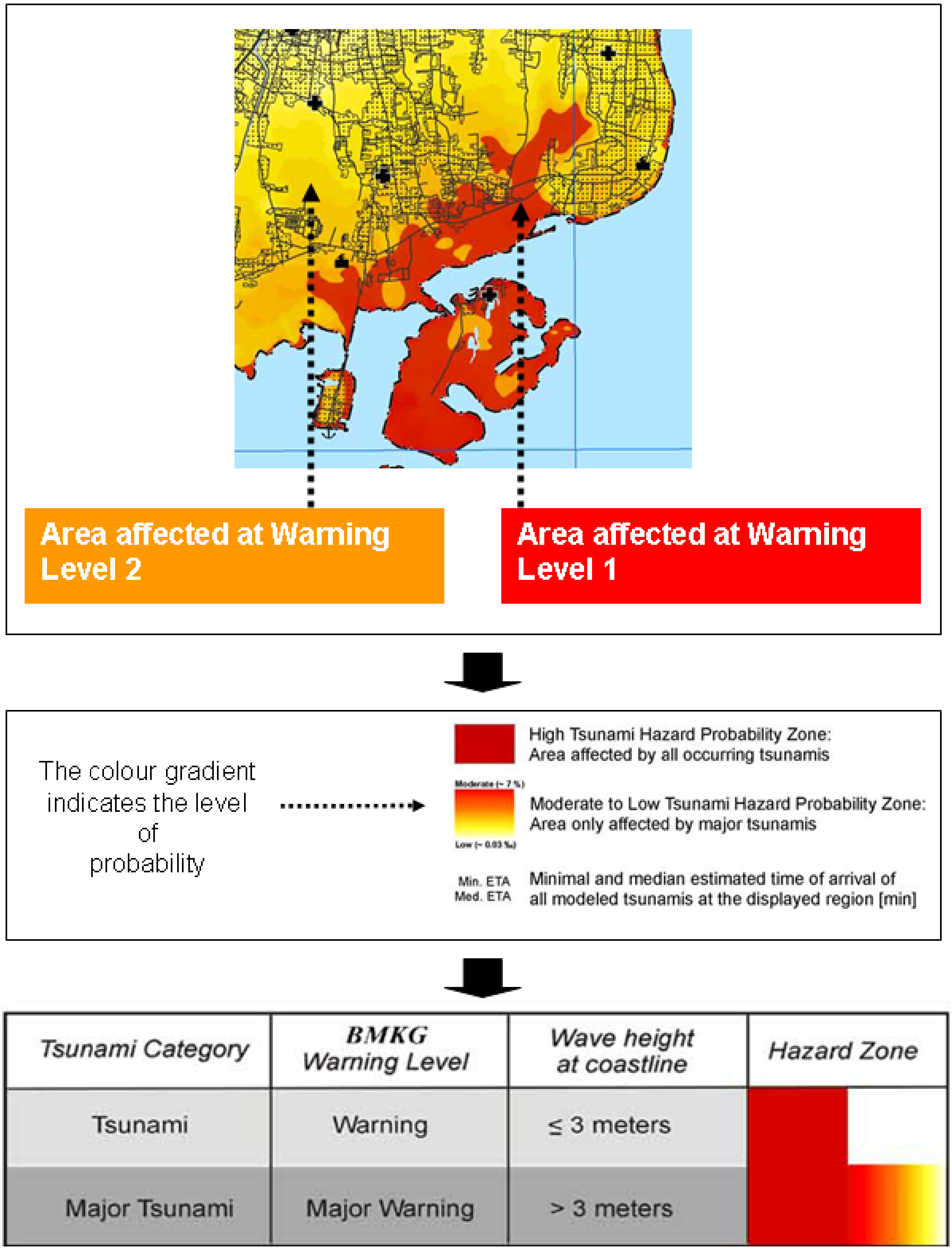


A number of hypothetical tsunami sources with different locations and earthquake magnitude were used in the mapping process. The grey and black points indicate which location with what earthquake magnitude characteristic lead to tsunami impact at the respective coast.	The red and yellow colours show the areas affected by the calculated scenarios. Yellow areas are affected only by bigger tsunamis, while the red zone is affected already by smaller tsunamis.

Figure 34: Explanation of hazard map features: tsunami sources and hazard probability visualization

The tsunami hazard map is also zoned. It groups all calculated scenarios into two zones. The red zone represents the area impacted by tsunamis with wave heights at coast up to 3 m. The orange and yellow zone represents areas impacted only by major tsunamis with a calculated wave height at coast of more than 3 m. This zone is displayed with a continuous color gradient representing decreasing probabilities (from orange to yellow) that a location will be inundated. Both zones are directly linked to the InaTEWS warning levels (see Figure 35).

One parameter in the tsunami scenario database is the estimated time of arrival of the tsunami (ETA) per scenario and for predefined coastal locations. To derive a valid value for the ETA from all available scenarios, two values are shown in the hazard map.The Min. ETA represents the minimum ETA which was found in all available scenarios. This is the worst case for the displayed point in the map. But this can be also a very rare event, so the Med. ETA is also added to the point in the map. This value is the Median (50%-value) of the ETAs of all relevant scenarios for the regarded region. These values can be taken as estimation for the time to react which is left after the earthquake event happened.



Tsunami Category	***BMKG*** *Warning Level*	*Wave height at coastline*	*Hazard Zone*
Tsunami	Warning	≤ 3 meters	🟥
Major Tsunami	Major Warning	> 3 meters	🟥 🟧

Figure 35: Tsunami hazard probability linked to InaTews warning levels

The results of the tsunami modelling are based on global datasets and provide a level of detail usable only for maps of a scale of 1:100,000 or below which are suitable to provide tsunami hazard information at district level in the context of early warning.

It must be made clear that the hazard assessment results based on these input data only provide coarse information on potentially inundated areas. Therefore the large-scale tsunami hazard map is intended to be an indication for areas potentially affected by a tsunami and is not recommended as a detailed planning basis for disaster management at community level.

Main benefit of this map product is to achieve a better understanding of tsunami hazard at a certain region and the possible impacts on society in order to enable national level decision makers and other stakeholders to get better prepared for future tsunami events.Tsunami hazard maps on this coarse level of detail are available for the entire coast of Sumatra, Java and Bali and are implemented in the Decision Support System at BMKG. Therewith, the hazard maps have a direct link to tsunami early warning in Indonesia and are used as reference product for the warning decision in case of a tsunami event. Furthermore the assigned ETA values are useful information to familiarize with potential arrival time for a region of interest. The overview on tsunamigenic sources help in learning which locations with what earthquake magnitude characteristics cause tsunami impact in a certain region.

3.2.2 Exposure assessment products (coarse)

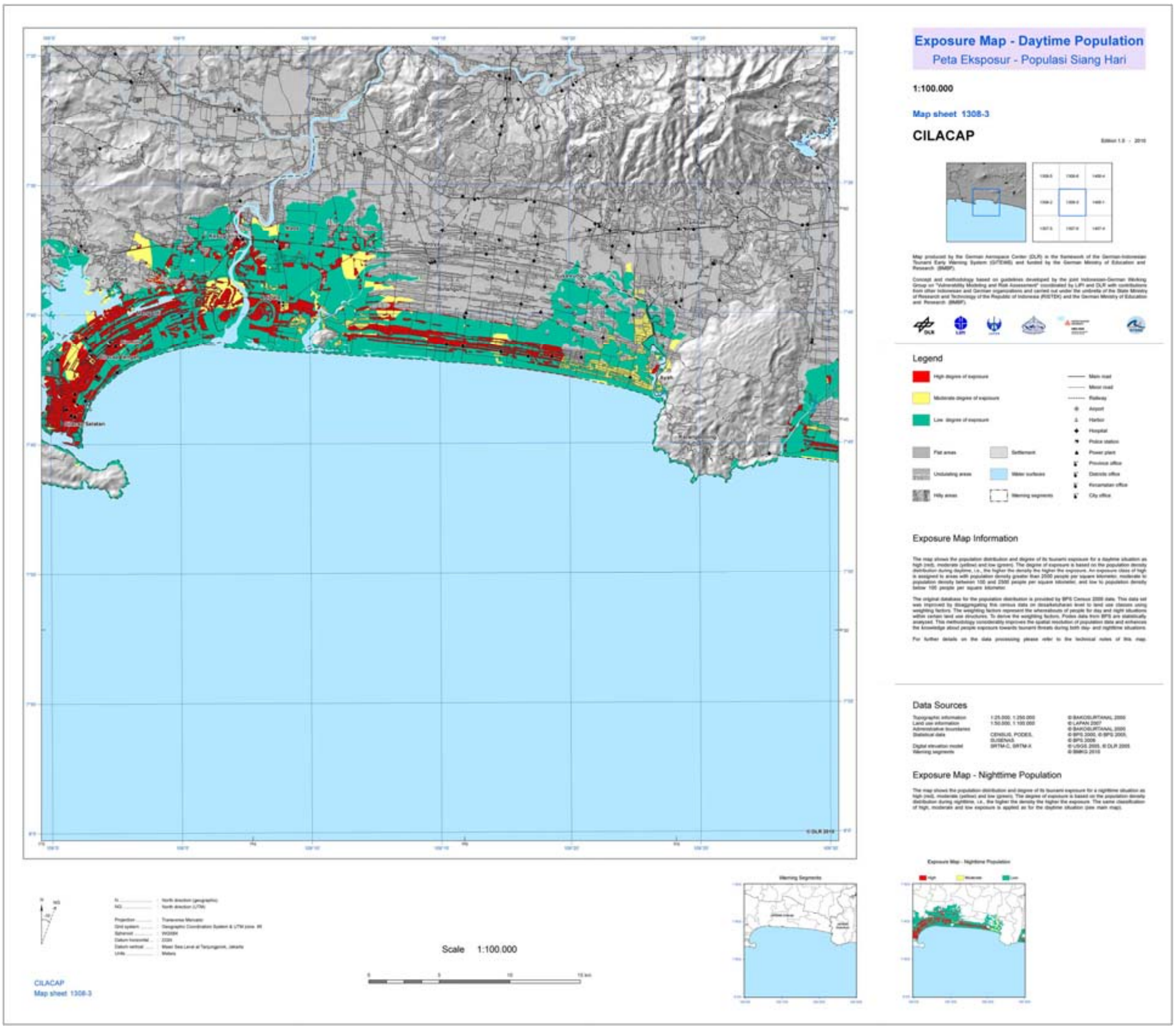
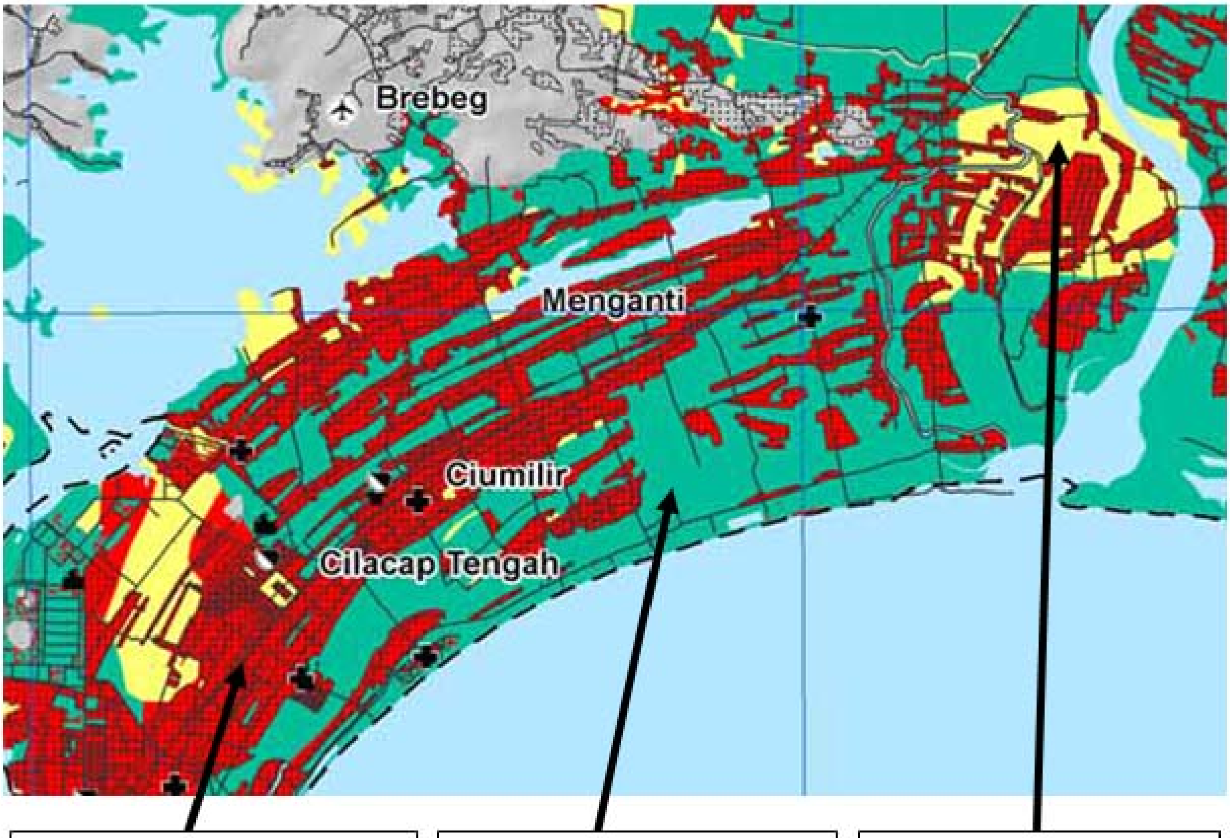


Figure 36: Exposure map of Cilacap (sample map sheet)

Map description and results

The map shows the population distribution and degree of its tsunami exposure for a daytime situation as high (red), moderate (yellow) and low (green). The degree of exposure is based on the population density distribution during daytime, i.e. the higher the density the higher the exposure. An exposure class of high is assigned to areas with population density greater than 2500 people per square kilometer, moderate to population density between 100 and 2500 people per square kilometer, and low to population density below 100 people per square kilometre. Figure 37 gives an example.



High population density in the city center

Low population density in coastal areas with low building density and little employment opportunities

Moderate population density in an area with large utilized agricultural areas where many people are working during day time

Figure 37: Example of areas with different population density

Map application

Map products of a scale of 1 : 100 000 show a level of detail that is only suitable to provide information on people exposure at district level in the context of early warning. The benefit of map information itself on this scale is various. Population distribution is crucial information to get an overview of the population exposed in a tsunami prone area in order to better estimate the emergency potential. Therefore the exposure map can be seen as stand alone product for people vulnerability. In the DSS, the exposed population is stated as reference number to calculate the tsunami risk in a specific warning segment and is therefore an important factor in the early warning phase.

Further profit of the exposure map is its function as intermediate product for other risk assessment products. The evacuation capability, for example, as displayed in the 'Evacuation Time map' (see chapter 3.5), is strongly dependant on population data. A high population density influences the demand of tsunami evacuation shelters as well as the evacuation speed. Also the 'Risk map' (see chapter 3.5) includes population information. The higher the population density, the higher the tsunami risk.

3.2.3 Evacuation Time map (coarse)

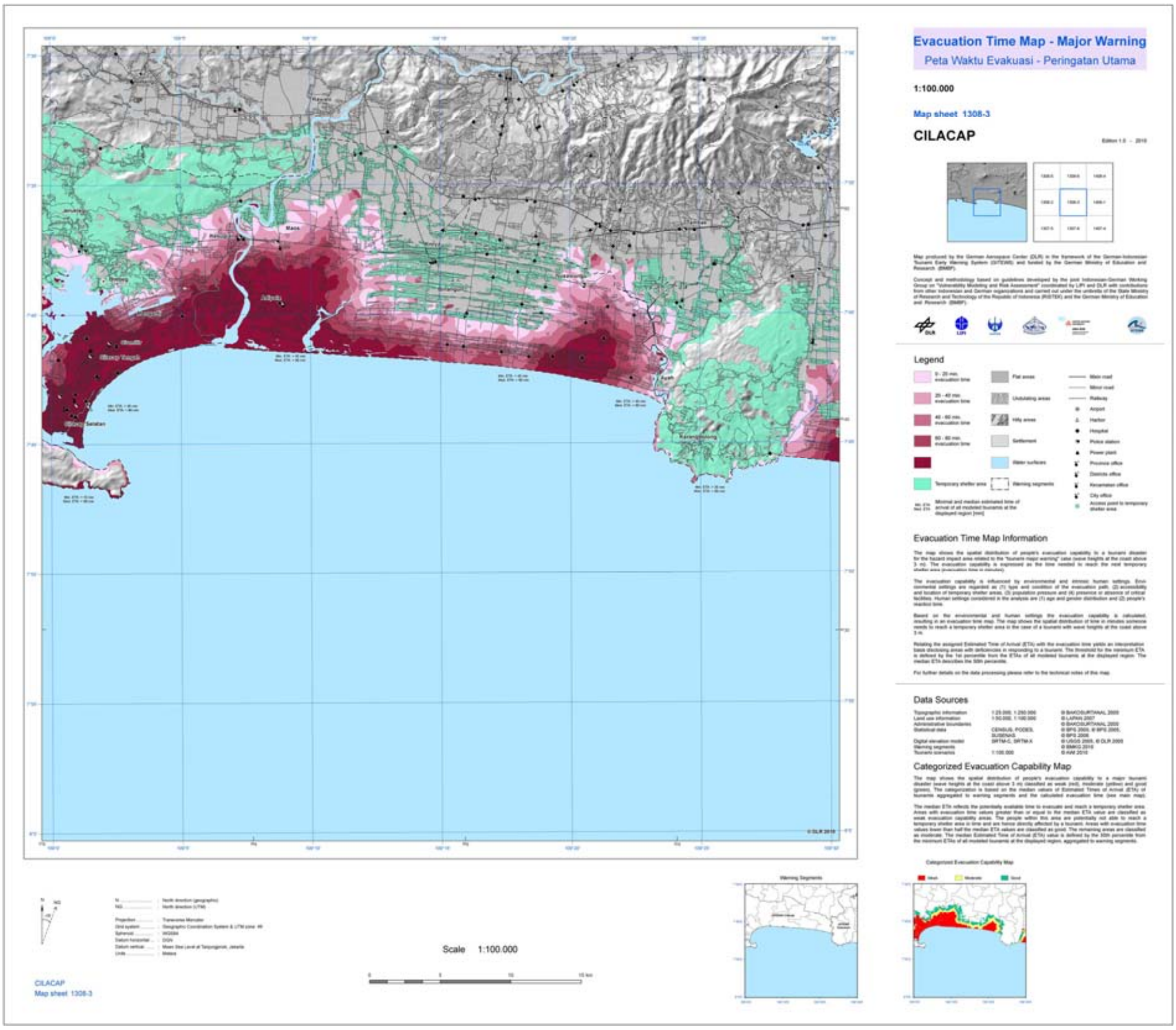


Figure 38: Evacuation Time map of Cilacap (sample map sheet)

Map description and results

The map shows the spatial distribution of people's evacuation capability to a tsunami disaster for the hazard impact area related to the "tsunami major warning" case (wave heights at the coast above 3 m). The evacuation capability is expressed as the time needed to reach the next temporary shelter area (evacuation time in minutes).

The map shows the spatial distribution of time in minutes someone needs to reach a temporary shelter area (horizontal evacuation target point) by foot. Those areas which can be evacuated within a certain amount of minutes are marked in green whereby within red areas, displayed in 30 minutes steps, people are not able to evacuate themselves in time. The maximum available evacuation time depends on the Estimated Time of Arrival (ETA) of a tsunami which is displayed in every map sheet accordingly. It is assumed that after an earthquake 10 minutes elapse before evacuation measures start; thus, ETA – 10 minutes are available for evacuation. The underlying maximum evacuation time is mentioned in the ‘Evacuation Time Map Information’ of each map sheet.

Due to the coarse scale of this map product, only horizontal evacuation possibilities are considered based on the available street network for the accordant area. Vertical evacuation possibilities are only available for the detailed map product for the GITEWS pilot areas (see Chapter 3.5).

Map application

The evacuation time map on this scale is an important product to better estimate the hazardous situation for larger coastal areas as it links the hazard component with the exposed population and gives therefore a statement about necessary planning measures in the respective area.

As this map product is available for the entire coast of Sumatra, Java and Bali, the evacuation capability of large coastal area can be identified and allows therefore a first assessment of a potential evacuation situation in order to better estimate an immediate need for action during the warning decision phase. These findings are a crucial decision support for coordinating measures that can be communicated via the warning chain to the appropriate authorities in the specific area. Additionally this products is the base to calculate time dependant casualty information (see chapter 3.2.3)

3.2.4 Evacuation failure products (coarse)

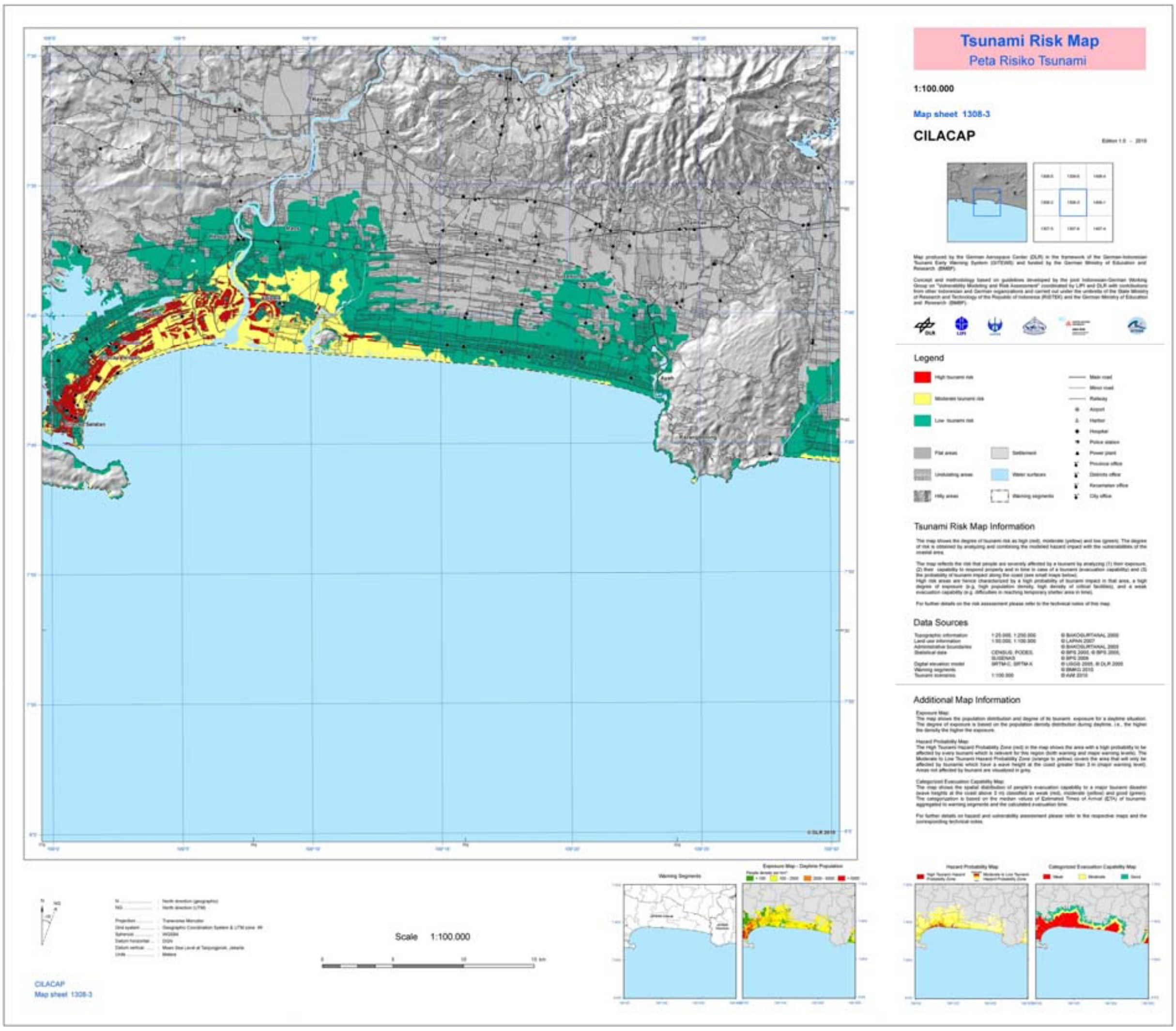
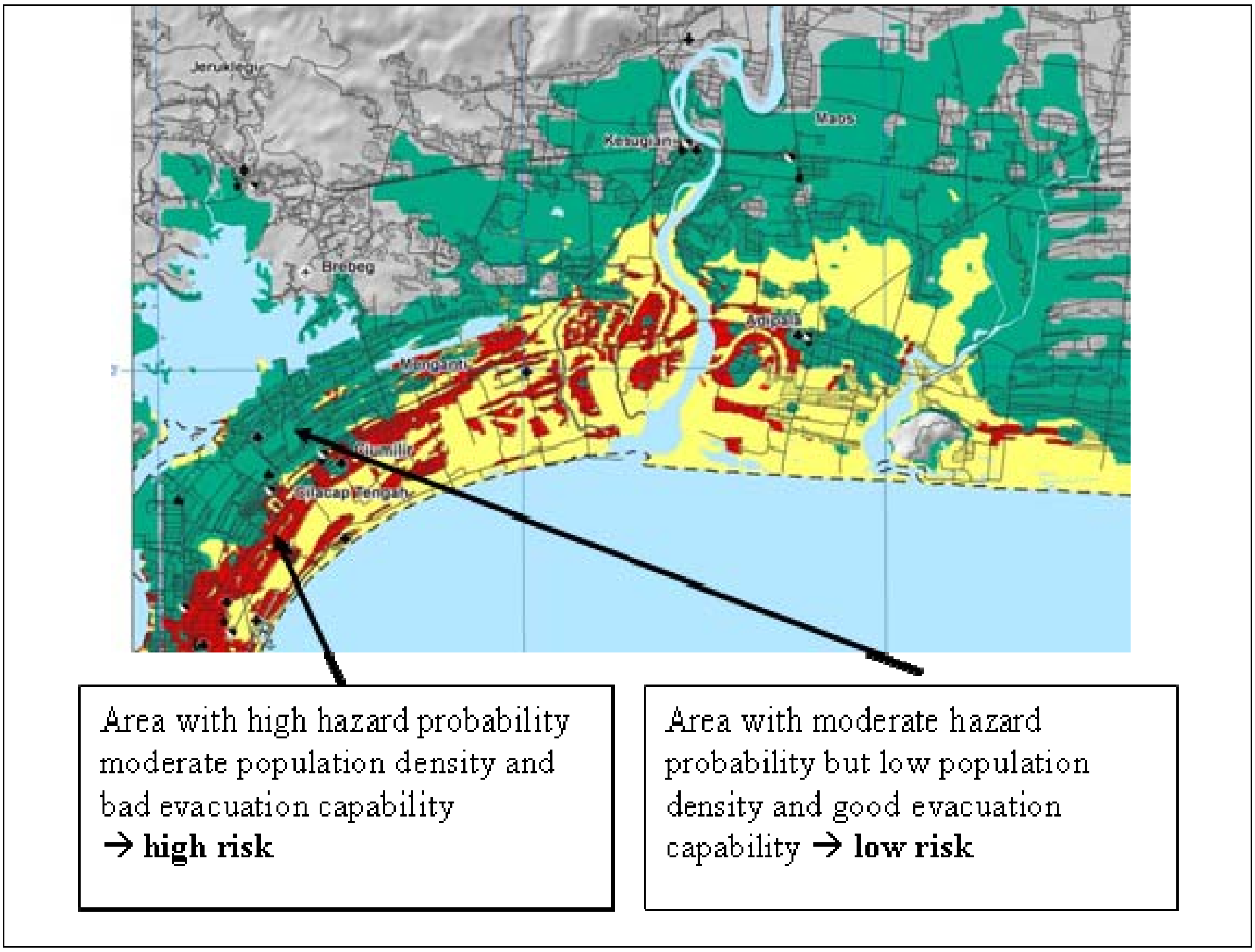


Figure 39: Tsunami Risk map of Cilacap (sample map sheet)

Map description and results

The tsunami risk map shows six classes ranging from very low (dark green) to very high (red). Basically, it can be stated that the class of very low risk contains areas where either (i) people's evacuation capability is good (i.e. a successful evacuation within available evacuation time is possible), or (ii) the hazard probability is low at a certain location, or (iii) the population density is low (i.e. only few people exposed to tsunami risk).

In contrast, high and very high risk areas are those areas where (i) additional shelter possibilities are urgently needed (moderate and high people exposure and weak evacuation capabilities), (ii) a tsunami impact is likely to happen. Figure 40 shows an example.



Area with high hazard probability moderate population density and bad evacuation capability
→ **high risk**

Area with moderate hazard probability but low population density and good evacuation capability → **low risk**

Figure 40: Example of areas with different tsunami risk

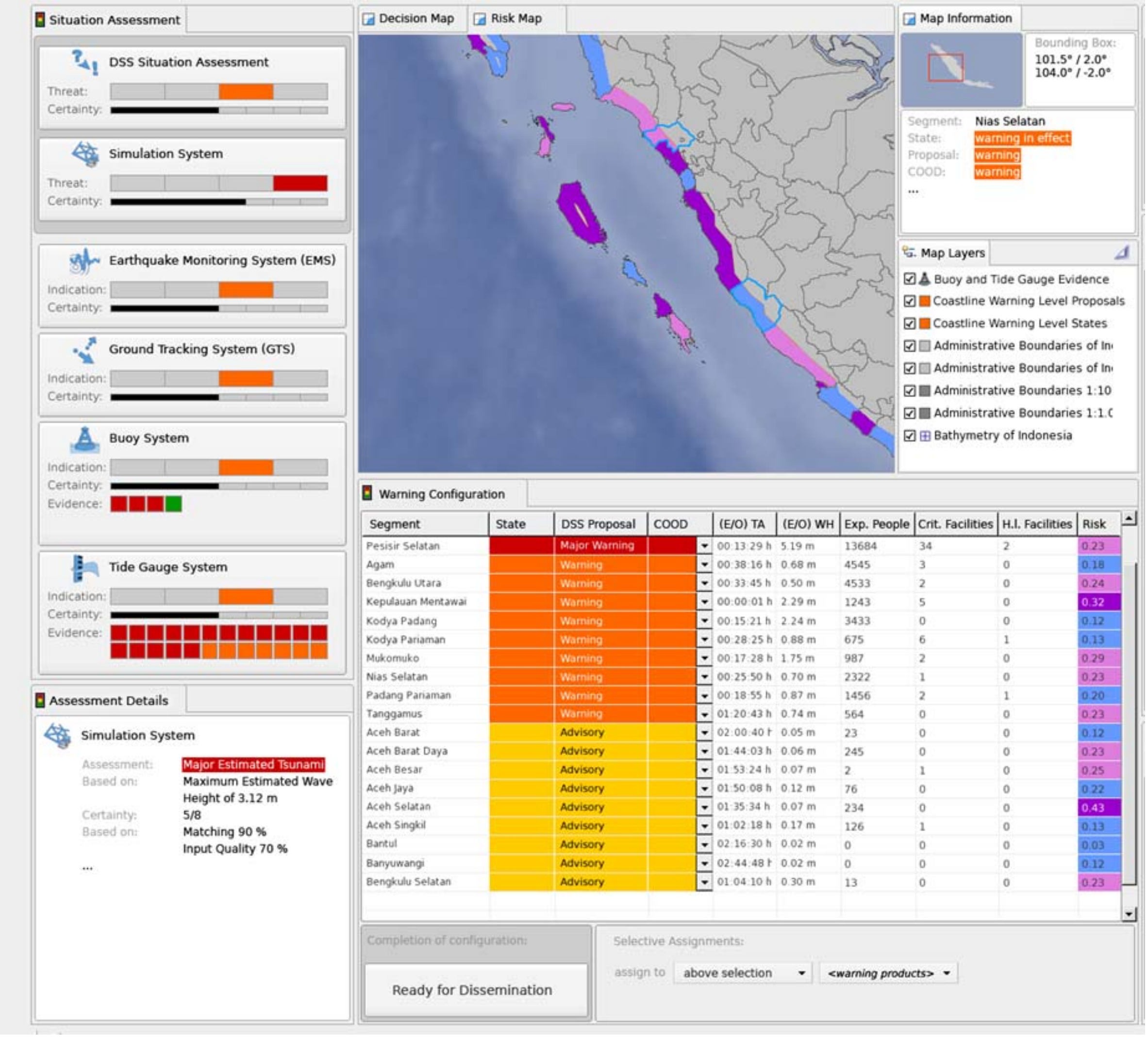
Map application

Effective communication of the risk assessment outputs to all levels involved in the national emergency management processes is of great importance. The assessments are vital inputs to policy-making, determining the nature and level of response for mitigating tsunami risk. The risk map on this coarse level of detail provides crucial information in the warning decision phase.

The stated degree of risk is important information to valuate the tsunami risk for the entire coast of Sumatra, Java and Bali in order to support national and regional decision makers regarding necessary planning requirements for a certain coastal area. Possible information for decision support could be as follows and an appropriate flow of information via the warning chain could be communicated:

Low risk = No direct casualties/ damage from tsunami inundation is likely. It is maybe suitable for staging recovery operations such as evacuation shelters and other emergency services.

High risk = Buildings and human life are unlikely to survive. Evacuation is the only viable response measure.



Bounding Box:
101.5° / 2.0°
104.0° / -2.0°

Segment: Nias Selatan
State: warning in effect
Proposal: warning
COOD: warning
...

Assessment Details

Simulation System
Assessment: Major Estimated Tsunami
Based on: Maximum Estimated Wave Height of 3.12 m
Certainty: 5/8
Based on: Matching 90 %
Input Quality 70 %
...

Segment	State	DSS Proposal	COOD	(E/O) TA	(E/O) WH	Exp. People	Crit. Facilities	H.I. Facilities	Risk
Pesisir Selatan		Major Warning		00:13:29 h	5.19 m	13684	34	2	0.23
Agam		Warning		00:38:16 h	0.68 m	4545	3	0	0.18
Bengkulu Utara		Warning		00:33:45 h	0.50 m	4533	2	0	0.24
Kepulauan Mentawai		Warning		00:00:01 h	2.29 m	1243	5	0	0.32
Kodya Padang		Warning		00:15:21 h	2.24 m	3433	0	0	0.12
Kodya Pariaman		Warning		00:28:25 h	0.88 m	675	6	1	0.13
Mukomuko		Warning		00:17:28 h	1.75 m	987	2	0	0.29
Nias Selatan		Warning		00:25:50 h	0.70 m	2322	1	0	0.23
Padang Pariaman		Warning		00:18:55 h	0.87 m	1456	2	1	0.20
Tanggamus		Warning		01:20:43 h	0.74 m	564	0	0	0.23
Aceh Barat		Advisory		02:00:40 h	0.05 m	23	0	0	0.12
Aceh Barat Daya		Advisory		01:44:03 h	0.06 m	245	0	0	0.23
Aceh Besar		Advisory		01:53:24 h	0.07 m	2	1	0	0.25
Aceh Jaya		Advisory		01:50:08 h	0.12 m	76	0	0	0.22
Aceh Selatan		Advisory		01:35:34 h	0.07 m	234	0	0	0.43
Aceh Singkil		Advisory		01:02:18 h	0.17 m	126	1	0	0.13
Bantul		Advisory		02:16:30 h	0.02 m	0	0	0	0.03
Banyuwangi		Advisory		02:44:48 h	0.02 m	0	0	0	0.12
Bengkulu Selatan		Advisory		01:04:10 h	0.30 m	13	0	0	0.23

Figure 41: Risk information in the DSS

Risk information on a coarse scale is also implemented in the DSS as map products and tabular data. The upper part of Figure 41 shows parts of the Indonesian coastline, divided into warning segments and marked with a specific tsunami risk. The risk estimation is based on the hazard probability, population distribution and evacuation capability of the certain warning segment and is based on the calculation for the tsunami risk map (see Chapter 3.3). Figure 42 highlights the different risk classifications for some areas along the coast of Java. Tabular data (see lower part of Figure 41) include both information about the exposed population, critical and high loss facilities within each warning segment. Is must be made clear that there is no direct correlation of the exposed population with the risk category within a warning segment as the risk class is also based on information about hazard probability and evacuation capability. Figure 43 gives an example.

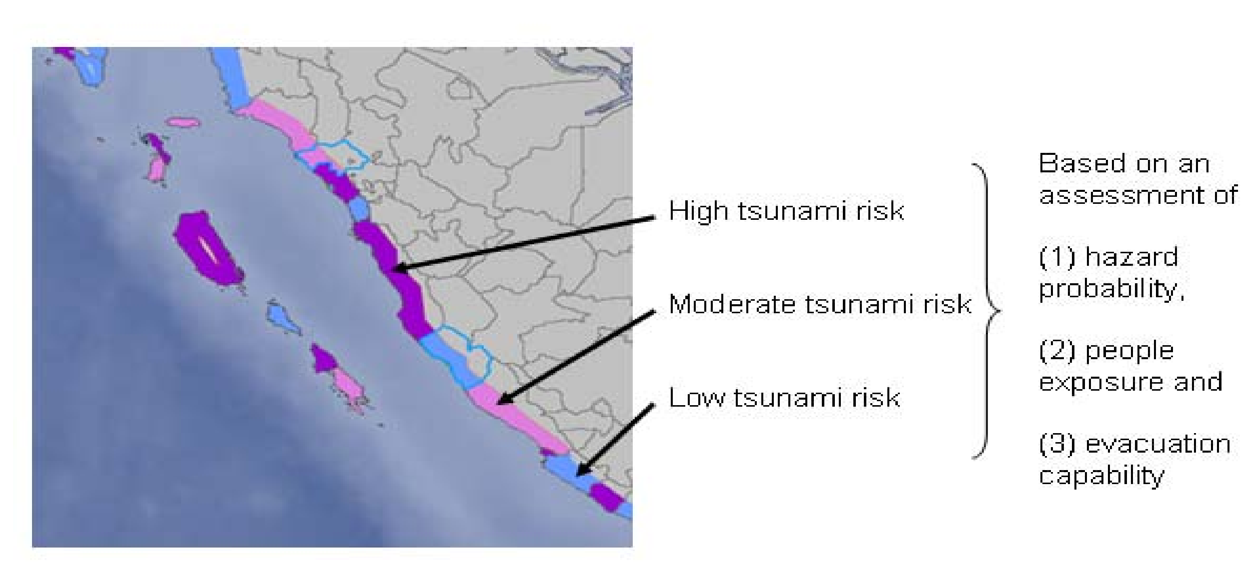
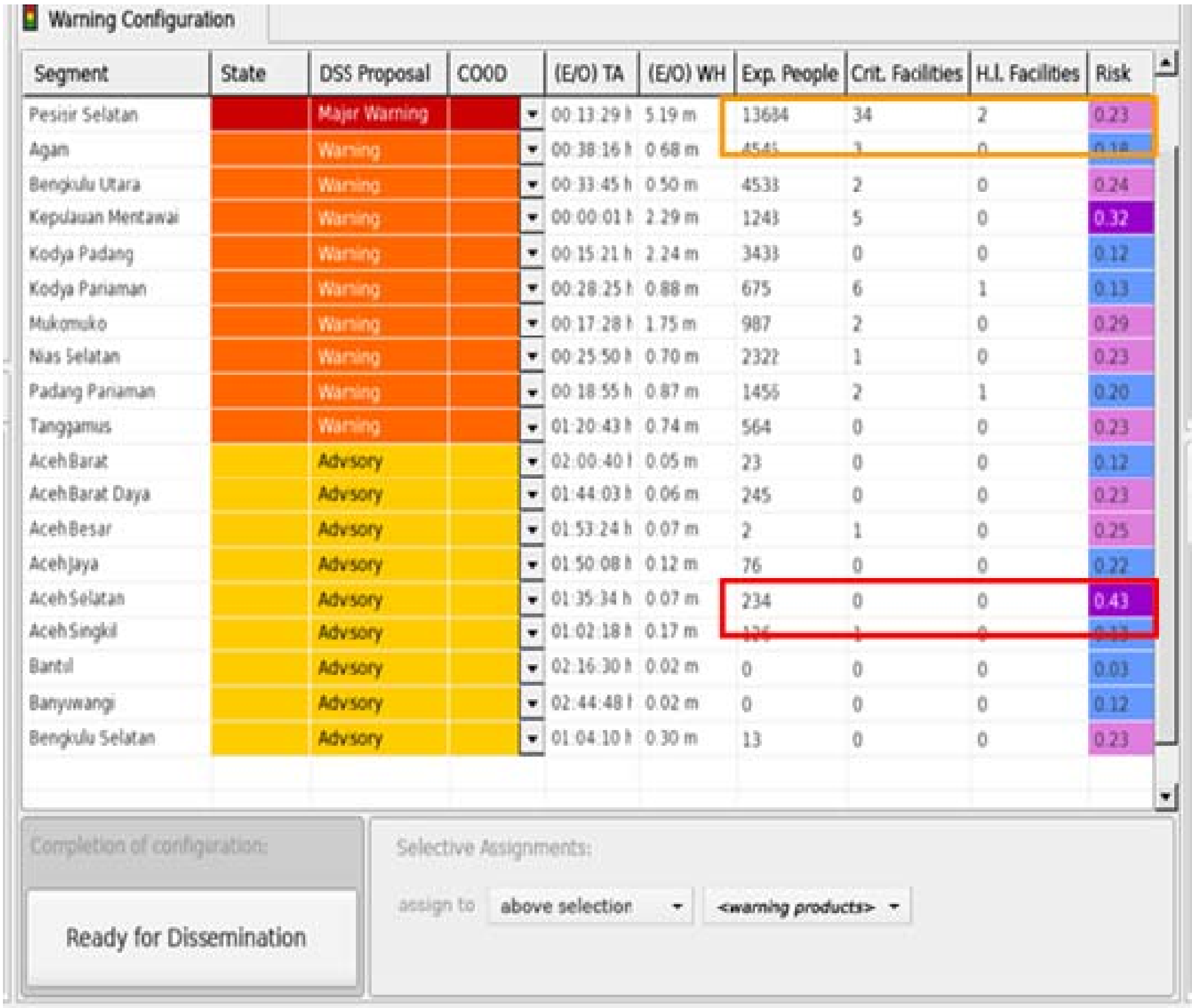


Figure 42: Risk information in the DSS on warning segment level



Segment	State	DSS Proposal	COOD	(E/O) TA	(E/O) WH	Exp. People	Crit. Facilities	H.I. Facilities	Risk
Pesisir Selatan		Major Warning		00:13:29 h	5.19 m	13684	34	2	0.23
Agam		Warning		00:38:16 h	0.68 m	4541	3	0	0.18
Bengkulu Utara		Warning		00:33:45 h	0.50 m	4533	2	0	0.24
Kepulauan Mentawai		Warning		00:00:01 h	2.29 m	1243	5	0	0.32
Kodya Padang		Warning		00:15:21 h	2.24 m	3433	0	0	0.12
Kodya Pariaman		Warning		00:28:25 h	0.88 m	675	6	1	0.13
Mukomuko		Warning		00:17:28 h	1.75 m	987	2	0	0.29
Nias Selatan		Warning		00:25:50 h	0.70 m	2322	1	0	0.23
Padang Pariaman		Warning		00:18:55 h	0.87 m	1456	2	1	0.20
Tanggamus		Warning		01:20:43 h	0.74 m	564	0	0	0.23
AcehBarat		Advisory		02:00:40 h	0.05 m	23	0	0	0.12
AcehBarat Daya		Advisory		01:44:03 h	0.06 m	245	0	0	0.23
AcehBesar		Advisory		01:53:24 h	0.07 m	2	1	0	0.25
AcehJaya		Advisory		01:50:08 h	0.12 m	76	0	0	0.22
AcehSelatan		Advisory		01:35:34 h	0.07 m	234	0	0	0.43
AcehSingkil		Advisory		01:02:18 h	0.17 m	126	1	0	0.13
Bantul		Advisory		02:16:30 h	0.02 m	0	0	0	0.03
Banyuwangi		Advisory		02:44:48 h	0.02 m	0	0	0	0.12
Bengkulu Selatan		Advisory		01:04:10 h	0.30 m	13	0	0	0.23

ORANGE BOX: High population exposure and many critical/ lifeline facilities

→ **but:** only moderate risk

→ **possible explanation:** low tsunami probability and good evacuation capability

RED BOX: Low population exposure and no critical/ lifeline facilities

→ **but:** high risk

→ **possible explanation:** high tsunami probability and bad evacuation capability

Figure 43: Example for tabular risk information in the DSS

3.2.5 Casualty products (coarse)

The time dependent casualties can be calculated for defined spatial units (e.g. administrative units, warning segments) based on the methods described in chapter 2.3.2.

Result description

The following figure provides an example for selected warning segments in Indonesia of calculated time-dependent casualties. This information is available for the entire coast on warning segment level.

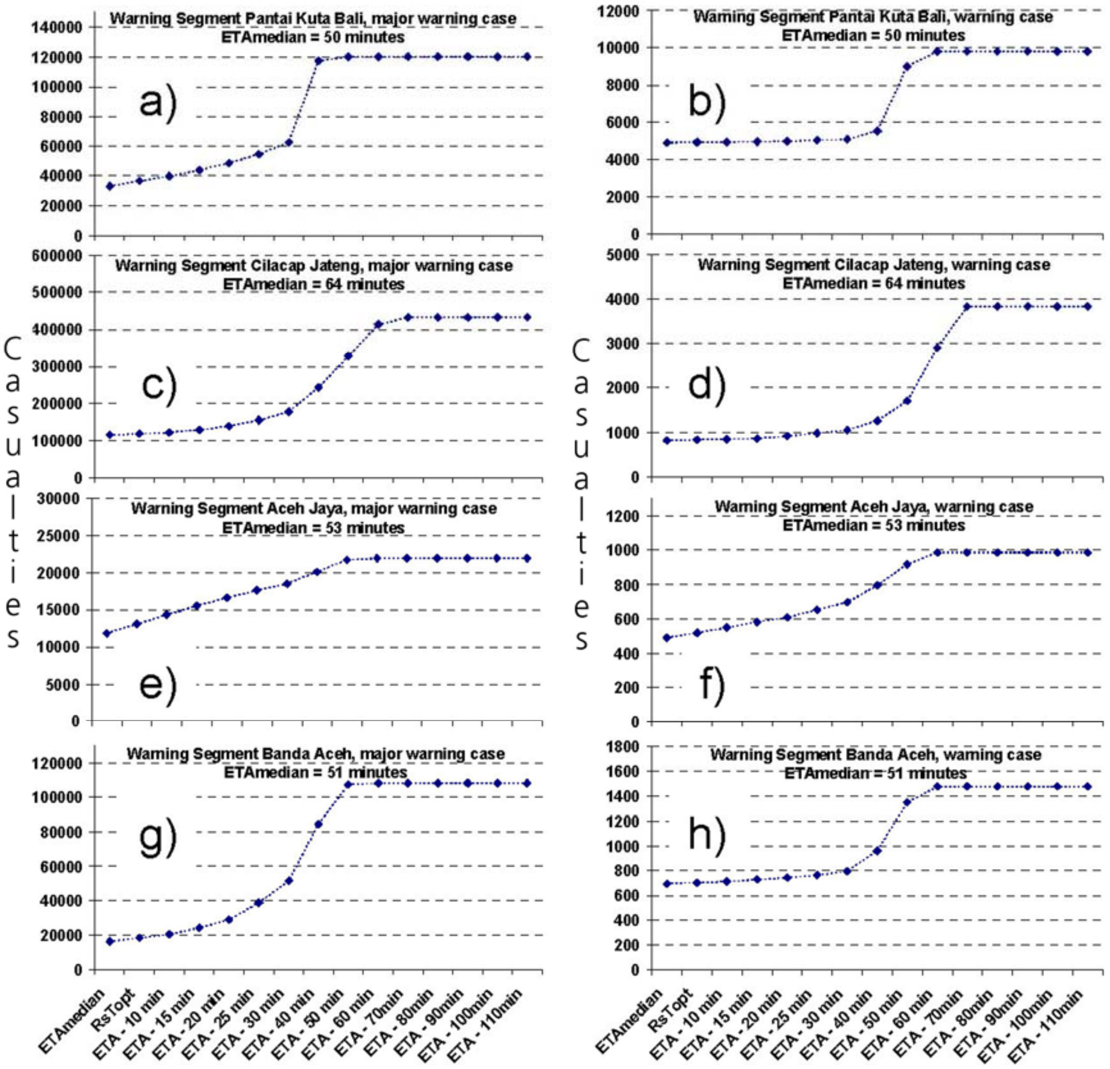


Figure 44: Number of casualties as a function of response time and median ETA values for warning segments Pantai Kuta Bali (a, b), Cilacap Jateng (c, d), Aceh Jaya (e, f) and Banda Aceh (g, h) and considering major warning impact zone (left) and warning impact zone (right)

Figure 44 illustrates the casualties for selected warning segments, as a function of available response time (RsT). At RsT=0 minutes(see e.g. ETA-51 minutes in figure 44 g left) all people within the tsunami affected area are directly impacted. Generally the curves in Fig. 44 feature small increases followed by a rapid increase in casualties at a certain time and then approaching the number of people exposed (amount of people within the tsunami affected area). For the case of “warning level” tsunami warning the relatively slow increase of casualties in the first 10– 15 min is more pronounced than for the major warning case. As expected, the longer the response times for evacuation procedures the fewer casualties.

Only an effective early warning system, evacuation planning together with knowledge on tsunami together with correct interpretation of natural tsunami warning signs can improve the response time. Without these conditions and with only a very short response time casualties are a multiple. The result for Kuta (Bali, Figure 44 b) for a major warning case results in approx. 25 000 casualties for optimal response times (RsTopt, direct evacuation when receiving a tsunami warning sign) to 120 000 for RsT=0 min (no evacuation action until tsunami hits the land).

Result application

Currently, the time dependent casualty information is not yet implemented in the decision support system (DSS) of the Tsunami Warning Systems. Potentials exist in the future to integrate this information.

In case of a tsunami incident (real event), the potential casualties per time can be used to be displayed per warning segment as key numbers. As time progresses during an incident, number of potential casualties will increase. For certain warning segments, tsunami intensities and estimated times of arrival, potential numbers of casualties are expected to be zero as long as response times are optimal. Hence for these warning segments the time for warning decision can be longer until the certainty for a correct warning decision is sufficient and no casualties are to be expected. This would avoid false warnings. Additionally, the number of casualties and the number of displaced people are essential information for emergency relief measures. The situation pictures on how many people are casualties, and on how many people need first aid at a very early stage because they are displaced offers novel opportunities for effective emergency relief measures.

3.3 Warning Dissemination and Warning Receipt

Mapping peoples' access to outdoor and indoor warning infrastructure allows for understanding the spatial pattern of bottlenecks in warning dissemination. With this information end-users can prioritize and develop strategies for investments into warning dissemination infrastructures and procedures.

3.3.1 Access to Warning Infrastructure Product (detailled)

Figure 45 provides the full picture of the access of the population to indoor and outdoor warning.

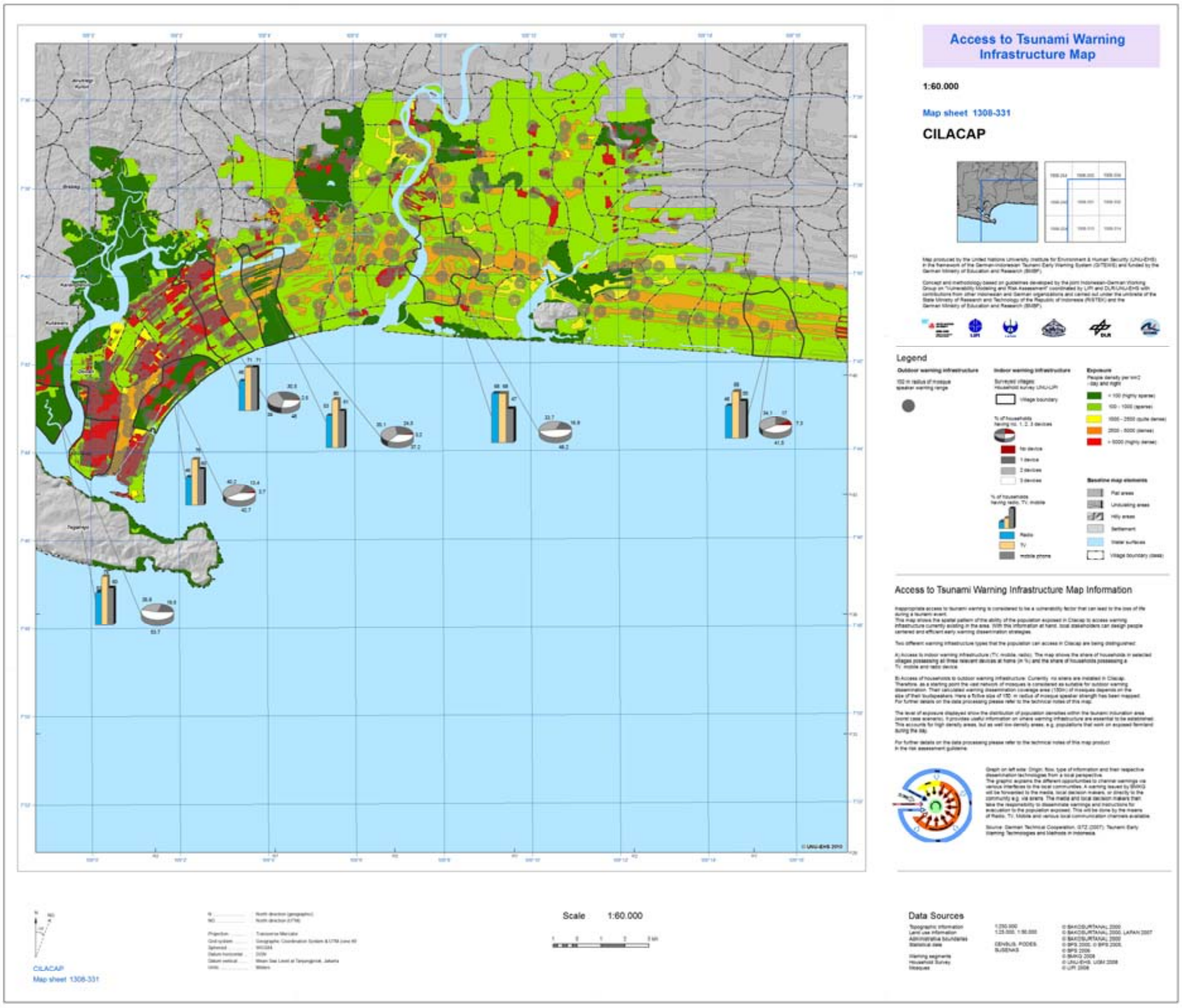


Figure 45: Access to warning map, Cilacap

Thereby, three different information layers are integrated:

1. Hazard zone: Provides information the spatial entity that requires warning infrastructure.
2. Exposure information: Provides information about those areas within the hazard zone that require a dense network of dissemination infrastructure.
3. Information on existing warning infrastructure: Provides an overview about the current status of warning infrastructure distribution and accessibility by the population.

Map description

a) Area covered with outdoor mass notification devices

- Grey circle: Coverage area of the mosque loudspeaker
- Red circle: Coverage area of the sirens (only Padang, Bali)

b) Access of households to indoor mass notification devices in selected villages

- Bar chart (blue, yellow, grey): % of households in a village possessing a radio, a TV and a HP (indoor mass notification devices).
- Pie chart (grey, white, red): % of households in a village possessing all three, two, or only one of the indoor mass notification devices.

c) Hazard and exposure information (for details see following chapter 3.3.2)

- Hazard inundation: This is the area of focus of the assessment, indicated by the color boundaries of the exposure information.
- Exposure levels: The degree of exposure (people exposed per km^2) at day- and nighttime classified as high (red), moderate (yellow) and low (green). The intervals are set according to the exposure map description in chapter 3.2.

Results

<u>People's access to outdoor warning devices</u> Since in Cilacap so far no sirens are installed and the majority of the population have a strong religious affiliation to Islam, mosques play a key role for outdoor mass notification. But also here the mosque coverage is unevenly distributed. Although the total number of mosques is very high (as in Padang), the urban areas show a higher density. Since the map shows the population densities in the tsunami inundation zone (major warning) the location of the mosques and their speakers' coverage, the hotspots of outdoor mass notification deficiencies can be identified. Especially, in non-settlement areas, but where a substantial amount of people works at daytime (such as in agriculture), warning dissemination infrastructure is missing. And in places where population densities are very high the current setup of warning dissemination infrastructure is also not sufficient.

People’s access to indoor warning devices: The map for Cilacap clearly shows the spatial variation of the access to warning among the different households and villages. For example, in the city centre of Cilacap, more than 50% of the population possess three devices in their households, thus increasing the likelihood that households have immediate access to tsunami warnings compared to the far eastern rural village Widarapayungwetan, where a share of 7.3% of the population does not have any access to indoor mass notification and only 40% have access to all devices.

Map application

With such assessments at hand, decision makers and NGOs can prioritize and develop knowledge based investment plans and strategies for setting up people centred warning dissemination infrastructure. Taking stock of all existing dissemination infrastructures (including traditional ones, such as mosques); and knowing the critical areas where warning dissemination is needed (high levels of exposure) is the bases for discussion amongst responsible stakeholders how to proceed. E.g. the map shows that mosques are well established in Cilacap and Padang. To take advantage of this vast existing network, religious leaders need to participate in designing SOPs for local warning dissemination. But still, the installation of sirens is important, they could fill the gap, where mosques cannot reach citizens. This also accounts for non-settlement areas, which also have a significant level of exposure.

But only relying on outdoor warning infrastructure is not enough. With the information on which population groups have good or bad access to warnings via indoor devices, such as Radio, TV and mobile phone the dissemination strategy can be adapted. Here, the map raises awareness especially for the need to develop different strategies for rural and urban areas.

Recommendation for improvement and monitoring

Aside calculating and mapping the spatial distribution of physical criteria of access to tsunami warnings it is also important to evaluate their reliability (e.g. risk of blackouts due to earthquake).

Further more it is important to get an understanding of the social criteria that either enhance or worsen timely access to warnings, such as how the devices are used during day at night at different places. As can be seen from the map not all villages were surveyed, since this is only an example. But for achieving full coverage of tsunami exposed villages additional funds and official commitments are needed. Thus, it is recommended to select the most important criteria and add them into standardized official surveys, e.g. by BPS. Finally, the pilot assessment only provides information on household level access to warnings, but decision makers need an information tool for critical infrastructures, too.

Outdoor mass notification

A major constraint of this assessment is that in the pilot areas no data was collected about the location specific outreach area of mosque or siren speakers. Here it would be necessary to measure the clearness and sound of warning messages under real-life conditions as a function of the speaker capacity, and acoustic noise absorbing features such as time and location specific background noise and buildings depending on their distance from the source. Using mosques as channels of warning dissemination does only fit in areas in Indonesia where Islam is the predominant religion. Thus, decisions on warning channels are tasks incumbent on local governments and civil society and not national authorities.

3.3.2 Hazard and Exposure Products (detailled)

Relevant products for the warning dissemination and warning receipt phase within the warning reaction scheme are the detailed ‘tsunami hazard map’, the detailed ‘exposure map’ that are integrated in the ‘access to warning infrastructure map’. Here, the hazard and exposure map are explained in detailed because they serve as important baseline information for risk management as such and for the further processing of other risk and vulnerability products.

Hazard assessment product (detailed)

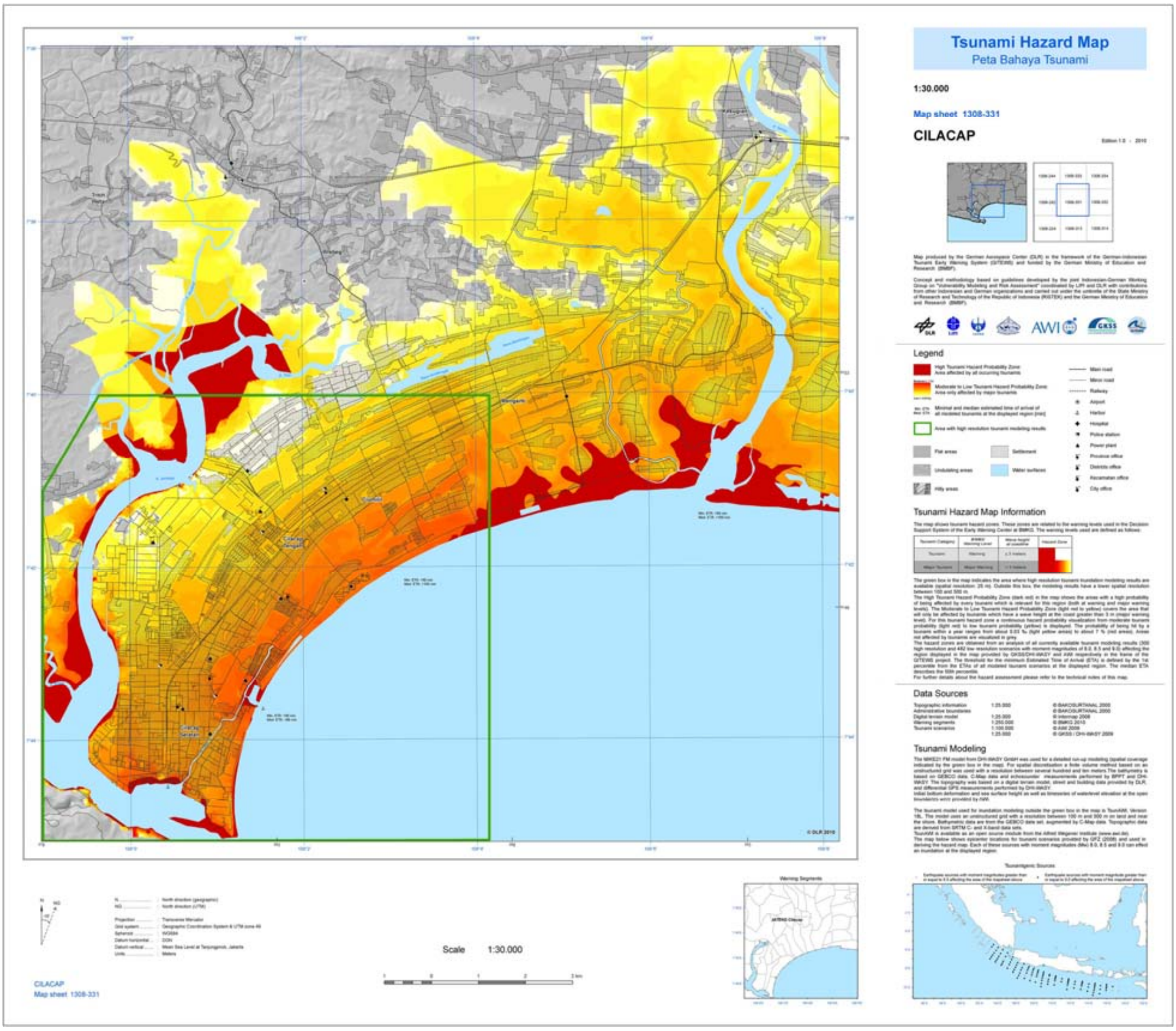


Figure 46: Detailed tsunami hazard map of Cilacap (sample map sheet)

Map description and results

The map contents in the tsunami hazard map of a scale of 1 : 25 000 correspond to the coarse map of a scale of 1 : 100 000. Please refer to chapter 3.2.1 for details. The hazard zones are obtained from an analysis of scenarios with moment magnitudes of 8.0, 8.5 and 9.0 affecting the region displayed in the maps, provided by GKSS/ DHI-WASY in the frame of the GITEWS project. The spatial resolution of the hazard impact zone data is 25 meters.

Map application

As preparedness is the key to cope with tsunamis, development of local preparedness strategies is essential. This requires a good understanding of the hazard. A tsunami hazard map provides all stakeholders with a crucial reference for development of preparedness strategies and is therefore needed as the basic reference and most important planning tool for developing evacuation strategies and maps for the respective area. The hazard map is also relevant for land use planning and development of mid-term measures to mitigate possible impacts of tsunamis.

It has to be pointed out that the provided hazard information is based on modelling results which naturally possesses uncertainties. Hence, the hazard maps have only to be seen as best available reference information for the development of local specific disaster preparedness, adaptation and mitigation strategies, always considering that modelling results will differ from reality.

Exposure assessment product (detailed)

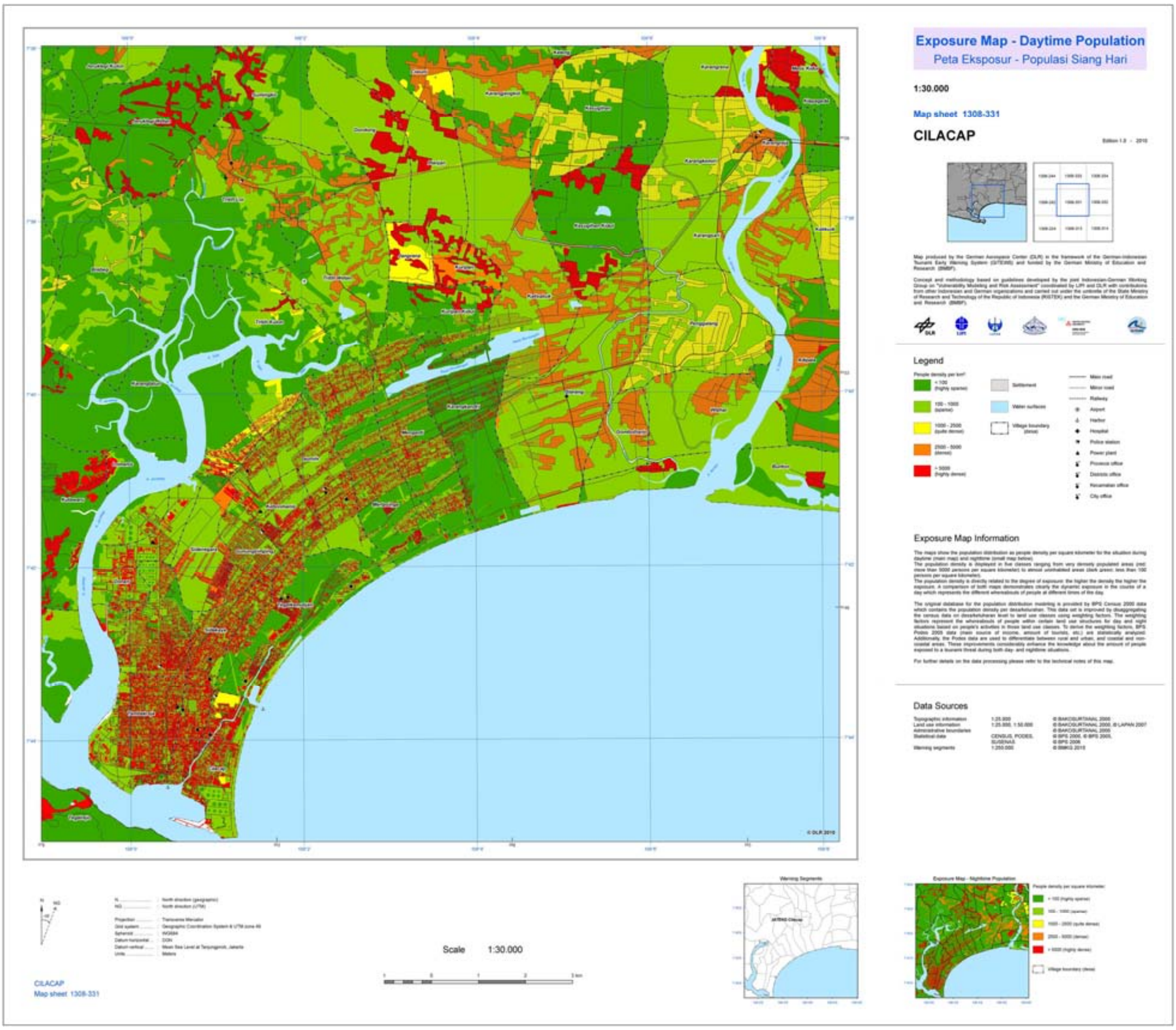


Figure 47: Detailed exposure map of Cilacap (sample map sheet)

Map description and results

The map shows the population distribution and degree of its tsunami exposure for a daytime situation as high (red), moderate (yellow) and low (green). The degree of exposure is based on the population density distribution during daytime, i.e., the higher the density the higher the exposure. An exposure class of high is assigned to areas with population density greater than 2500 people per square kilometre, moderate to population density between 100 and 2500 people per square kilometre, and low to population density below 100 people per square kilometre.

Map application

This map product on a scale of 1 : 25 000 show a level of detail that is suitable to provide information on people exposure at sub-district level contributing to local specific risk management, e.g. warning dissemination infrastructure planning, evacuation planning and urban planning. The benefit of the map information itself on this scale is various. Population distribution is crucial information to get an overview of the population exposed in a tsunami prone area in order to better estimate the emergency potential. Therefore the exposure map can be seen as a baseline vulnerability product, upon in-depth vulnerability analysis is to be conducted. Further the exposure map acts as an intermediate product for other risk assessment products. The evacuation capability, for example, as displayed in the ‘Evacuation Time map’ (see chapter 3.5), is strongly dependent on population data. A high population density influences the demand of tsunami evacuation shelters as well as the evacuation speed. Also the ‘Risk map’ (see chapter 3.5) includes population information as the population density strongly influences the degree of risk in a specific area.

3.4 Warning Reaction

To enhance communities warning reaction vulnerability products are needed that indicate people’s degree of evacuation readiness. It was agreed amongst scientists and end-users from Padang (e.g. Kogami) to first explore on the factors of evacuation readiness and then to develop an “Evacuation Readiness Index” for mapping the factors of evacuation readiness. Moreover, it was agreed to disaggregate the index into a set of sub-indexes to get a more in-depth understanding of the different topics that factor evacuation readiness. Mapping evacuation readiness means showing the spatial distribution of the index and sub-index values. Besides explaining the products and its results, their field of concrete application is going to be described.

Relevant products for the warning reaction phase within the warning reaction scheme are the ‘evacuation readiness map’ and further related products, the detailed ‘tsunami hazard map’ (already explained in Chapter 3.3) as well as the detailed ‘exposure map’ (already explained in Chapter 3.3).

3.4.1 Evacuation Readiness Products

The guideline showcases two different evacuation readiness products. End-users can chose themselves which of the products is most helpful to manage programmes that increase of the evacuation readiness of their citizens.

In the following two products are described in detail as well as their area of application:

1. Factors of evacuation readiness: Awareness creation amongst stakeholders involved in EWS governance and designing the content of awareness material.

2. Measured and mapped index and sub-indexes of evacuation readiness: Understanding the degree and spatial distribution of individuals’ evacuation readiness

In the following each of the products and their utility will be briefly explained.

3.4.1.1 Factors and Index System of Evacuation Readiness

The following factors (table 10) that influence individuals’ evacuation readiness were identified in the regression analysis. Knowing these factors is of utmost importance for designing effective socialization and awareness strategies.

Table 10: Factors of evacuation readiness

Factors of Evacuation Readiness	**Example of factor explanation**
1. Knowledge of tsunami definition 2. Knowledge of tsunami indications 3. Knowledge of tsunami ETA 4. Tsunami seen as permanent danger	*E.g. r*espondents possessing the correct knowledge of the Estimated Time of Tsunami Arrival (ETA <= 30 min) rather tend to respond quickly to a given warning.
5. Knowledge about own exposure 6. Cause of harm: Not enough protection & preparedness 7. Tsunami regarded as major concern 8. Fear of tsunami	Those respondents, who generally fear a tsunami impact and those who even consider and perceive a tsunami as a major threat unlike other threats such as car accidents or the struggle for daily livelihoods, rather tend to quickly respond to tsunami warnings.
9. Warnings relate to call for Immediate evacuation 10. EWS precisely predicts tsunami occurrence	Respondents, who rather expect guidance for action and not just a tsunami warning alert, tend to hesitate before they start evacuation. Vice versa, those who understand warning alerts as an indirect call for evacuation, also tend to quickly respond to warnings and evacuate immediately.
11. Knowledge of safe area 12. Knowledge of safe building 13. Knowledge of routes and signs 14. Perceived manageability of evacuation	The knowledge of evacuation routes and safe areas (higher ground or vertical shelters) are of utmost importance for quick reactions to tsunami warning alerts. Especially those who are familiar with the shelters accessible to them (relatives living at higher ground) tend to quickly respond to warnings

The results show that in the absence of warning guidance information and evacuation infrastructure it is very unlikely that the population will start timely evacuation. Also when the population’s knowledge on tsunami threats (and their specific characteristics) as well as their degree of exposure is lacking commencing evacuation is highly unlikely.

The findings are highly relevant for understanding the conditions of human behaviour in response to tsunami early warnings and to develop efficient early warning and response structures: Early warning messages need to include a clear guidance for action with spatial reference, the spatial setup of evacuation related infrastructures (hazard and evacuation zoning signs, defining and labelling routes and identifying shelters with basic service provisions). In addition, and not less importantly, socialization of the population at risk is a precondition for efficient warning response.

The single evacuation readiness variables are aggregated into understandable and logic clusters, here termed sub-indexes. Figure 48 shows the set up and clustering of the evacuation readiness factors into four sub-indexes: Hazard knowledge, vulnerability perception, warning perception and evacuation perception. Finally, an overall Evacuation Readiness Index was developed.

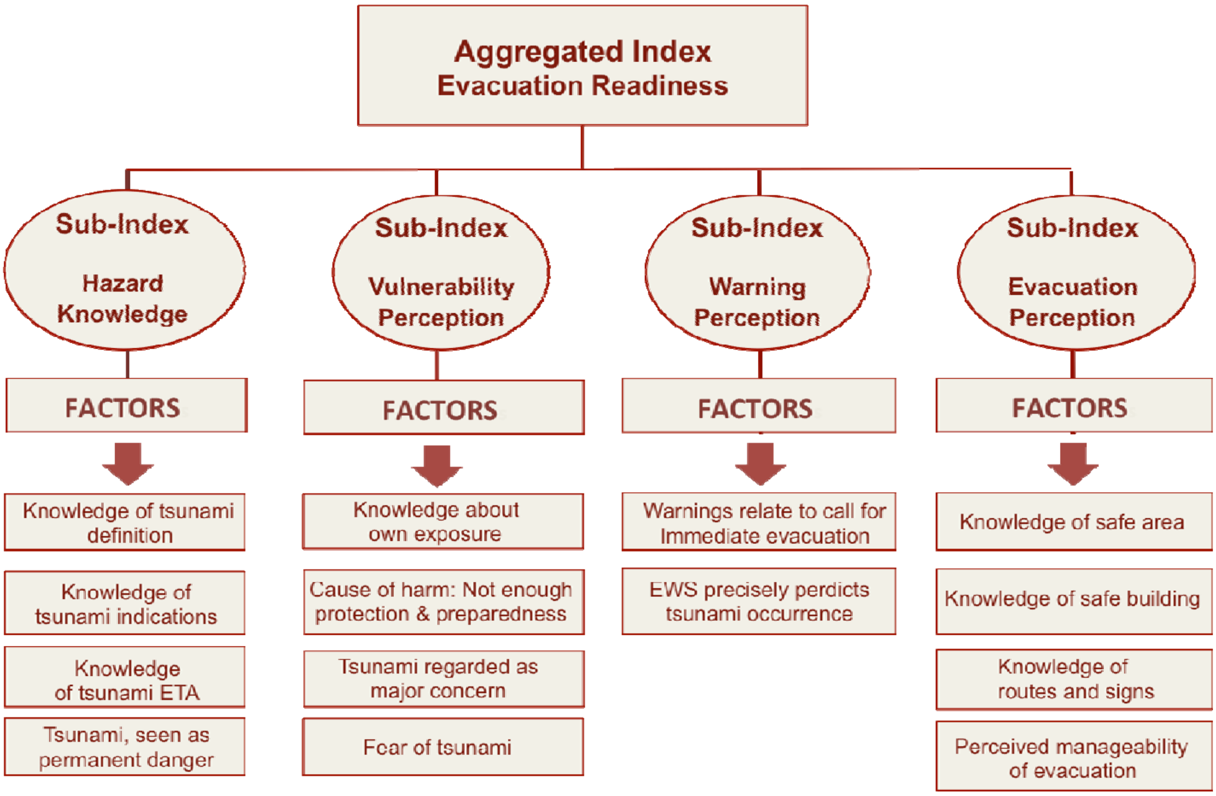


Figure 48: Evacuation readiness sub-indexes and aggregated index

Product Application

(1) Awareness creation amongst decision makers: The identified factors provide awareness on the conditions for Early Warning Systems to be efficient. With this information priorities can be set how and in which order to invest in EWS infrastructure. The factors prove the need to focus very much on the last mile and to invest more in last mile related EWS infrastructure than it is done up to now. Especially for Indonesia with a vast exposed coastline this poses a huge challenge, in organizational and financial terms.

(2) Socialization material development: The knowledge of the factors of evacuation readiness defines the topics that need to be addressed in any kind of activity that is associated with awareness raising and socialization.

3.4.1.2 Tabular data and mapped index and sub-indexes of evacuation readiness

The set of sub-indexes and the final evacuation readiness index are designed to measure the degree of evacuation readiness of the population in a way that it is of use for decision makers. Based on this indexing system, evacuation readiness is measured, allowing disaggregating or to get an overall picture of evacuation readiness. Measuring evacuation readiness allows for comparing the degree of evacuation readiness of individuals, villages or districts. The example given here is the village level aggregation.

(1) Tabular data

The statistics and data generated can be displayed and utilized in various ways. The example presented here shows the visualization of the results using bar charts that indicate the percentage of individuals within in a village having “very low”, “low”, “high”, and “very high” levels overall evacuation readiness, evacuation, warning, vulnerability perception and hazard knowledge.

The bar charts in Figure 49 indicate how the different readiness levels are distributed among the households within each village. Taking Cilacap as an example the calculated index suggests that the overall evacuation readiness of the population in the district is quite low (majority of cases fall in the yellow class) and generally no significant differences between the villages can be discovered.

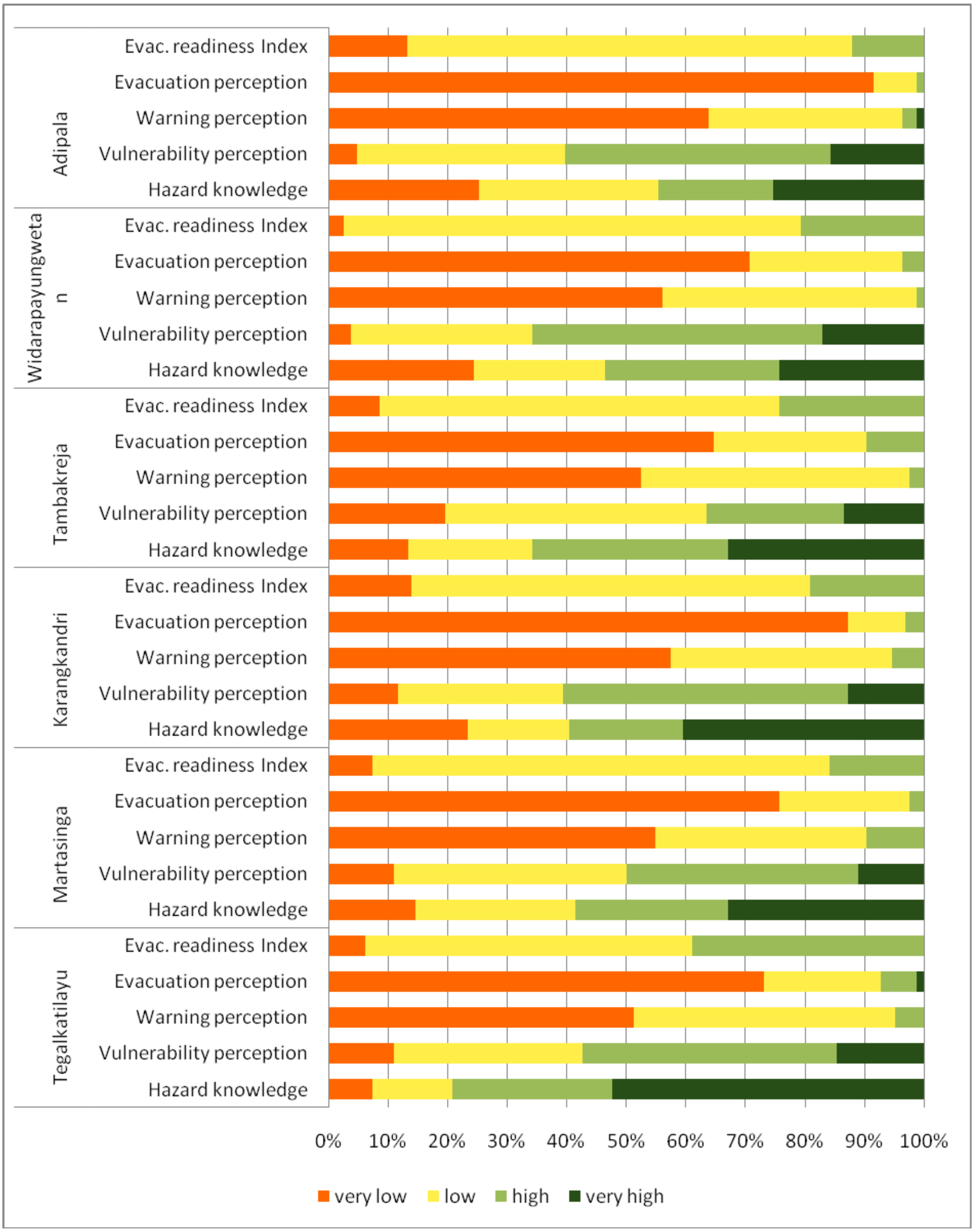


Figure 49: Evacuation readiness assessment results

Looking at the overall mean values of the sub-indexes one clear trend in Cilacap can be discovered: Since Cilacap recently experienced a fatal tsunami, it seems that the hazard and vulnerability knowledge amongst citizens is high. But in the absence of a functioning early warning system and no evacuation infrastructure people's knowledge and perception on early warning systems and evacuation infrastructure is very low leading to an overall low degree of evacuation readiness. The results presented here show that a warning system alone is of little value when place-specific spatial configurations related to evacuation infrastructure are not developed and the spatiality of threats is not effectively communicated to tsunami-exposed populations. In their absence, warning systems are not effective and warning response behaviour is left to individuals.

(2) Evacuation Readiness Map

Another option to visualize the index results is to map them. Added value to mapping evacuation readiness is to even more simplify the index results and to get a more precise picture of the spatial distribution of evacuation readiness and its factors. The map is provided at a scale of 1 : 50 000.

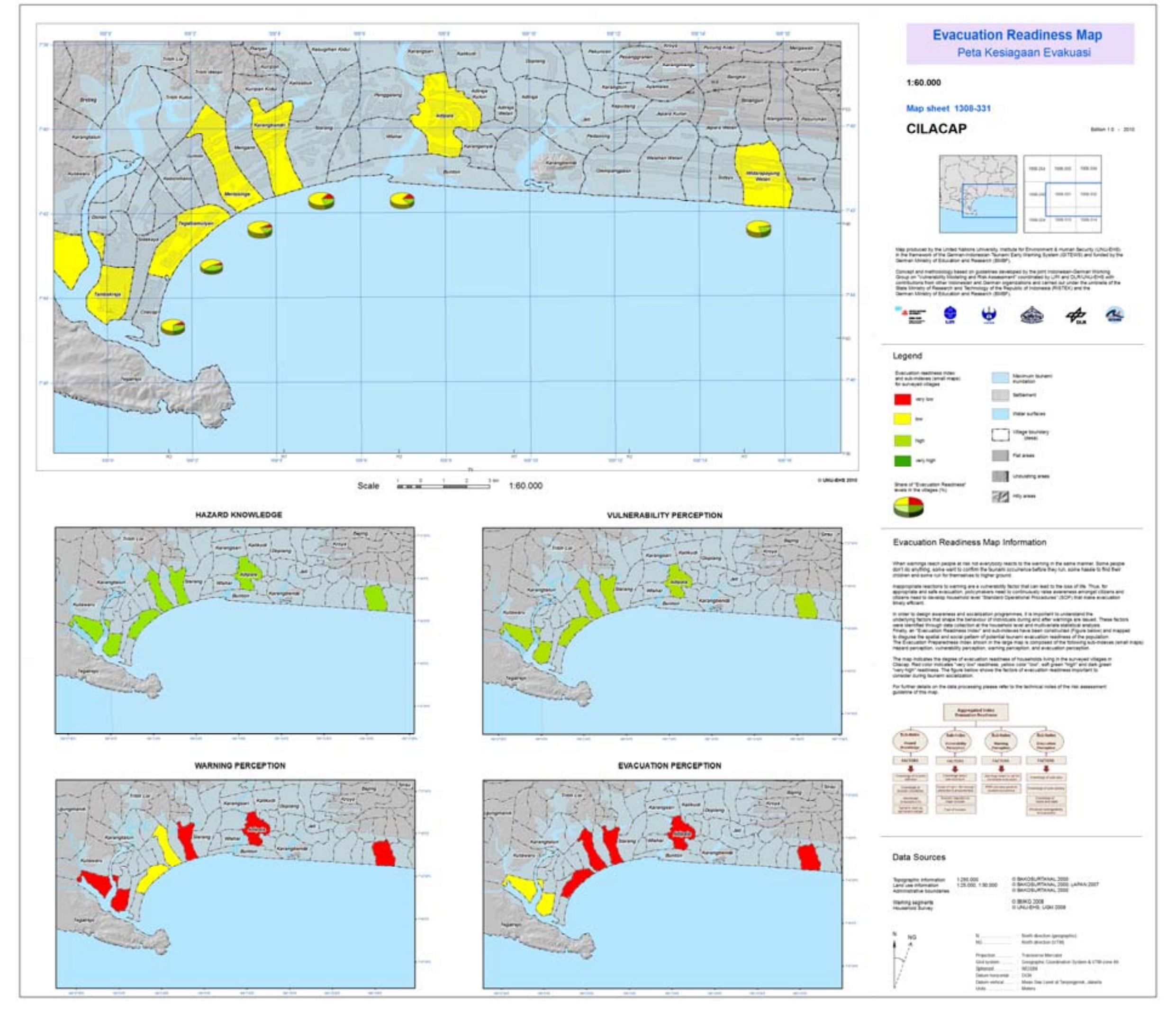


Figure 50: Evacuation readiness map of selected Kelurahan in the GITEWS pilot area of Cilacap (Central Java)

Contents of the different maps:

- Large Map: Evacuation Readiness Index
- Small maps: Upper left: Hazard Knowledge; Upper right: Vulnerability Perception; lower left: Warning perception; Lower right: Evacuation perception.

Label description:

- Texture: Equal intervals classification of the (sub) index values at the village level (0 – 0.25; 0.26 – 0.5; 0.51 – 0.75; 0.76 – 1) indicating very low, low, high very high levels of evacuation readiness. Index levels with the highest share of cases within each class are displayed.
- Pie charts: Distribution of evacuation readiness levels amongst households within the surveyed villages

(3) Application of Results

Both, analysing tabulated and mapped evacuation readiness indexes can be used to prioritize areas and topics that need special attention during socialization and awareness programmes. E.g. for the case of Cilacap the results show that communicating and building trust into the EWS and the participatory identification of evacuation routes and shelters is urgently needed and a matter of priority. Decision makers are urged to facilitate the communication process of societal change with respect to the acceptance of the EWS as a new technology of Disaster Risk Reduction. When awareness creation and socialization outputs shall be monitored, mapping evacuation readiness at the village level can provide significant decision support during operationalization.

(4) Recommendation for monitoring evacuation readiness

For decision makers, measuring the evacuation readiness of the Indonesian population does not require to reproduce the same methodology applied in this case study whose aim was to identify the factors of warning response and evacuation readiness (see logistic regression). With the results end-users get an idea on the different topics that you need to address when designing and conducting awareness campaigns and you can identify those groups that need particular education on those different topics.

Since the factors of evacuation readiness are now known it is important to develop an “easy to use” monitoring system that can regularly measure the level of people’s evacuation readiness and the success of awareness and socialization activities. In addition, knowing the locations and villages that need specific attention is an add-on that requires the mapping of evacuation readiness, if desired and if decision support is needed for prioritizing investments into community socialization.

If you want to assess the evacuation readiness by using a questionnaire in your community you should follow some important rules:

- Develop criteria for the assessment together with colleagues from different departments, community leaders, NGOs and the population itself. But keep in mind that all of the four sub-index components (Hazard knowledge, vulnerability perception, warning perception and evacuation perception) are represented.
- If you have little experience with designing a questionnaire and a survey, you might find advice with your local university or statistical office (BPS)
- Develop simple questions that people can understand.
- Develop a system of answer categories (metrics) , with which you can develop a scoring system of the index calculation.
- Take enough samples, so that the different social groups in the community are represented. Try to find a balance between different ethnical, occupational, income and age groups.
- Only select samples in the hazard zone, but try to capture households close to the coast as well those located more inland.
- You can also collect up to 80 Samples for the different exposed Kelurahans. Then you can even map the different evacuation readiness levels of the Kelurahan.
- Discuss the results with the relevant stakeholders and develop an awareness strategy that is accepted by those who implement the awareness campaigns.

A template questionnaire can be found in the Technical Guideline document.

3.5 Evacuation Time

Relevant products for the evacuation phase within the warning reaction scheme (see figure 31) are the detailed ‘evacuation time map’, the detailed ‘tsunami risk map’, the detailed ‘tsunami hazard map’ (already explained in Chapter 3.3) as well as the detailed ‘exposure map’ (already explained in Chapter 3.3).

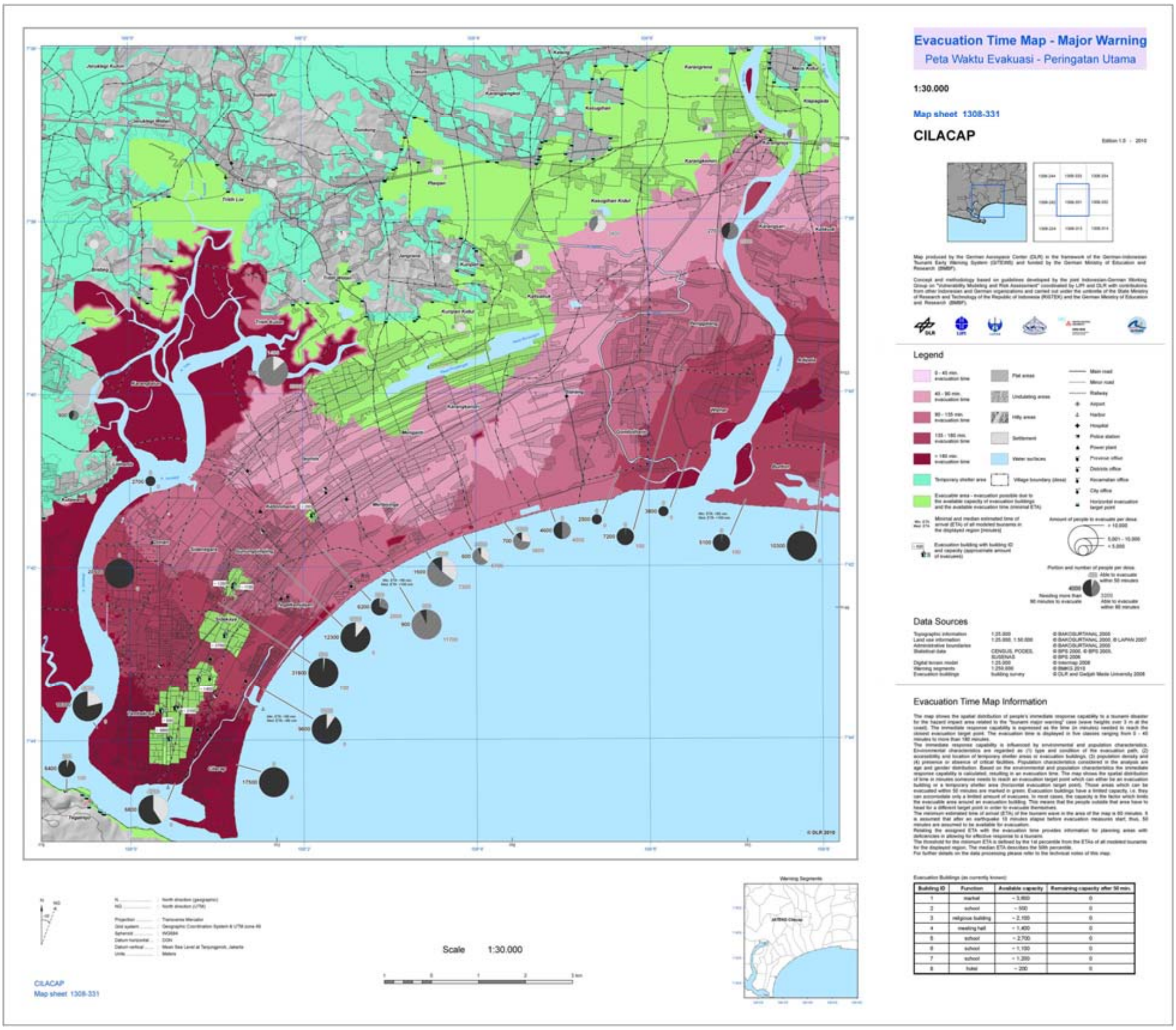


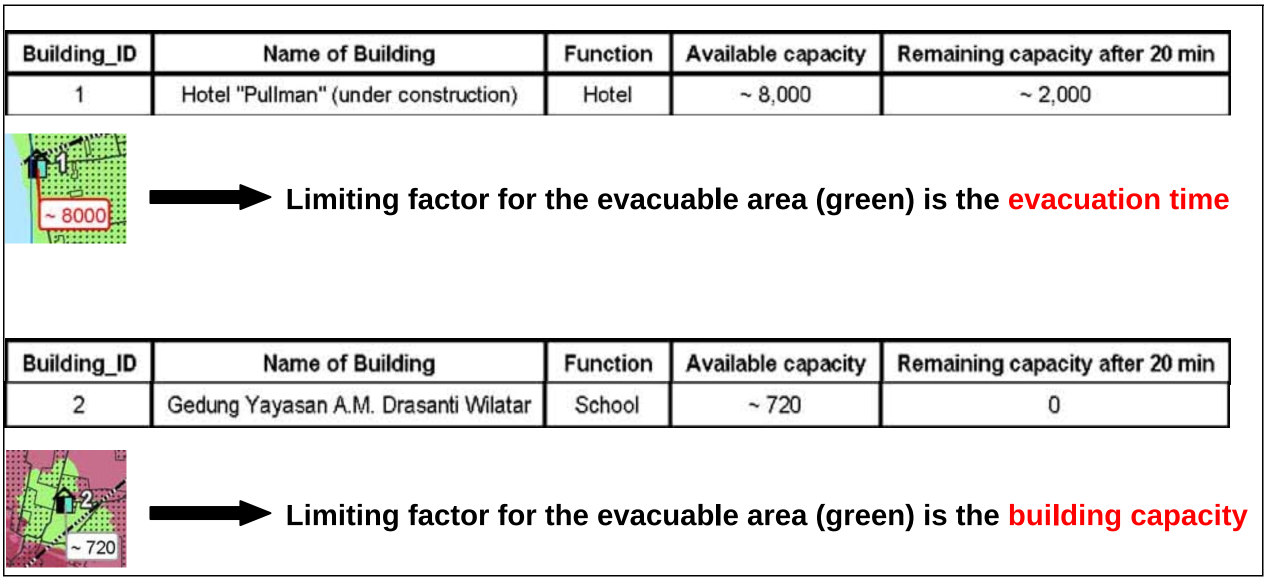
Figure 51: Detailed Evacuation Time map of Cilacap (Example)

Map description and results

Basically, the map contents of the detailed ‘evacuation time map’ of a scale of 1 : 25 000 correspond to the coarse map of a scale of 1 : 100 000 (see chapter 3.2.3). Main difference is the consideration of buildings suitable for vertical evacuation and their carrying capacities. While for the small scale assessment only horizontal evacuation possibilities are indicated, all currently known potential evacuation buildings within the displayed area of the detailed map are taken into account for the evacuation modeling. The green area around the displayed buildings in the map reflects the area that can be evacuated within a certain time (as stated in the 'Evacuation Time Map Information').

Evacuation buildings have a limited capacity, i.e. they can accommodate only a limited amount of evacuees. In most cases, the capacity is the factor which limits the evacuable area around an evacuation building. For a few evacuation buildings (marked with red font colour), the time needed to reach the building is the limiting factor of the evacuable area (green area) while the building's capacity would be sufficient to cover a larger area. The map also provides detailed information about the used buildings (see Figure 52).

It has to be pointed out that all considered evacuation buildings are based on survey results in cooperation with local civil engineers. The method to detect buildings suitable for vertical evacuation is given in chapter 2.2.4 and the technical description together with the used questionnaire is provided in Technical Guideline document. However, for an actual utilization of the buildings within local evacuation planning, it is strongly recommended to recheck all buildings again regarding national or international standards for evacuation buildings.



Building_ID	Name of Building	Function	Available capacity	Remaining capacity after 20 min
1	Hotel "Pullman" (under construction)	Hotel	~ 8,000	~ 2,000

→ **Limiting factor for the evacuable area (green) is the evacuation time**

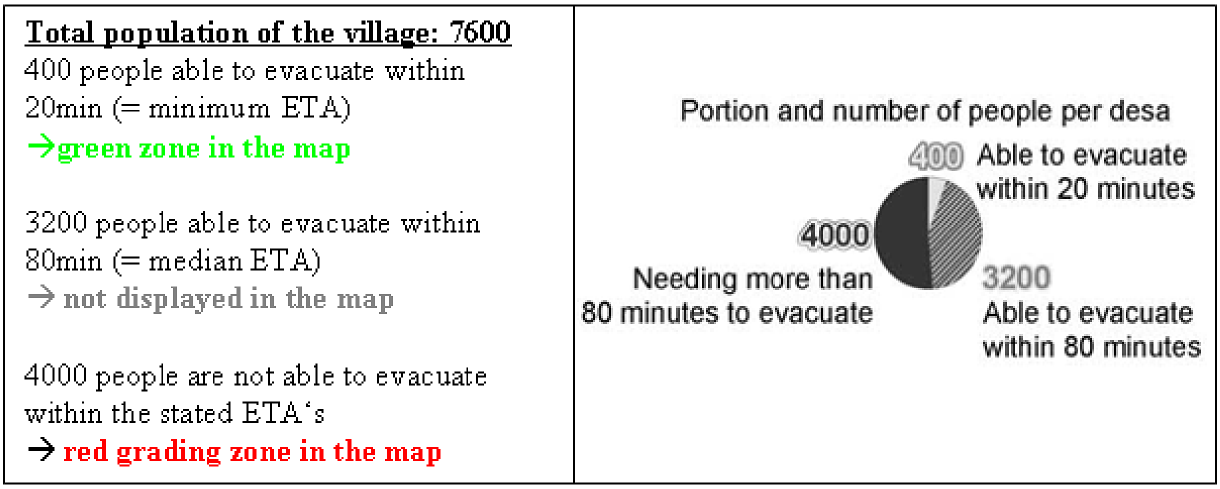
Building_ID	Name of Building	Function	Available capacity	Remaining capacity after 20 min
2	Gedung Yayasan A.M. Drasanti Wilatar	School	~ 720	0

→ **Limiting factor for the evacuable area (green) is the building capacity**

Figure 52: Example for vertical evacuation capability

Further crucial information in the detailed evacuation time map is the reference to the evacuation capability of the population for each village within the displayed area in the map sheet. Pie charts (see example in Figure 53) indicate the portion and number of people per village that are able to evacuate within a specific time, depending on the Estimated Time of

Arrival (ETA). The displayed time values in the pie chart are related to the minimum and median ETA. The portion and number of people that are able to evacuate within the stated minimum ETA are displayed in light grey, an evacuation capability within the median ETA is displayed as shaded grey and the portion and number of people that are not able to evacuate within the minimum and median ETA is displayed in black.



Total population of the village: 7600
400 people able to evacuate within 20min (= minimum ETA)
→**green zone in the map**

3200 people able to evacuate within 80min (= median ETA)
→ **not displayed in the map**

4000 people are not able to evacuate within the stated ETA's
→ **red grading zone in the map**

Figure 53: Example for the evacuation capability per village

Map application

Large areas within the pilot areas featuring weak response capabilities can be identified. Prioritization of intervention measures, such as evacuation planning, increasing warning dissemination devices and awareness rising, within these areas can be implemented.

The level of detail of this product allows decision makers at local level to identify hotspots of weak response capabilities and to evaluate estimated evacuation times related to expected tsunami arrival times. For identified hotspots and knowing the amount of people therein additional vertical evacuation shelters can be assigned or installed. Knowing the approximate number of casualties and dislocated people helps in planning evacuation shelter, basic need supply (food, water, medicine) and medical care capacity needed to cope with a tsunami disaster. Hence the information provided is an important contribution to evacuation and contingency planning.

Additionally the integration of presented findings in community awareness and preparedness efforts helps to raise disaster knowledge and risk perception. People can learn about the approximate arrival times of potential tsunamis affecting their regions, what their potential evacuation time is and where tsunami safe areas are located. This might foster the urgent need of quick/direct tsunami response (evacuation action) at the local level. Highly important in terms of local level tsunami response is trust and believe in tsunami warnings and information issued by the warning centre. The link of warning information provided from the national level and the knowledge and implications of this information at the local level is crucial and needs continuous attention within disaster preparedness efforts. Tying national warning centre definitions (e.g. warning level information) to information and products derived from the presented work is seen to help understanding and to directly relate warning information to local disaster management implications.

3.5.1 Risk of evacuation failure product (detailed)

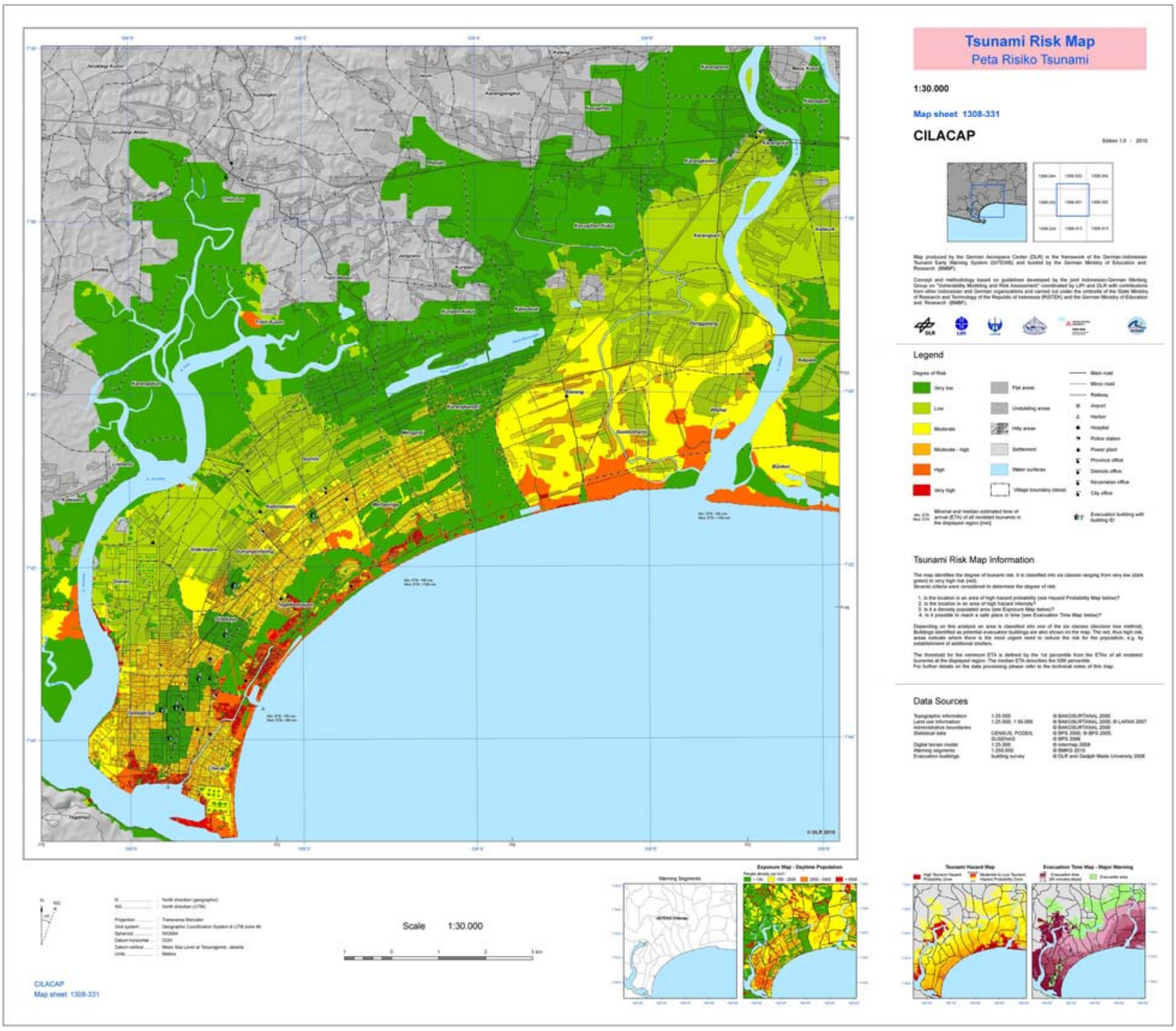


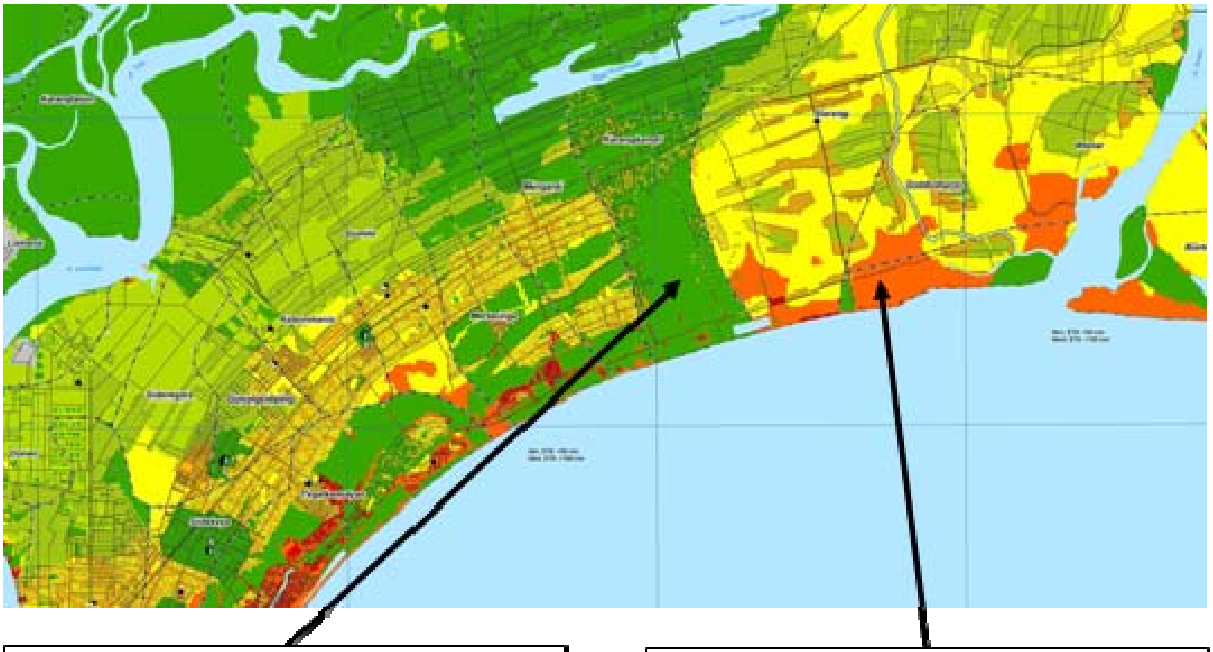
Figure 54: Detailed Risk map Cilacap (example)

Map description and results

Basically, the map contents in the tsunami risk map of a scale of 1 : 25 000 correspond to the coarse map of a scale of 1 : 100 000. Main difference is the consideration of the ‘hazard intensity’ using modeled flux values in the tsunami hazard assessment (see the Technical Guideline document for details) as further input parameter for the detailed risk map presented here. The hazard intensity allows a characterization of the tsunami impact with respect to the estimated force impacting people and buildings. The setting of thresholds allows a tsunami impact zoning and therefore, in combination with the other input parameters, a more detailed assessment of the tsunami risk.

Map application

There are two different points of view on tsunami risk. On one hand, there is the planner’s or the authority’s perspective, which focuses on risk hotspots. A planner needs answers to questions like “Where are areas with insufficient evacuation possibilities?”, “Where are additional shelters needed?” or “Where might emergency aid be most needed in case of a tsunami and for how many people?”. The population and also critical infrastructures have a high importance as planners need to consider the entire population at risk and organize risk reduction strategies accordingly. On the other hand, there is the perspective of an individual who focuses on their personal risk for life and property. Additionally, this individual perspective also applies to planners who focus on single infrastructures considering the question of the risk at a location where a building or road is planned. The purposes of risk products for planners as well as for individuals comprise both pre-disaster (preparedness and prevention phase) and post-disaster (emergency response and recovery phases) applications.



Area with moderate hazard probability and tsunami intensity (flux) but low population density and good evacuation capability
→ **low risk**

Area with high hazard probability, high hazard intensity (flux), moderate population density and bad evacuation capability
→ **high risk**

Figure 55: Example of areas with different tsunami risk

The detailed risk map available for the GITEWS pilot areas covers more the planner’s interests, as a strong emphasis is placed on the population, its exposure and evacuation capability. The map shown in Figure 54 is a result in which the calculation of people’s evacuation capabilities considers both horizontal and vertical evacuation possibilities. Areas where evacuation is likely to be successful, i.e. an evacuation building or area can be reached within the available time, are reflected as low risk areas (dark green, see Figure 54 and 55). Logically, these areas are subject to great variation depending on the amount of time available.

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