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Rapid Assessment of Potential Impacts of a Tsunami

Lessons from the Port of Galle in Sri Lanka

by Juan Carlos Villagrán de León

SOURCE

'**S**tudies **O**f the **U**niversity: **R**esearch, **C**ounsel, **E**ducation' - Publication Series of UNU-EHS

No. 9/2008

The European Commission and the Governments of Finland, Germany, Japan, Netherlands, Norway and Sweden have contributed generously - through the UN Flash Appeal for Indian Ocean Earthquake-Tsunami 2005- to support the UN/ISDR coordinated initiative: "Evaluation and Strengthening of Early Warning Systems in countries affected by the 26 December 2004 Tsunami

UNU Institute for Environment and Human Security (UNU-EHS)
UN Campus
Hermann-Ehlers-Str. 10
D-53113 Bonn, Germany

Cover design by Gerd Zschäbitz
Copy editor: Ilona Roberts, Abigail Weiss
Printed at Paffenholz, Bornheim, Germany
1. edition, 1000 copies, June 2008

ISBN: 978-3-939923-10-7 (printed version)
ISBN: 978-3-939923-11-4 (electronic version)
ISSN: 1816-1154

SOURCE

'Studies of the University: Research, Counsel, Education'

Publication Series of UNU-EHS

No. 9/2008

Acknowledgements

This project, as many conducted in the wake of the 26 December 2004 Indian Ocean tsunami, benefited from the support provided by many institutions and persons. The author would like to extend his sincere thanks and appreciation to:

Mr Lalith Chandrapala, Deputy Director of Meteorology and Coordinator of the Technical Committee on Early Warning and Disaster Management; Mr Sarath Weerawarnakula, former Director of the Geological Survey and Mines Bureau of Sri Lanka and member of the Technical Committee on Early Warning and Disaster Management of Sri Lanka; and to Professor S. S. L. Hettiarachchi of Moratuwa University and Member of the Science and Technology Foundation of Sri Lanka for their support throughout the project in Sri Lanka.

Mr Srimal Samansiri of the United Nations OCHA Humanitarian Information Center in Galle, who contributed through the elaboration of the maps used in this report, as well as for the GIS work carried out during the project and to Ms Inés Hinsberger and Mr. Jakob Rehbach for the adaptation of such maps to the format presented in this document.

Ms Stefanie Dannenmann, Ms Luna Abu-Swaireh, Mr Yuichi Ono, Mr Reid Basher, and Mr Douglas Patie for their continued support during all stages of the project.

Ms Carlota Schneider, Ms Suzanne Lenz, Mr Yuichi Ono, and in particular Mr Alexander Fekete for revising the manuscript and offering excellent suggestions regarding how to improve it. Special thanks to Dr. Laura Kong, Director of the International Tsunami Information Center and Dr. Patricio Bernal, Executive Director of the Inter-governmental Oceanographic Commission of UNESCO for their valuable comments and suggestions regarding the proposed model.

The staff within UNU-EHS who supported these efforts during the project and provided the necessary logistical support for this research to be carried out both in Sri Lanka and in Germany.

The Platform for the Promotion of Early Warning of the International Strategy for Disaster Reduction, (PPEW-ISDR), for supporting these efforts in Sri Lanka through the Flash Appeal Programme.

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About the Author

Juan Carlos Villagrán de León holds M.A. and Ph.D. degrees in experimental condensed matter physics from the University of Texas in Austin where he was a Pre- and a Post-Doctoral Fellow of the Robert A. Welch Foundation. Within UNU-EHS, he heads the Risk Management Section, where he conducts research focusing on the identification and systematisation of root causes and factors which are leading to the generation of risks in developing countries; as well as on issues related to early warning systems. His interest in the topic of natural disaster reduction began in 1993 supporting the *Guatemalan Disaster Management Agency* (CONRED) and the *Central American Coordination Centre for Natural Disaster Prevention* (CEPREDENAC) on issues of early warning and risk management. His research in Asia and Latin America has led to the development of methodologies for vulnerability and risk assessment. In addition to his research activities, Juan Carlos contributes to the strengthening of institutional capacities in these topics through seminars and training programmes conducted by UNU-EHS; and to higher education through contributions to academic programmes at the Master and Ph.D. levels. Juan Carlos is the author of several publications in Spanish and English languages on topics like risk assessment, risk management, and early warning.

Foreword

The 26 December 2004 Indian Ocean tsunami was one of those very rare, but catastrophic, events which displayed the continental nature of such hazards. In terms of fatalities, this tsunami is at the top of the list at the global scale along with earthquakes in the People´s Republic of China in 1927 and 1976. In Sri Lanka, a country exposed to few hazards, this tsunami provoked the worst disaster in its history, killing over 35,000 inhabitants and affecting over a million people in coastal areas throughout the country. As any other large disaster, the tsunami provoked extensive losses which manifested themselves in a variety of sectors. However, this tsunami offered an opportunity to dimension the multi-faceted impacts of such events in coastal cities and communities.

Supporting the efforts of the international community towards the establishment of the Indian Ocean Tsunami Early Warning System, Academic Officers of UNU-EHS embarked on a multi-disciplinary effort to measure the impacts of the tsunami in Sri Lanka and to identify the complex nature of vulnerability in coastal communities of this country, particularly in the city of Galle. Under the umbrella of the UN Flash Appeal for Indian Ocean Earthquake – Tsunami 2005, UNU-EHS provided support to the Sri Lankan Disaster Management Centre, in particular to the Technical Committee on Tsunami Early Warning set up by the government as part of the efforts toward the establishment of the Indian Ocean Tsunami Early Warning System.

Under the motto of the United Nations University, "Advancing Knowledge for Human Security and Development", UNU-EHS has focused its attention on environmental hazards which have a direct impact on human security. Efforts carried out by Dr. Joern Birkmann with the support of colleagues in Sri Lanka and Germany focusing on the vulnerability and coping capacities of people in the port of Galle have been summarized in the recent SOURCE publication "Rapid Vulnerability Assessment" edited by Dr. Birkmann. Similar efforts have been carried out in urban and rural areas by Dr. Fabrice Renaud focusing on the environmental component of vulnerability. Parallel efforts by Dr. Juan Carlos Villagrán de León focusing on the strengthening of early warning capacities in the district of Galle in Sri Lanka led to this publication.

Considering the need to assess potential impacts of tsunamis present in many coastal cities and ports, particularly in the case of developing countries where data on hazards and vulnerabilities may be scarce or inexistent, this publication outlines an approach to identify and assess potential impacts in a variety of sectors of development such as health, education, industry, commerce, telecommunications, transportation, lifelines, and government services. The use of such information concerning potential impacts is essential for the elaboration of emergency and contingency plans by municipal authorities and disaster managers. As such, this publication is essential reading material for those interested in emergency preparedness, risk management, and early warning. Praxis-oriented and example-based, the present work by Dr. Villagrán de León provides an excellent entry point into the complex processes related to the development of scenarios of impacts or events such as tsunamis which can disrupt the day-today activities of any society.

Janos J. Bogardi
Director UNU-EHS

Foreword

The Indian Ocean tsunami was an awakening call regarding the threat of tsunamis for coastal populations. The losses of life and property were immense. The immediate and generous response of people and nations of the world to this tragedy was swift and because of its magnitude had no precedent in the history of humanitarian operations of the UN. The tsunami showed us nature at its worst and humanity at its best.

Since December 2004, the UN system started to build an effective tsunami system for the Indian Ocean and to extend that protection to all oceans of the world; after all, tsunami hazards exist to a different degree in all ocean basins. Much has been done and we, in the Intergovernmental Oceanographic Commission, are extremely satisfied contributing our accumulated experience from the Pacific Ocean Tsunami Warning System to this collective effort. Since April 2005, there is an alert system linking all nations of the Indian Ocean to existing tsunami warning centers in Hawaii and Tokyo. Since July 2006, there is a new early warning network operating there, owned and operated by the nations of the Indian Ocean. Many countries are improving their capabilities to issue warnings to their populations and nations are sharing real-time data and information, helping to mutually enhance those capabilities.

However, there is a weak link in the chain of actions that needs to be in place to provide effective protection to populations. A timely tsunami warning needs to be followed by an effective emergency response. Exposed populations need to react in a few minutes and take appropriate actions. This emergency response cannot be improvised and needs to be prepared ahead of time. Everybody needs to know exactly what to do when the emergency arrives. Local communities, as well as large cities, need to have concrete plans and their populations fully informed. Authorities must know that they can take action without creating an additional risk if an evacuation needs to be announced.

The assessment of risk is the first stage of the development of an appropriate emergency response. Although numerical modeling can produce a precise map of the inundation caused by a tsunami, in many cases this information is not readily available and it will take some time to have it for all coastal regions.

This is why this paper by Juan Carlos Villagrán is so important and useful now, when the memory of the tsunami is still alive in communities. Juan Carlos, as part of the team of the United Nations University, has been involved in the field work since the first day of the tsunami response organised by the United Nations. His work in Galle prompted him to develop a practical tool to guide the actions of local authorities and local communities in their efforts to assess the risk of tsunamis and to design appropriate actions. It is a hands-on approach, simple but effective, since it allows the identification of priorities and the assignment of the scarce resources available to maximize an effective response. During the writing of this paper, I remember him mentioning to me some of the practicalities he was considering: The alert will arrive by radio to the police station. But what if an evacuation is issued at night? How can we alert the population? How long will it take? How many police cars equipped with loudspeakers need to be available? Which is the optimal route for each of those police cars to maximize coverage? This handbook should be an extremely useful tool, teaching through examples to translate the rather abstract terms of "risk" and "vulnerability" into concrete terms and actions. It is not a theoretical handbook. It is a book that, nurtured by the experience, proposes a simple "what-needs-to-be-done" approach.

It gives me great pleasure to present this contribution of the UNU to all those working in emergency preparedness at the community level and therefore contributing to making those communities safer from the risk posed by a tsunami hazard.

Patricio A. Bernal
Executive Secretary of the Intergovernmental Oceanographic Commission
Assistant Director-General of UNESCO

TABLE OF CONTENTS

Abstract

This document presents a simple approach to elaborate a scenario regarding the potential impacts of a tsunami in a city exposed to such a hazard. The approach has been tailored to span eleven typical development sectors which are present in every city such as health, education, housing, life-lines, transportation, telecommunications, industry, government, etc.

The development of this approach was carried out as part of the project "Strengthening Early Warning Capacities in Sri Lanka", which was executed between May 2005 and September 2006 by the *Institute for Environment and Human Security of the United Nations University* (UNU-EHS). This project, under the umbrella of the Flash Appeal Program, was designed to complement the efforts of UNESCO-IOC and the Indian Ocean countries aiming at:

- Strengthening capacities on early warning at the national level;
- Contributing to the efforts to strengthen people-centred, end-to-end, and efficient early warning capacities in the coastal city of Galle in Sri Lanka.

From the point of view of early warning and disaster management, the document aims to provide an overview of potential impacts related to a tsunami in the city. It is intended to be employed by the District-Level Disaster Management Centre, so that emergency plans can be adapted with such information. The approach complements earlier work carried out within this project focusing on the assessment of vulnerability, the identification and demarcation of evacuation routes, and means to ensure that the warnings are transmitted to the most vulnerable groups within the city, particularly hospitals, nursing schools, schools located close to the shore and densely populated areas also close to the shore.

The approach has been developed considering the typical situation of cities in developing countries where data may be either inexistent, not accurate enough to carry out a precise risk assessment, or there are limitations regarding the level of training of personnel who may work within the disaster management committees in such cities. In this respect, the approach trades of the precision in the numerical estimates which emerge as an outcome of risk assessment for practicality in carrying out such scenario assessments. As such, the approach should be considered as providing a general overview of potential impacts which may be caused by a tsunami rather than a very precise outcome, which can only emerge if data of sufficient resolution and accuracy are available. Nevertheless, the strength of the approach can be seen from three points of view:

- It has been developed to highlight the potential impacts of a tsunami which span different sectors present within any city.
- It includes not only potential impacts to infrastructure, but also with respect to people, functional and economic aspects within each sector.
- It allows the user and the emergency management committee at the city level to understand some of the linkages among sectors when a tsunami impacts a given city.

The document includes a set of matrices to elaborate the scenarios for different sectors, as well as examples that compare the proposed outcomes with the impacts provoked by the 26 December 2004 tsunami. The comparison allows the reader not only to visualize how the scenario matrices are to be used, but also to display the strengths and weaknesses of the proposed method.

1. Introduction

The devastation caused by the 26 December 2004 tsunami in several Asian nations has exposed many facets of risk within coastal communities of all sizes related to these large, infrequent events. From collapsed housing infrastructure, communication networks, lifelines, damaged health centres and tourist facilities, to the nearly full destruction of traditional fishing capacities and local commercial outfits; what emerged is the fragility of livelihoods, processes, and services with respect to such events. Livelihoods, those ways in which people combine their capabilities, skills, knowledge, and resources at their disposal to carry out the activities which are necessary to sustain a way of life, are interwoven in coastal communities. Fishing communities interact with the local commercial sector and with the tourist sector in markets and small restaurants. If recovery has to take place in coastal communities which have been destroyed or damaged by a tsunami, new models of development are required to ensure that the next tsunami will have a smaller impact on such communities and their livelihoods. At this point, it is important to understand not only the vulnerabilities that lead to such catastrophic losses and fatalities, but also the processes which lead to these vulnerabilities. Those processes, implicit in the livelihoods, are not allowing people to achieve sustainable development.

Considering the fact that many coastal communities are permanently exposed to risks associated with tsunamis and other coastal hazards, it is imperative to use the opportunity created by the 26 December 2004 tsunami to develop frameworks and methodologies to conduct risk assessments with the purpose of identifying measures to be implemented to reduce existing risks, or to enhance the capacity of the population to respond efficiently in case a warning is issued to minimise the impacts of an event with the aid of scenarios related to potential tsunamis of various magnitudes. This rare event offered opportunities for researchers[1] from different disciplines to uncover obvious and hidden vulnerabilities associated with tsunamis with the purpose of identifying means to reduce them and sharing lessons learned with other coastal communities located along the coasts of the Pacific Ocean and the Caribbean and Mediterranean Seas, where tsunamis also can take place. This document is an example of such an outcome, where a methodology is being presented to elaborate scenarios of impacts for tsunamis of disastrous proportions based on systematised observations of damages and destruction provoked by this particular tsunami. The document focuses on the development of a scenario at the level of a city spanning many sectors typically present within a city. The outcomes from such scenarios should provide emergency managers and municipal authorities with information regarding potential fatalities, injuries, losses, as well as interruptions in services and lifelines in case a tsunami impacts a given city.

This approach is put to the test in the port of Galle, a large coastal city located in the southwestern region of Sri Lanka which was severely affected by the 26 December 2004 tsunami. The proposed outcomes in the scenario are compared with observed damages as a consequence of this tsunami in relation to fatalities, injuries, destruction or damage of infrastructure, lifelines, and disruption of institutional processes and social services. While the approach is successful in forecasting potential impacts which agree with observed impacts in some sectors, it is unsuccessful in other sectors due to its simplicity. In particular, the coastal geomorphology of some parts of this city enhanced the interaction of tsunami waves leading to increases in damages and losses.

1 The special issue III of the journal *Earthquake Spectra,* published in June 2006 by the Earthquake Engineering Research Institute, EERI, contains a systematisation of damages spanning lifelines, critical facilities, and infrastructure for several countries which were affected by the 26 December 2004 tsunami.

2. Risks and Scenarios Related to Tsunamis at the City Level

Considering the framework proposed by the author (Villagrán, 2001) in terms of risks preceding disasters and being composed of *hazards, vulnerabilities,* and *deficiencies in preparedness* it can be stated that coastal communities are at risk with respect to tsunamis because:

- *such coastal communities are permanently exposed to a tsunami hazard;*
- *such communities often employ frameworks of development not properly adapted to this tsunami-hazard, and therefore such frameworks allow the establishment of vulnerable social, technological, and institutional processes, as well as services in high-hazard areas;*
- *as tsunamis are rare, traditional building codes do not target such hazards, and thus vulnerable infrastructure is constructed on a regular basis; and*
- *there is a lack of an efficient, end-to-end early warning system to minimise fatalities, injuries, and material losses with respect to tsunamis.*

Figure 1

A framework for risk spanning hazard, vulnerability, and deficiencies in preparedness

For example, if an efficient early warning system for tsunamis had been operational in the Indian Ocean, people in the city of Galle would have had sufficient time to evacuate to safe areas located inland, and the number of fatalities would have been greatly reduced (PPEW, 2006). In a similar fashion, if there had been zoning laws and strict building codes for infrastructure in coastal areas, the exposition and vulnerability of the built environment would have been reduced.

According to the proposed framework, risk assessment requires an assessment of hazards, vulnerabilities, and deficiencies in preparedness, and a subsequent integration of these three components. Hazard assessment in the case of tsunamis is difficult to carry out at this time due to the fact that it involves very complex hydrodynamic modeling of the tsunami wave as it enters land, and thus precise data regarding the topography of the coastal area and the built environment is required, along with bathymetry near the coastal area. In most cases, such surveys are inexistent, and thus the hydrological modeling cannot be carried out in a way which could yield precise results to characterize the hazard. Considering the lack of such information on hazards, one is forced to the use of very simple assessments just based on distances from the coast or elevation levels for the time being.

Vulnerability assessment is also complicated due to the social, economic, political, and institutional patterns of societies. As commented by several researchers (Villagrán 2006; Thywissen 2005; Alwang et al, 2001; Brooks, 2001), there is yet no standard model regarding how to carry out a vulnerability assessment, but there are many pilot case studies on the subject. One strategy to carry out such a vulnerability assessment is to analyse and systematise damages caused by a historical or a recent tsunami to develop guidelines.

In a similar fashion to other scientists who assign dimensions to the different facets of vulnerability (Wilchex-Chaux, 1993; Birkmann, 2006), the author (Villagrán, 2006) has proposed a framework to decompose vulnerability assessment in a city analysing how disasters can impact the various sectors which compose a society with typical sectors being: *housing, communications, education, health, energy, government, industry, commerce, finance, transportation, public infrastructure, environment, tourism, etc.* In addition, the framework proposes the differentiation within each sector in terms of five components: *human, physical, functional, economic, and environmental.* These components could be related to the factors which the *International Strategy for Disaster Reduction* (ISDR) has identified as increasing the susceptibility of communities to the impact of a hazard. A third dimension would target the scale of consideration spanning from the household level to the national level. Figure 2 represents this three-dimensional framework which is proposed to assess vulnerability.

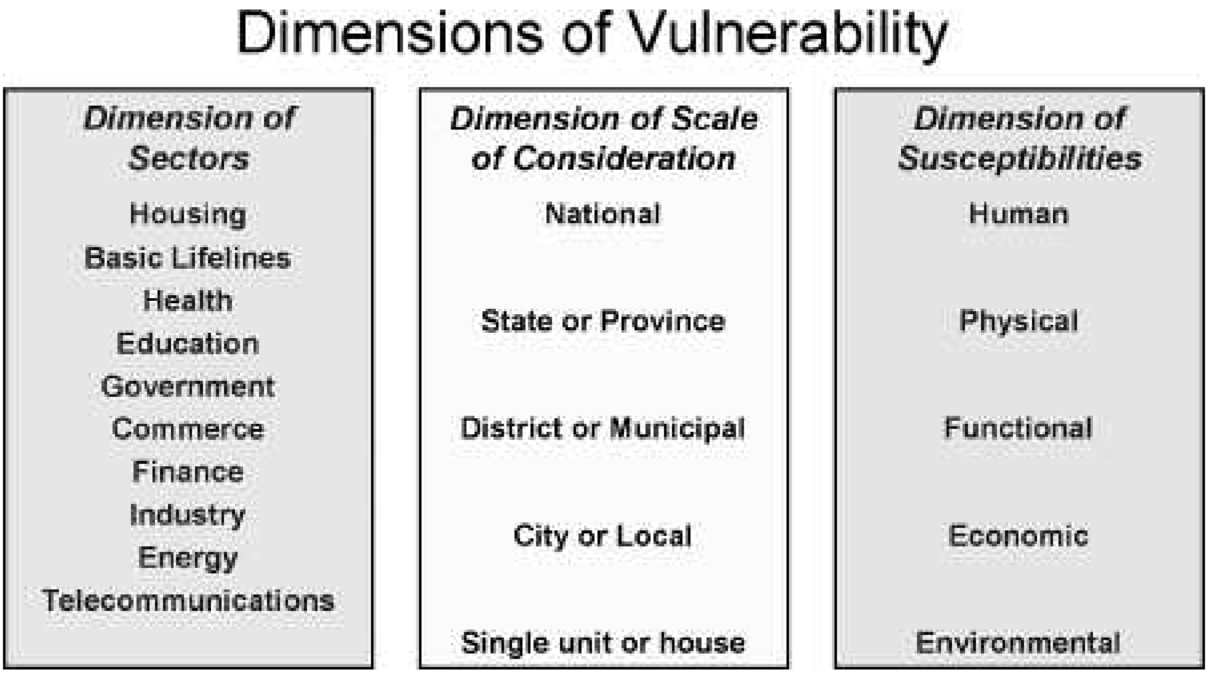

Figure 2

The approach employing sectors has been proposed by the author from the policy point of view because it promotes the assignment of responsibilities regarding the reduction of vulnerabilities to those private or public institutions in charge of each sector and spans various political-administrative levels, whether these may be government ministries or chambers of various kinds (chamber of commerce, industry, tourism, etc.). For example, it is the responsibility of the minister of education to assess and reduce the vulnerability of the public education system at the national level. In contrast, it would be up to the principal of a local school in a community to reduce the vulnerability of his school using resources at his or her disposal and requesting for this purpose whichever resources are required from the Ministry of Education.

Vulnerability assessment within the context of the proposed sector-approach must start by defining which hazard is to be addressed, then the sector, subsequently the geographical level at which the assessment is being made, and finally the types of susceptibility being assessed:

- *The **human** susceptibility relates to the predisposition of human beings to be injured or killed and encompasses issues related to deficiencies in mobility and differential weaknesses of human beings associated with gender, age or disabilities. In the case of tsunamis, there are reports of women, children, and elder persons who are more vulnerable than men (Guha-Sapir et. al, 2006; Birkmann, 2006).*
- *The **physical** susceptibility relates to the predisposition of infrastructure (buildings) employed by the sector to be damaged by an event associated with a specific hazard. In the case of tsunamis, one would investigate the fragility of infrastructure with respect to the impact of the tsunami wave. It is important to recognise the relevance of this component, as if a building collapses, it may kill or injure people, and many of the functional aspects may be affected even by a partial collapse.*
- *The **functional** susceptibility relates to the predisposition of functions, processes, or services which are required for the sector to function properly. It focuses on such aspects as the functionality of lifelines (energy, water, drainage, and communications) and their predisposition to be affected. This susceptibility would also include routine management operations and tasks carried out within each sector by staff members.*

- *The **economic** susceptibility is related to the predisposition to undergo economic losses and loss of income. For example, the income of fishermen impacted by the tsunami not only diminished because of the destruction of their fishing gear, but by the temporary avoidance of people to eat fish in several coastal communities after the tsunami.*
- *The **environmental** susceptibility relates to the predisposition of ecosystems to be damaged and services provided by the environment to be affected. For example, in many coastal communities, wells used to gather potable water were contaminated by the tsunami surge for several weeks, and thus water had to be distributed by several agencies for human consumption and household uses.*

As stated earlier, the assessment of vulnerability must be carried out separately at different levels. For example, the vulnerability of a particular hospital requires the analysis of the structural susceptibility of the building, a functional susceptibility comprising elements which are essential to the functionality and spans specialised medical equipment and processes such as the flow of gases, potable water, and electricity, as well as the storage of certain chemicals and medicines in controlled environments, the presence of trained staff and medical personnel, etc. In the case of private health institutions, an economic susceptibility must be considered. In the case of a hospital, self-mobility (in the expanded sense to include elderly, children, and other classifications) is an issue which has to be considered due to the higher susceptibility to injuries of patients temporarily hospitalised whose mobility is restricted due to their illness or treatment, or the intrinsic susceptibility of infants due to their lack of mobility while remaining in the hospital after birth. Additional issues related to administrative or management processes, as well as functional relationships within different sections or departments within institutions, should be considered (PAHO 2000). In extreme cases, problems related to environmental contamination may need attention, as in the case of spills of particular chemicals, solids and liquid waste, and those of biological origin.

Deficiencies in preparedness encompass such aspects as the lack of emergency committees or agencies to coordinate and execute the response; the lack of awareness of the population and agencies regarding the phenomena and probable impacts; the lack of early warning systems and the lack of emergency plans and resources to execute such a plan; as well as the lack of measures such as sea walls, levees, and other types of natural or artificial measures to minimise the impact of the tsunami wave within the city.

2.1 From Risk Assessment to Scenario Assessment

As described in the previous section, risk assessment spans the evaluation of hazards, vulnerabilities, deficiencies in preparedness, and the combination of these elements using a particular method. In contrast, a scenario would characterize potential impacts to be expected for a particular event of a certain magnitude. While susceptibility and deficiencies in preparedness are introduced as parameters to elaborate the scenario, the hazard is replaced by a potential event of a particular magnitude. In the case of a tsunami, such a potential event could be characterized in terms of its run-up elevation or the inundation distance, for example.

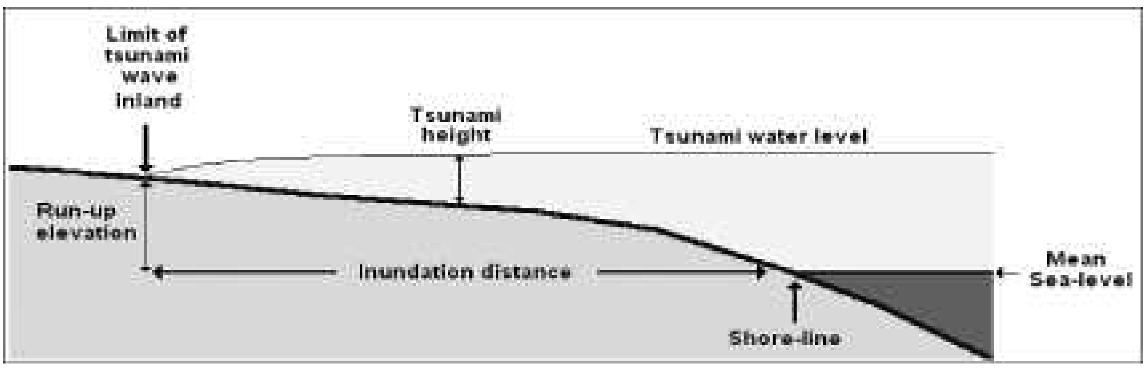

Figure 3

The run-up elevation represents the height a tsunami reaches above the sea level as it propagates inland.

The inundation distance represents the horizontal distance tsunami waves reach inland from the shoreline. However, from an engineering point of view, the height of a tsunami wave and its speed (momentum) are more relevant parameters in relation to potential destruction or damage of infrastructure and losses.

From the point of view of how to use the information gathered from such assessments, a risk assessment is more complete in the sense that it outlines how to approach the risks in a holistic fashion via hazard management through zoning laws and land-use norms; vulnerability management, in terms of building codes and social, political, institutional, and economic measures which reduce the vulnerability of cities; and preparedness through the establishment of a variety of measures, such as early warning, sea walls, and emergency planning. The use of scenarios is limited to assessing potential impacts and thus is more related to disaster preparedness, spanning the elaboration of emergency plans and the design and implementation of early warning systems.

3. The Proposed Approach to Elaborate Tsunami-Scenarios for Cities

The proposed approach to elaborate a scenario is based on a hypothetical tsunami characterised in terms of a run-up elevation from 4 – 8 meters, typical of what was observed in several areas of Sri Lanka, Thailand, and India during the 26 December 2004 tsunami. However, the model does not consider additional impacts generated by an earthquake. In this sense, it focuses on damages associated to long-range or tele-tsunamis. The approach is based on the definition of buffer zones spanning 200 meters from the shore, in such a way that the segment of the city located within the 0 – 100 meter buffer zone will experience tsunami heights two meters or higher with respect to the level of the ground, leading to severe damage or destruction, as well as fatalities. In contrast, in the segment located between 100 meters and 200 meters from the shore, the wave height would be lower, leading to moderate damages, and people would only be injured, not killed. The selection of the 100 meter buffer zones stems from its practicality when there is no precise hazard information or hydraulic modeling regarding how such a tsunami may propagate within the city. In this context, three levels of exposure are then proposed:

High exposure – geographical region located inside the 100 metre buffer zone

Medium exposure – geographical region located between the 100 and 200 metre buffer lines.

No exposure – geographical region of the city located inland, outside the 200 metre buffer zone.

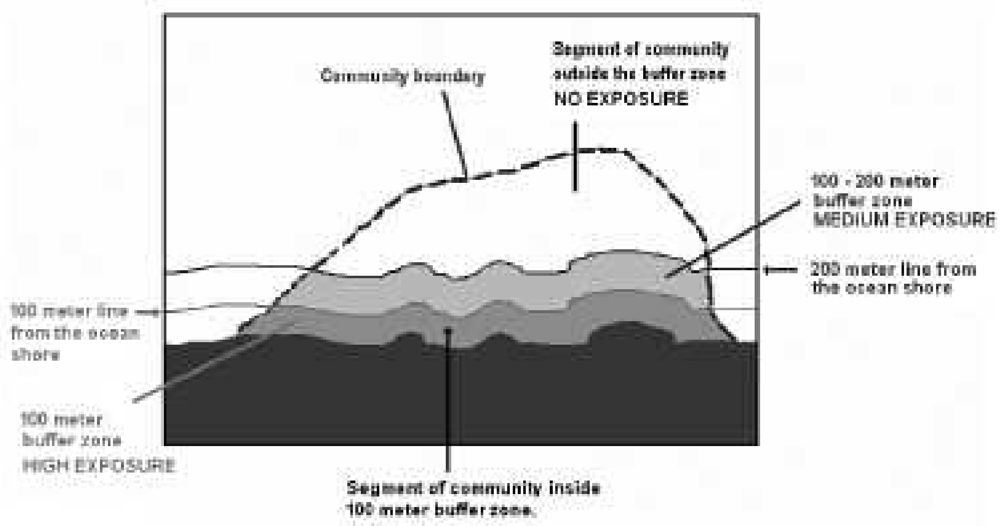

Figure 4

With respect to vulnerability, the proposed approach focuses on dispersing the city into sectors, and identifying four different types of susceptibilities and deficiencies in preparedness for each sector according to simple guidelines via the use of a single or a two-level scale.

The three elements **(exposure, susceptibilities,** and **deficiencies in preparedness)** are combined through simple products to elaborate the scenario. Matrices have been developed and included in the document, as well as examples presenting how such matrices are employed to elaborate the scenarios associated to each particular component within the sector being addressed.

3.1 The Port of Galle

The Port of Galle was the most important port of Sri Lanka until 1873, when a harbour was constructed in Colombo. It gained importance in the 12th century, and was visited by the Chinese in the year 1411. By 1505, the Portuguese had conquered the port, and later it was conquered by the Dutch in 1640. Between 1640 and 1796 the port became an important regional trading center for the Dutch. In 1796, the country was ceded to the British and became independent in 1948. The city of Galle has thrived ever since, and continues its tradition as a port. Capital to the Southern Province, its population according to the recent 2001 census is at the order of 91,000 inhabitants. Historically, its urban growth was aligned with the coastal highway connecting the port with Colombo to the north and Matara to the west, but in recent decades, it has also grown inland. Map 1 presented on page 86 displays some of the topographic features of the city of Galle, including the natural bay and the harbour which now houses the port facilities. The map also displays the 100 and 200 meter coastal buffer lines as dotted lines.

3.2 The 26 December 2004 Tsunami in the Port of Galle

The port of Galle was heavily impacted by the tsunami. Nearly 900 people lost their lives within the city, and almost one thousand people were injured during the event. In relation to the housing sector, more than one thousand houses were destroyed and more than 2,600 houses were damaged, leading to the need to carry out large reconstruction efforts in the months following the tsunami. The commercial sector was heavily affected, as well as the local fishing industry.

Most of the destruction occurred in areas exposed to the shore which had no protection in terms of sea walls or levees. However, the surrounding wall protecting the fort proved to be very successful in preventing destruction or damage to infrastructure inside such a fort. Nevertheless, the wavelike nature of the tsunami in areas behind the fort and behind the port enhanced the pattern of destruction. In particular, the main bus stand within the city was heavily destroyed, and buses were piled up against a two-storey facility. Map 2 shown on page 87 shows which coastal areas were inundated to depths more than 3.5 metres deep.

4. Housing Sector

4.1 Physical – Structural Component

This component of the scenario is associated with the predisposition of houses to be destroyed or damaged as a consequence of being impacted by a tsunami. Such a component is associated with the location of the houses with respect to the coast **(level of exposure),** as well as factors associated to their construction **(susceptibility),** and any measures implemented either in the ocean or in the shore to minimise the run-up of a tsunami wave, such as sea walls, concrete or stone dykes or levees, mangrove protection measures, or similar natural protection measures **(deficiencies in preparedness)**.

Physical or Structural Susceptibility

The structural susceptibility of houses within a city depends on parameters such as the type of building materials employed, the engineering design, and the building technique employed[2]. However, only with a detailed inspection can one determine the susceptibility of each house considering these three parameters. Thus, for a rapid elaboration of the scenario spanning a city, a compromise has to be made in terms of assuming all houses to possess the same degree of physical susceptibility.

Structural susceptibility = the same for all houses within the city.

Deficiencies in Preparedness

In this case, such deficiencies relate to the lack of dykes, sea walls, or mangrove forests which may reduce the impact of a tsunami wave in the coastal area of the city. Numerically, it is represented in terms of the proportion of the coast of a city that is not protected by such measures.

Elaborating the Scenario of Structural Damages for the Housing Sector

To elaborate the scenario of structural damages for any city in terms of houses destroyed or damaged in very general terms, the following approach is proposed:

Scenario of Impacts = Exposure x Structural Susceptibility x Deficiencies in Preparedness (E, S, DP) [1]

Combining **exposure, susceptibility** and **deficiencies in preparedness** via a simple product, the model proposes two outcomes:

- potential number of houses destroyed by the tsunami; and
- potential number of houses damaged by the tsunami.

The calculation of these outcomes is carried out determining the following data which can be obtained from the census data, from municipal authorities or from other sources such as water and electrical companies:

Total number of houses within the city	• Area within the 100 metre buffer zone • Area within the 100 metre – 200 metre buffer zone • Total area of the city	• Number of kilometres of coastal area within the city. • Number of kilometres unprotected with dykes, seawalls, etc.

The proposed matrix to elaborate this scenario is presented in table 1. The scenario is elaborated by multiplying the magnitude of the exposure (numerical factor) times with the proportion of area inside

2 For a broader discussion on impacts of the tsunami on houses and infrastructure, see the special issue III of the journal *Earthquake Spectra,* published in June 2006 by the Earthquake Engineering Research Institute, EERI.

the respective buffer zone times with the number of houses within the city times the proportion of coastal area not protected with sea walls or dykes. Impacts should be assessed separately for the high exposure area, for the moderate exposure area, and for the non-exposure area. As the approach proposes no impacts in the non-exposed area, the numerical factor corresponding to the exposure has been set to zero deliberately. The outcome of the calculation is an integer number expressing the potential number of houses which can be destroyed, damaged, and unharmed.

The degree to which the proposed outcome is similar to the impacts provoked by a tsunami is highly dependent on factors related to the topography of the city, in particular the location of hills inside the buffer areas, the geographical distribution of houses within the city, as well as factors related to the structural susceptibility of houses.

Table 1: Scenario Matrix – Structural Damages in the Housing Sector

Exposure			Structural Susceptibility	Deficiencies in Preparedness	Outcome	Comment
High exposure level	1	proportion of 100 metres buffer area to total area of city	Number of houses in city	Proportion of coastal area without dykes sea walls mangrove forest or forests of similar types, etc.	Number	This quantity expresses the potential number of houses which could be **destroyed**
Moderate exposure level	1	proportion of 100/200 metres buffer area to total area of city			Number	This quantity expresses the potential number of houses which could be **damaged**
No exposure	0	Proportion of area of the city outside the 200 metre zone			0	**No impacts** expected because houses are located outside the exposed area.

Example 1 presents results for the city of Galle.

Example 1: Potential Impacts on Houses in the City of Galle

The National Water Supply and Drainage Board states that in Galle city there are about 12,000 houses.

Area of city: **17.2 km^2**
Houses in the city: **12,000 houses**
Number of kilometres of coastline: **11.5 km;**

Area of 100 metre buffer zone: **1.33 km^2**
Area between 100 and 200 metre buffer lines: **1.36 km^2**
Number of kilometres coastline not protected: **8.9 km**

The scenario of impacts in the **high exposure area** is elaborated out as follows:

Exposure		Susceptibility	Deficiencies in Preparedness	Outcome	Comment
1	1.33 km^2 / 17.2 km^2	*12,000 houses*	*8.9km/ 11.5 km*	**718**	This quantity expresses the potential number of houses which could be **destroyed**

The numerical calculation is as follows: *1 x (1.33 km^2/ 17.2 km^2)* **x** *12,000 houses x (8.9km/ 11.5 km) =* ***718***

The scenario of impacts in the moderate exposure area is elaborated out as follows:

Exposure		Susceptibility	Deficiencies in Preparedness	Outcome	Comment
1	1.36 km^2 / 17.2 km^2	*12,000 houses*	*8.9km/ 11.5 km*	**734**	This quantity expresses the potential number of houses which could be **damaged**

The numerical calculation is as follows: *1 x (1.36 km^2/ 17.2 km^2)* **x** *12,000 houses* **x** *(8.9 km/ 11.5 km) =* ***734***

Remaining number of houses within the city which are not expected to be damaged = 10,548

According to the model, nearly 6% of the houses in the city would be destroyed and another 6% of the houses would be damaged. These outcomes emerge considering a uniform distribution of houses throughout the entire city.

According to statistics provided by the local *United Nations Volunteer* (UNV) aiding the District of Galle on issues of disaster preparedness during the time of the tsunami, the housing sector in the city of Galle experienced the following damages:

Completely damaged houses: 1061
Partially damaged houses: 2619

Analyzing these figures it can be concluded that the model underestimates the number of destroyed houses in this city and the number of damaged houses. Such a discrepancy could be explained considering three factors:

1. *There is a non-uniform distribution of houses within the city of Galle as the coastal area within the 100 metre buffer zone is used for commercial purposes and for activities related to the port and the government.*
2. *Not all houses possess the same degree of vulnerability. A visual inspection of damages in houses located in the coastal area suggests that 1-storey houses are more vulnerable than 2- or 3-storey houses.*
3. *There are hills inside the 200 meter buffer zone in areas of the city which were not affected by the tsunami.*

4.2 Human Component

This component addresses the weakness of human beings to be affected by a tsunami wave either through an initial, direct impact from such a wave as it is propagating within the city, or through the impacts related to its dynamical processes and the debris it carries.

Human Susceptibility

The approach proposes to treat all human beings as equally vulnerable in case of tsunamis within the context of this housing sector. A single category will be employed as it is expected that in any city, children and elderly persons are randomly distributed when it comes to housing, even though it is recognised that orphanages and elderly homes may concentrate such groups. Nevertheless, the case of children is considered specifically within the education sector, and the case of women is considered on aspects of technical education.

Human susceptibility = population living in the city regardless of gender or age or social group.

Deficiencies in Preparedness

Deficiencies in preparedness are linked to the inexistence of sea walls[3] (Sheth. A. et al, 2006), levees and to deficient operation of an early warning system, to the lack of emergency planning, and the capacity to evacuate people quickly to safe areas. The estimation of such deficiencies is carried out by splitting the component related to sea walls and the component related to the early warning system and emergency planning.

Deficiencies in preparedness Sea walls	= *A numerical fraction between 0 and 1 related to the proportion of coastline which is not protected with sea walls, levees, or dykes. The numerical value would be 1 if the entire coastline is not protected by a sea wall, a dyke or by levees.*
Deficiencies in preparedness EW & DP	= ***1*** *if no early warning system or emergency planning are in place.* ***0.5*** *if an early warning system is in place, but no emergency planning or vice versa.* ***0*** *if both an early warning system and emergency planning are in place.*

3 As mentioned by A. Sheth et al (2006), sea walls reduced the impact of the tsunami in several cities of India.

Elaborating the Scenario of Impacts on People within Houses

To elaborate the scenario for any city in terms of people injured or killed in houses, the following approach is proposed:

Scenario of impacts = Exposure x Human Susceptibility x Deficiencies in Preparedness

Combining these three parameters via a simple product, the model proposes two outcomes:

- Proposed number of people killed by the tsunami
- Proposed number of people injured by the tsunami

The calculation of these outcomes is carried out by using the following data which can be obtained from the census bureau or from municipal authorities.

Total area of city	Area within the 100 metre buffer zone
Coastline	Ratio of unprotected to the total length of coastline
Total population of the city	Area between the 100 and 200 metre lines

Additional data regarding early warning and disaster preparedness can be obtained from municipal authorities. The proposed matrix to elaborate the scenario is presented in table 2. The model proposes outcomes in terms of people killed, injured, or not affected at all. The dark-grey-shaded cells relate to those conditions which can lead to fatalities. The light-grey-shaded rows relate to those conditions which lead to injuries. In particular, the model proposes that in the absence of any preparedness measures, 20% of all people located within the 100 metre buffer zone would be killed by the tsunami, and 20% of all the people between the 100 and 200 metre lines would be injured. The selection of this factor is based on the fact that not all people who resided in the buffer zones were killed or injured during the 26 December 2004 tsunami, but only a small fraction. The selection of the particular percentage is based on a review of mortality rates in Sri Lanka.

The proposed approach assumes that if some degree of preparedness exists, then there would be fewer fatalities and injuries stemming from both high and moderate exposure areas. In the case when the entire city is protected by a sea wall or when the city is prepared through both early warning and disaster preparedness, the approach assumes no fatalities. When elaborating this scenario, one must keep in mind that the model has been set up to provide an estimation of the number of people which could be killed or injured in the entire city, and not an exact figure, which could only be estimated by analysing in very precise details the demographics of a particular city, the precise susceptibility of physical infrastructure, as well as the dynamics of the population within coastal areas.

To calculate the impact in the highly exposed area, one has to multiply directly the numerical values corresponding to the proportion of this area with respect to the total area of the city; the susceptibility, which is calculated as 20% of the total population of the city; the proportion of coastal area unprotected by seawalls, levees or dykes, and then the numerical coefficient (1, 0.5, or 0) associated with the current situation in relation to capacities related to early warning and disaster preparedness. The reduced matrix in the case of the **high-exposure** area is presented in table 3 and in table 4 for the case of the **moderate-exposure** area.

Table 2: Scenario Matrix – Casualties and Injuries in Houses

Exposure			Human Susceptibility	Deficiencies in Preparedness		Outcome	Comment
				Sea-walls, dykes, and levees	Early Warning and Emergency Planning		
High exposure level	1	Proportion of 100 metre buffer area to total area of city	20% of the number of people in the city	Proportion of coastal area without dykes, sea-walls, mangrove forest or forests of similar types, etc.	**1** (no early warning system and no emergency planning or preparedness in place)	Number	This quantity expresses the potential number of people **killed**.
					0.5 (either early warning system or emergency planning or preparedness in place)	Number	This quantity expresses the potential number of people **killed** as well as the number of people **injured**.
					0 (both early warning, emergency planning and preparedness in place)	0	**No** people **killed** or **injured** assuming people evacuate to safe areas.
Moderate exposure level	1	Proportion of 100/200 metre buffer area to total area of city			**1** (no preparedness at all)	Number	This quantity expresses potential number of people **injured**.
					1 (no preparedness at all)	Number	This quantity expresses potential number of people **injured**.
No exposure	0	Proportion outside the 200 metre line			Independent of degree of preparedness	0	**No people killed or injured** because this segment of people is outside the exposed area.

Table 3: Scenario Matrix – Casualties and Injuries in Houses in a High Exposure Area

Exposure			Human Susceptibility	Deficiencies in Preparedness		Outcome	Comment
				Sea-walls, levees	Early Warning and Emergency Planning		
High exposure level	1	Proportion of 100 metre buffer area to total area of city	20% of the number of people in the city	Proportion of coastal area without dykes, sea-walls, levees, etc.	**1** (no early warning system and no emergency planning in place)	Number	This quantity expresses the potential number of people **killed**.
					0.5 (either early warning system or emergency planning in place)	Number	This quantity expresses the potential number of people **killed** as well as the number of people **injured**.
					0 (both early warning, emergency planning in place)	0	No people **killed** or **injured** assuming people evacuated to safe areas.

Table 4: Scenario Matrix – Casualties and Injuries in Houses in a Moderate Exposure Area

Exposure			Human Susceptibility	Deficiencies in Preparedness		Outcome	Comment
				Sea-walls, Levees	Early Warning, Emergency Planning		
Moderate exposure level	1	Proportion of 100/200 metre buffer area to total area of city	20% of the number of people in the city	Proportion of coastal area without dykes, sea-walls, levees, etc.	1 (no preparedness at all)	Number	This quantity expresses potential number of people **injured.**
					1 (no preparedness at all)	Number	This quantity expresses potential number of people **injured.**

Example 2: Potential Casualties and Injuries in the City of Galle

At the time of the tsunami, Galle did not have an early warning system in operation, nor an emergency plan. Using the same data as in Example 1, the following results are obtained:

Exposure		Human Susceptibility	Def. in Preparedness		Outcome	
			Sea-walls, dykes	Early Warning & Planning		
1 (High exposure)	1.33 km²/ 17.2 km²	18,200	8.9 km / 11.5 km	1	**1,089**	**persons killed**
1 (Moderate exposure)	1.36 km²/ 17.2 km²	18,200	8.9 km / 11.5 km	1	**1,114**	**persons injured**

According to the local UNV-UNDP office set up in Galle to support emergency relief operations, as well as according to the census data, there were **767 deaths** reported in Galle, **996 injured,** and **28,840 people affected.** Comparing the proposed figures and the impacts provoked by the 26 December 2004 tsunami, it can be seen that the model overestimates the number of people killed for such a city by roughly a factor of 40%, and also overestimates the number of people affected by roughly a factor of 10%. An explanation for the discrepancy could be related to the fact that there is an uneven distribution of housing within the city, as there are very few houses located inside the 100 metre buffer zone, and it could also be related to the fact that not all houses display the same degree of structural vulnerability, in particular two- and three-storey houses next to the ocean would have suffered less damages than one-storey houses and people would have had the possibility to evacuate to the second and third floors during the tsunami.

As example 2 shows, there can be some discrepancies when using this model, which can only be reduced via a more detailed assessment of the situation.

4.3 Functional Component

This component is basically associated with the potential incapacities of houses to function as such after a tsunami due to the interruption of lifelines or the interruption of processes which are carried out within the house (sleeping, socialising within the family, self-care, cooking, etc.).

Functional Susceptibility

The functional susceptibility of a house is related to the capacity of the house to provide the services and functions required for people to live in such a house. For purposes of this assessment, it will be linked to availability of water and electricity and will be assumed as equal for all houses within the city.

Deficiencies in Preparedness

As in the previous case the deficiencies will be related to the lack of dykes, sea walls, or mangrove forests which may reduce the impact of a tsunami wave in the coastal area of the city. Numerically, it is represented in terms of the proportion of the coast of a city that is not protected by such measures.

Elaborating the Scenario of Impacts on Functionality of the Housing Sector

To elaborate the scenario of functional damages in any city in terms of this susceptibility in very general terms, one again has to multiply the numerical factor associated to exposure times a similar factor representing susceptibility times the corresponding factor for deficiencies in preparedness. The model proposes as an outcome the number of houses which will experience functional problems. The calculation of this outcome is carried out by using the following data, which can be obtained from the census data or from city authorities.

Total area of city	Area equivalent to the area inside the 200 metre buffer zone
Total number of houses the city	Percentage of coast not protected with a sea-wall, dyke, etc.

The proposed method to elaborate the scenario is presented in table 5.

Table 5: Scenario Matrix – Houses Experiencing Functional Problems within the City

	Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
1	Proportion of 200 metre buffer area to total area of city	Number of houses in city	Proportion of coastal area without dykes, sea-walls, mangrove forest or forests of similar types, etc.	Number	This outcome expresses the potential number of houses that will experience problems with their functionality.

Example 3: Potential Functional Problems in Houses within the City of Galle

The National Water Supply and Drainage Board states that in Galle city there are about 12,000 houses.

Area of city = **17.2 km²**

Area of 200 metre buffer zone = **2.69 km²**

Scenario = 1.0 x (2.69 km^2/ 17.2 km^2) x 12,000 houses x (8.9 km/ 11.5 km) = **1452 houses**

(Exposure: 2.69 km^2/ 17.2 km^2; Susceptibility: 12,000 houses; Def. in Prep.: 8.9 km/ 11.5 km)

According to statistics provided by the local UNV representative aiding the District of Galle on issues of disaster preparedness during the tsunami, there were 2,619 houses partially damaged. The model underestimates such a number by roughly 45%.

The model assumes that those houses located between the 100 and 300 metre buffer lines will experience difficulties associated to functionality (houses inside the 100 m buffer zone are expected to be destroyed). It also assumes that the area between the 100 and 300 metre buffer lines is equal to the area comprised between the ocean shore and the 200 metre buffer line.

4.4 Economic Income Component

This component is associated with the potential loss of income at the household level as a result of the tsunami.

Susceptibility

High susceptibility	*income is derived from activities which can be severely affected by a tsunami; for example, fishing and local commercialisation of such products; informal economy in public markets, etc.*
Moderate susceptibility	*income is derived from activities which can be indirectly affected by a tsunami. This could apply to some services within the city, such restaurants specialising in seafood, local produce markets, etc.*

Deficiencies in Preparedness

Deficiencies in preparedness would be linked to the inexistence of insurance mechanisms or limited access to such mechanisms.

Deficiencies in preparedness	*=* ***1***	*if there are no contingency measures in place.*
	0	*if there are contingency measures in place.*

Elaborating the Economic Income Scenario

This scenario combines **Exposure** (E), **Suscepatlibility** (S) and **Deficiencies in Preparedness**(DP). The procedure outlined in table 5 has to be applied again. In the case of Galle, this would lead to a figure of 1452 households experiencing such problems. According to information provided by a UNV volunteer in charge of disaster-risk management activities in the District of Galle, 1360 persons were affected because of unemployment. In this case, care must be taken when comparing the outcomes and impacts, as the number of people affected may not necessarily coincide with the number of households affected, due to the fact that within a single household several people may have been affected in terms of employment.

5. Lifelines

Water is a resource which is essential to life. Wells and rivers represent the typical sources of water for any city. Once extracted from the source, it normally undergoes some initial treatment, including chlorination, and is then distributed to end-users via a network of distribution pipes usually buried. The elaboration of the scenario associated with the use of water in a city spans the contamination of the sources and the disruption in its distribution.

5.1 Scenario of Damages to the Sources of Water

Susceptibility of Sources of Water to Contamination

Because of the nature of water as a liquid, it can be easily contaminated by different types of substances, either liquids or solids which are dissolved when coming into contact with water. Once contaminated, water must be treated again before it can be distributed throughout the city.

Susceptibility	*associated with possibility of contamination of water when it comes in contact with the surge provoked by the tsunami. It is proposed that water extracted from deep wells in closed loop systems and sealed piping systems is not vulnerable to contamination when compared with open sources, such as open wells and open river intakes, which can be easily contaminated by the tsunami surge (Tang et al, 2006 a).*

Deficiencies in Preparedness

Deficiencies in preparedness are related to the lack of measures which may be in place to isolate the sources of water from the tsunami surge to avoid contamination; or the incapacity to link to and use alternate sources located inland, far away from the coast, that are not exposed to the tsunami surge at all.

Elaborating the Scenario of Contamination of Sources:

Combining the three terms **(E, S, DP)** using equation [1] on page 16, the model proposes an outcome related to the proportion of water in cubic metres per second that can be made useless at the source as a consequence of its contamination if it comes in contact with the tsunami surge. The calculation of the outcome is carried out via determining data on the sources of water which can be obtained from city authorities or managers of the water supply department for the city. The proposed matrix to elaborate the scenario is presented in table 6.

Table 6: Scenario Matrix – Potential Contamination of Sources of Water

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Production in cubic metres per second in open wells, open rivers	1 (if no preparedness measures are in place).	Quantity	This quantity expresses the potential amount of the water which can be **contaminated.**
		0 if source is inside mountain or deep well		0	**No contamination** of the source is possible by the tsunami.
Moderate exposure level	1	Production in cubic metres per second in open wells, open rivers	0 (if preparedness measures are in place)	Quantity	This quantity expresses the potential amount of the water which can be **contaminated.**
		0 if source is inside mountain or deep well		0	**No contamination** of the source is possible by the tsunami.
No exposure level	0	Any type of source		0	**No contamination** of the source is possible by the tsunami.

The model proposes two possible outcomes: either the source is contaminated or not, depending on its location with respect to the 200-metre buffer line (Edwards, 2006); whether the source is susceptible or not and if there are preparedness measures in place to impede the contamination of sources. It is expressed in terms of the amount of flow of water which can be contaminated.

Example 4: Potential Impacts to Sources of Water in the City of Galle

According to the National Water Supply and Drainage Board, there are two types of sources employed to supply water within the city:

Main Source: river intake located far inland = 36,200 m^3/day.
Secondary source: deep wells located far inland = 800 m^3/day.

$$\textbf{Scenario of contamination} = \underbrace{0}_{\textbf{Exposure}} \times \underbrace{37{,}000\ m^3/day}_{\textbf{Susceptibility}} \times \underbrace{1}_{\textbf{Def. in Prep.}} = \mathbf{0\ m^3/day.}$$

For the city of Galle, it can be concluded that there is no scenario associated with contamination of the sources of water because the sources of water are outside the exposure area, far inland.

5.1.2 Functional Component

The functional component in case of the water lifeline is related to the possibility of an interruption in the supply of potable water to end-users in the city due to damage, destruction of the distribution network, or the incapacity to deliver water as pumping of water through the network cannot be achieved due to lack of electricity required by systems requiring electrical pumps (in contrast to systems using gravity to force water through the network).

Functional Susceptibility

The functional susceptibility in the case of water systems is associated with two elements: the networks to distribute water within the city and the source of energy required to pump the water through the network.

Susceptibility of network: associated with rupture or damage to distribution networks (Ballantyne, 2006 a), leading to leaks or incapacity to deliver water to the end users (buildings);

Susceptibility of process: associated with the incapacity to deliver water through the networks due to lack of electricity in case pumps are being used. Note that a gravitation distribution network would not require electricity; hence, in such a case, it would not be vulnerable. (Edwards, 2006)

Deficiencies in Preparedness

Deficiencies in preparedness would be related to the lack of sea walls or dykes to protect infrastructure within the city. In this case, such deficiencies in preparedness will be incorporated using two levels: *High* when there are no measures throughout the coastlines or *Low* when the entire coastline is protected.

Elaborating the Scenario of Functional Damages to the Network

To assess the functional damages of the network to distribute potable water in any city, one has to combine the three terms proposed before. The model proposes an outcome related to the possibility that water may not be delivered to the final user as a consequence of the disruption of water service due to damage or destruction of distribution networks or pumping stations. The calculation of the outcome is carried out via determining the following data, which can be obtained from authorities in charge of water within the city:

Segments of main delivery network in bridges   Need of electricity for pumping water through network

The scenario is elaborated using table 7. The method proposes two possible outcomes: either the network is unharmed, but unable to deliver water due to lack of electricity, or network is physically damaged in some segments (bridges) and will require rehabilitation and reconstruction.

Table 7: Scenario Matrix – Potential Damage to Network to Distribute Water within the City

Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	**High** (segments of network on surface in bridges)	**High** (if no sea-walls or dykes are in place)	Type	This outcome expresses the possibility of **damages to the water distribution system** if a segment of a network in a bridge is destroyed by a tsunami.
	Low (network requiring electricity)		Type	This outcome expresses the potential **temporary disruption** of delivery of water until electricity is restored.
Moderate exposure level	**High** (segments of network on surface in bridges)	**Low** (if sea-walls or dykes are in place to protect most of the city)	Type	This outcome expresses the possibility of **damages to the water distribution system** if a segment of a network in a bridge is destroyed by a tsunami.
	Low (network requiring electricity)		Type	This outcome expresses the potential **temporary disruption** of delivery of water until electricity is restored.
No exposure level	**High** or **Low** (any type of network)		0	**No disruption** in the delivery of water.

Of course, it is expected that these damages may have an impact on users which are located near the ocean shore.

Example 5: Potential Disruption of Water Service Within the City of Galle

A survey carried out by UNU-EHS shortly after the tsunami indicates that there are segments of the distribution lines which are exposed in bridges that are located inside the 100 metre buffer zone and only one small segment of the city is protected with a sea wall or dyke (2.6 km of 11.5 km). For the high-exposure area, the following results are obtained:

Exposure	Susceptibility	Def. in Prep.	Outcome
High	High (Segment of network in bridges)	High (No sea-walls in area of bridges)	Damages to the water distribution system

In case of the moderate exposure area, the following results are obtained:

Exposure	Susceptibility	Def. in Prep.	Outcome
Moderate	High (Segment of network in bridges)	High (No sea-walls in area of bridges)	Damages to the water distribution system

According to the National Water Supply and Drainage Board Office in Galle, the tsunami affected and damaged main distribution lines in areas near the coast on Galle Road and there were many leaks that had to be repaired. There is an estimate of about six kilometres of main distribution lines damaged. In addition, some segments of the distribution line located in bridges were also damaged by the tsunami and required intervention.

5.2 Scenario of Potential Damage to the Sources of Electricity

In modern societies, electricity is now an essential resource as machinery, household and office apparatuses, and processes use electricity. In general, electricity is generated in few facilities within a country and then distributed to urban and rural areas using a network of main stations, substations and high and low voltage transmission lines. As seen in the case of water, the assessment of a scenario will span both the sources associated to the production of electricity and the distribution networks.

Susceptibility of Sources

Considering the various options to generate electricity (hydro-electric, geo-thermal, nuclear, fossil-fuel driven), susceptibility will be classified as follows:

High Susceptibility	fossil-fuel-generating plants built on floating barges or platforms located in ports
Moderate susceptibility	All other types of generating plants (Scawthorn et al, 2006 a)

Deficiencies in Preparedness

Deficiencies in preparedness are related to the lack of measures which may be in place to isolate the power plants from the tsunami surge to avoid damage or destruction to the plant, or the incapacity to link to and use alternate sources located inland, far away from the coast, which are not exposed to the tsunami surge at all.

Elaborating the Scenario of Damages to the Sources of Electricity

To elaborate the scenario of damages for sources of electricity the approach combining the three terms **(E, S,** and **DP)** is employed. The model proposes an outcome related to the proportion of electricity that cannot be generated as a consequence of the tsunami. The calculation of the outcome is carried out via determining the types and location of electrical generating facilities, which can be obtained from the electrical company.

The proposed method to elaborate the scenario is presented in table 8.

Table 8: Scenario Matrix-Potential Damages to Sources of Electricity

Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	**High** (plants in barges or platforms in ports)	**High** (if no preparedness measures are in place).	**High impact**	This outcome expresses the **potential, long-term interruption of the electricity generation process** due to destruction of electric power plants.
	Moderate (other types of plants)	**Low** (if preparedness measures are in place)	**Moderate impact**	This outcome expresses the **potential, short-term interruption of the generation process** due to damage of plant.
Moderate exposure level	**Moderate** (other types of plants)		**Moderate impact**	This outcome expresses the **potential, short-term interruption of the generation process** due to damage of plant.
No exposure level	**Moderate** (other types of plants)		**No impact**	This is the number of plants that will not experience any damage associated with a tsunami.

The model proposes three possible outcomes: long-term interruption of electricity service due to destruction of plants; short-term disruption of this service due to damage to such plants; and no disruption of the service when plants are located far inland.

Example 6: Potential Impacts to Sources of Electricity within the City of Galle

According to the Ceylon Electricity Board and the Lanka Electrical Company, no electricity is generated within the city. Electricity for the city of Galle is generated in hydroelectric or thermal plants far inland (Ballantyne, 2006 b). Therefore, the scenario associated with damages to sources of generation of electricity is zero.

Scenario of generating plants = 0 x plants outside the city x High = 0 **– no damage to generating plants.**

5.2.1 Functional Component

As in the case of water, functional breakdowns in the context of electricity are related to the possibility that the distribution of electricity to end-users in the city is temporarily disrupted due to damage or destruction of main stations and substations, as well as the high-voltage and low-voltage transmission lines.

Functional Susceptibility

The functional susceptibility in the case of electricity systems is associated with two elements: the networks to distribute electricity within the city and the process of transformation of voltages in main stations and substations. In this case, the susceptibility is represented as follows:

Susceptibility of network:	associated with rupture or damage to transmission lines, leading to incapacity to deliver electricity to the end users (Tang et al, 2006 b; Ballantyne, 2006 b);
Susceptibility of the transformation process	associated with the potential damage of voltage transformers if they come in contact with the tsunami surge (high conductivity liquid).

Deficiencies in Preparedness

Deficiencies in preparedness would be related to the inexistence of sea walls, levees, and circuit breakers, which could be manually or automatically activated in the context of the tsunami early warning system in substations and main stations prior to a tsunami to minimise damage to equipment and short circuits and overload of transformers due to the high electrical conductivity of the tsunami surge.

Elaborating the Scenario of Impacts to Substations Within the City

To elaborate the scenario of impacts in the functionality of the sub-stations in any city one has to combine the three terms. The model proposes an outcome related to the disruption in the delivery of electricity to final users due to damages to such sub-stations. The calculation of the outcome is carried out via determining the number and location of sub-stations.

The proposed method to elaborate the scenario is presented in table 9.

Table 9: Scenario Matrix – Damage in Electrical Sub-Stations

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	**1** (all stations considered as highly susceptible)	**1** (if no preparedness measures are in place) **0.5** (if some measures are in place: either sea walls or circuit breakers and EWS) **0** (if all preparedness measures are in place)	Number	This outcome expresses the number of stations that can be destroyed, leading to **long-term** disruptions in the delivery of electricity to the city or some parts of it (weeks).
Moderate exposure level	1			Number	This outcome expresses the number of stations that can be damaged, leading to **short-term** disruptions in the delivery of electricity to the city or some parts of it (weeks).
No exposure	0			0	No impacts as stations would not be affected by the tsunami due to their location outside the exposed area.

The model proposes three possible outcomes: long-term disruption of the electrical service within the city due to extensive damage to sub-stations; short-term disruption of the electrical service within the city due to minor damages to the sub-stations; and no disruption of the service.

> ***Example 7: Sub-Stations Within the City of Galle***
>
> According to the Ceylon Electric Board, the two main substations in the city are located far inland. In addition, a visual inspection carried out by UNU-EHS in the year 2005 confirms the fact that the facilities are also located on top of small hills. Therefore, there is no possibility of these facilities being affected by the tsunami, thus, no scenario of short or long-term disruption of the delivery of electricity within the city is necessary. Map 3, on the page 88, shows the locations of these facilities within the city of Galle.

Table 10: Scenario Matrix – Electrical Distribution Network Within the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
1 High exposure level	Proportion of city in this area	**1** Any type of distribution network (concrete or wood posts)	Proportion of coastline not protected by sea-walls, dykes, levees, or similar.	Percentage	If the number is close to unity, there is a possibility of **long-term** disruptions in the delivery of electricity to some houses within the city (weeks)
1 Moderate exposure level	Proportion of city in this area			Percentage	If the number is close to zero, there is a possibility of **short-term** disruptions in the delivery of electricity to some houses within city (days)
0 No exposure	Proportion of city in this area			Percentage	No damage as distribution lines would not be affected by the tsunami due to their location outside the exposed area.

Elaborating the Scenario of Damages of the Electricity Distribution Network

The other component related to functionality in the context of electricity is the network of transmission lines which delivers electricity to all areas of the city. Table 10 on the previous page presents the matrix to elaborate the scenario with respect to this network.

The model proposes three possible outcomes:

- long-term disruption of the electrical service to houses near the ocean due to extensive damage to the delivery network;
- short-term disruption of the electrical service due to minor damages to such lines in the network; and
- no disruption of the service to neighborhoods.

Example 8: Potential Disruption of Electricity Within the City of Galle

The assessment of the scenario is carried out as follows:

Scenario for High Exposure Area: 1 x (1.33 km^2/17.2 km^2) x (8.9km/11.5km) x 100 = 6.0%

Outcome: long-term disruption of service for nearly 6% of the city in coastal areas.

Scenario for Moderate Exposure Area: 1 x (1.36 km^2/17.2 km^2) x (8.9km/11.5km) x 100 = 6.1%

Outcome: short-term disruption of service for nearly 6% of the city.

Scenario for area not exposed to tsunamis = No disruption of service for remaining 88% of the city.

According to a survey carried out by UNU-EHS in the city of Galle, electricity in areas away from the 200 metre buffer zone experienced short-term disruption of the service lasting between three and seven days. However, in large buildings located inside the 200 metre buffer zone, it took longer to re-establish the service as connections inside such buildings were affected by the tsunami. According to the Ceylon Electric Board, the network of low voltage transmission lines was destroyed along coastal roads within the 100 metre buffer zone, as well as within buildings, leading to the disruption in service lasting a few days for several segments of the city inland to about a week in segments of the city close to the shore.

While this model addresses those networks of transmission lines within the city, it does not address the network of high-voltage lines which may deliver electricity from the generating plant to the city, in particular, the segment of the network which lies outside the city. Therefore, the recommendation is to request the assistance of the electric company in completing the assessment through an in-depth analysis of the high voltage networks which deliver electricity to the city.

6. Health Sector

The health sector is responsible for activities carried out in facilities within the city to ensure the health of the population either in terms of preventive or curative medicine. Such activities include work carried out in hospitals and health centers, as well as administrative functions at the city level. Although the process covers private and public activities, the assessment will only span major facilities such as hospitals and administrative facilities.

6.1 Structural Component

Structural Susceptibility

As in the case of the housing sector, the structural susceptibility of hospitals within a city depends on parameters such as the quality of building materials, the engineering design, and the building technique employed. However, as the number of hospitals may be limited within a city, one can visit such hospitals and use the number of levels of the buildings to assess the degree of susceptibility as follows:

High structural susceptibility = one level building, ground level
Low structural susceptibility = hospital buildings spanning two or more levels

Deficiencies in Preparedness

In this type of scenario, such deficiencies relate to the existence of sea walls, dykes and other similar structures which could block the tsunami from affecting the hospital in relation to its structure.

Scenario of Structural Damages to Hospitals

To elaborate the scenario, of structural damages to hospitals within any city, the approach used for the housing sector is proposed. Combining **E, S,** and **DP,** the model proposes three outcomes:

- Proposed number of hospitals destroyed by a tsunami;
- Proposed number of hospitals damaged by a tsunami; and
- Proposed number of hospitals not damaged at all by a tsunami.

The calculation of these outcomes is carried out determining the number, type, and location of hospitals within the city, which can be obtained from the health department or from city authorities. The proposed scenario matrix is presented in table 11.

Table 11: Scenario Matrix – Structural Damages in Hospitals

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of hospitals in one-storey buildings only inside 100 metre buffer zone	1 If there are no sea-walls or levees in place in areas where hospitals are located 0 If there are protection measures in place.	Number	This outcome expresses potential number of hospitals **destroyed**
		Number of hospitals with several buildings which have one and two or more storeys inside 100 metre buffer zone		Number	This outcome expresses potential number of hospitals **damaged**
				0	No hospitals damaged
Moderate exposure level	1	Number of hospitals in one-storey buildings only inside 100 – 200 metre buffer zone	1 If there are no sea-walls or levees in place in areas where hospitals are located 0 If there are protection measures in place.	Number	This outcome expresses potential number of hospitals **damaged**
		Number of hospitals with several buildings which have one and two or more storeys inside the 100 – 200 metre buffer zone		Number	This outcome expresses potential number of hospitals **damaged**
				0	No hospitals damaged
No exposure	0	Any hospital outside the 200 metre line	Any type of preparedness	0	No damages associated with these facilities

As it can be seen, the model proposes that all hospitals which are only one-storey buildings and are located inside the 100 metre buffer zone will be destroyed or heavily damaged if there are no protection measures in place; whereas those hospitals which are multiple-level storeys will only undergo damages, but not total destruction even if there are no protective measures in place. In cases where there are solid protection measures in place, such as the sea wall surrounding the Fort of Galle, no structural damages are expected.

Example 9: Potential Impacts to Health Facilities Within the City of Galle

According to data provided by the Deputy Provincial Health Services Director of Galle, there are two national hospitals in the city of Galle, as well as several private hospitals and health facilities. A survey carried out by UNU-EHS after the tsunami in the city concluded that the national hospital (Mahamodera) and a small private hospital (Central Hospital) are located inside the 100 metre buffer zone. A health facility for children (Sambodhi Home) is located just inside the 200 metre buffer area and the other hospitals (both national and private) are located inland, several hundred metres or kilometres away from the coast. In addition, there are no seawalls protecting such hospitals.

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Central Hospital (one-storey)	1 (there are no protection measures in place)	1	1 hospital **destroyed**
		Mahamodera National Hospital (4 or more storeys)		1	1 hospital **damaged**
Moderate exposure level	1	Sambodhi Home Children's Home		1	1 facility **damaged**
No exposure	0	Karapitiya National Hospital and 3 other private hospitals		0	No damages associated with these 4 facilities

In the case of public hospitals, a post-tsunami damage assessment of the city carried out by UNU-EHS indicated that the Mahamodera national hospital and the Sambodhi Children's Home (orphanage) suffered damages, but were not destroyed. However, reconstruction efforts in the smaller Sambodhi Children's Home took months to complete. The small private hospital, a single-storey building, did not suffer structural damages, but was shut down for several weeks due to functionality problems associated with destruction or damage of its equipment. While the model correctly assesses the outcome for multi-storey hospitals, it does not yield the correct result in cases of one-storey buildings, which may be solid enough not to suffer structural damages or destruction. This results from the fact that the susceptibility classification is very crude. For a more precise susceptibility assessment, a structural engineer should be contacted to carry out such an assessment. Map 4, shown on page 89, displays the location of hospitals and health facilities within the city of Galle.

6.2 Human Component

Human Susceptibility

The susceptibility of hospitals when it comes to people is high, as patients can be considered a highly vulnerable group of people within any area.

Deficiencies in Preparedness

Deficiencies in preparedness are linked to the inexistence of sea walls, levees, the deficient operation of an early warning system, and to the lack of emergency planning, and capacity to evacuate people quickly to safe areas.

Deficiencies in preparedness	= ***1*** *if neither sea walls or levees nor an early warning system are in place.* ***0.5*** *if an early warning system is in place, but no sea walls or levees.* ***0*** *if both sea walls or levees and an early warning system are in place.*

Elaborating the Scenario

To elaborate the scenario of people injured or killed in the case of hospitals within any city, one has to combine **E, S,** and **DP.** The model proposes these outcomes:

- Proposed number of patients which could be killed or fatally wounded;
- Proposed number of patients injured; and
- Proposed number of patients which will not be affected.

Due to the fact that the number of patients within a hospital varies from day to day, the accurate number of patients is uncertain; thus, the model will use the number of beds in the hospital as a parameter to carry out the assessment, which can be obtained from the health office within the city. Table 12 is employed to elaborate the scenario.

Table 12: Scenario Matrix – Impacts to Patients in Hospitals

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Number of beds located on ground floor in hospitals with buildings 1, 2 or more storeys high	**1** If there are no sea walls or levees in place in areas where hospitals are located	**1** (no preparedness at all)	Number	This outcome expresses the potential number of patients **killed in hospitals**
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of patients **killed and injured in hospitals**
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** patients **killed** or **injured,** assuming they are evacuated to safe areas.
Moderate exposure level	1	Number of beds located on ground floor in hospitals with buildings 1, 2 or more storeys high	**1** If there are no sea-walls or levees in place in areas where hospitals are located	**1** (no preparedness at all)	Number	This outcome expresses the potential number of patients **injured**
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of patients **injured**
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** patients **injured,** assuming they are evacuated to safe areas
No exposure	0	Any facility, any number of beds	Any degree of preparedness and protection measures		0	No patients injured or killed.

Example 10: Hospitals within the City of Galle

Table 13 presents data on public and private hospitals as provided by the Medical Officer of Health of the city.

Table 13: Data on Hospitals Located Within the 100 Metre and 200 Metre Buffer Zones

Hospitals inside 100 m buffer zone	**Number of beds**	**Number of storeys**	**Number of beds on ground floor**
Mahamodera National Hospital (public)	215	4	54
Central Hospital (private)	9	1	9
Hospitals inside 100 - 200 m buffer zone	**Number of beds**	**Number of storeys**	**Number of beds on ground floor**
Sinbodhi Children´s Home		1	
Hospitals away from the ocean shore	**1480**	**3**	**493**

At the time of the tsunami, the city had no early warning system in place. In addition, hospitals were not protected by levees or sea walls. The model presupposes, then, that Mahamodera Hospital has 54 beds on the ground floor (215 / 4 = 54), and Central Hospital has nine beds; thus, the calculation would proceed as it follows:

Scenario (killed) = 1 x 63 patients x 1 = 63 patients could be killed

The proposed outcome stems from adding up the number of patients who are located on the ground floor.

If the number of beds located on the ground floor is not accessible, one may then divide the total number of beds in the hospital by the number of storeys of the building that houses the hospital and use this ratio as the number of beds on the ground floor.

6.3 Functional Component

Functionality at the city level is related to the capacity of people to find health services in the city, even in case of a tsunami. To assess this scenario, one has to link functional aspects with structural and administrative aspects. It will be assumed that if hospitals are destroyed or damaged, they cannot be functional until being repaired or reconstructed.

Functional Susceptibility

Susceptibility: The functional susceptibility of hospitals will be linked to the structural susceptibility of the buildings.

Elaborating the Scenario

To elaborate the scenario of the hospitals within any city which would experience functional problems, one has to use table 11. In this sense, the scenario associated to functionality will be strongly related to damage or destruction of infrastructure.

Example 11: Potential Functional Damages to Hospitals in the City of Galle

The distribution of hospitals facing functional problems in the city of Galle is as follows:

Public hospitals:

Scenario (destroyed) = 1 x 0 single-storey hospital = **0 hospitals destroyed**
Scenario (damaged) = 1 x (1 multi-storey hospital + 1 single-storey hospital) = **2 hospitals**
No damages = 1 x (1 multi-storey hospital (Karapititya) = **1 hospital**

Private hospitals:

Scenario (destroyed) = 1 x 1 single-storey hospital (Central Hospital) = **1 hospital**
Scenario (damaged) = 1 x 0 hospitals inside the buffer zone = **0 hospitals**
No damages = 1 x 3 multi-storey hospitals = **3 hospitals**

Therefore, it can be concluded that two out of three public hospitals can experience some difficulties with functionality, while one out of four private hospitals will experience difficulties with its functionality. However, due to the damages suffered by both national hospitals exposed to the tsunami (Mahamodera National Hospital and Simbodhi Children´s Home), these hospitals could not function as such during the days and weeks following the tsunami. All injured people were taken to Karapitiya National Hospital, which is very large and is located far inland.

Administrative Susceptibility

The administrative susceptibility of the health sector is related to those aspects or processes that are required at the city level to coordinate efforts regarding the provision of health services. Relevant parameters for this susceptibility at the city scale are:

- Processes that take place in this coordination office, such as bookkeeping, record-keeping, database management, etc.; and
- Procurement of medical supplies to health facilities in the city.

In this case, the susceptibility will be assessed through the analysis of the coordinating office in terms of its location and whether the building is a single or multi-storey building. If the building is located too close to the ocean and is a single-storey building, it is very likely that relevant information kept in paper or digital format may be lost, inhibiting the functionality for some period.

Deficiencies in Preparedness

These deficiencies will be addressed through the lack of sea walls or dykes, as well as the lack of an early warning system. The expectation is that these measures would minimise damages to processes and paperwork normally used in such facilities.

Elaborating the Scenario

To elaborate this type of scenario one again has to combine **E, S,** and **DP.** The proposed method to carry out the assessment is presented in table 14.

Table 14: Scenario Matrix – Administrative Component of Health Services within the City

Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	One - storey building	No measures in place	High impact	Administrative functions at risk of collapsing totally
		Measures in place	Medium impact	Administrative functions at risk of collapsing partially
	2 or more - storey building	No measures in place	Medium impact	Administrative functions at risk of collapsing partially
		Measures in place	Low impact	Administrative functions not affected.
Moderate exposure level	One - storey building	No measures in place	Medium impact	Administrative functions at risk of collapsing partially
		Measures in place	Low impact	Administrative functions not affected.
	2 or more - storey building	No measures in place	Medium impact	Administrative functions at risk of collapsing partially
		Measures in place	Low impact	Administrative functions not affected.
No exposure	Outside 200 metre line		No impact	No impacts expected with relation to the administrative process.

The model proposes that some management processes may be affected depending on the type of building where the coordinating office is located.

Example 12: Potential Collapse of Administrative Functions in the City of Galle

The Medical Officer of Health in Galle comments that the Health Office is located on the ground floor of the Municipal Council building, which is a two-storey building situated inside the 100 metre buffer zone and there are no disaster-preparedness measures in place. Because the tsunami took place on a public holiday, there was no staff present at the time, but paperwork and supplies stored in this place were lost.

Scenario = High Exposure x two-storey building x No EWS

= **Administrative functions collapsing partially.**

View of the Municipal Council Building which houses the office of the Medical Officer of Health on its ground floor.

7. Education Sector

The education sector spans three levels:

- **Basic level** covering elementary, primary, secondary, and high school education;
- **Technical level** related to vocational education; and
- **Higher level** related to education at the professional level, carried out in universities.

Children and minors, who should be considered as highly vulnerable, are grouped in the basic level; whereas, young adults comprise the population in the upper levels. Therefore, due to the age similarities of students in the upper levels, these levels can be grouped into a single category for the purpose of scenario assessment. Nevertheless, it is also important to recognise women as more vulnerable than men; thus, it is important to identify those higher level institutes and universities which target women separately, as such institutes or universities could be labeled as more vulnerable than other institutes which encompass population of both sexes. Examples of education centers focusing on women are nursing schools and convents.

7.1 Basic Level Education

7.1.1 Structural Component

This scenario is related to the potential damage or destruction of the infrastructure employed by this sector, in particular schools.

Structural Susceptibility

As in the case of hospitals and houses, the structural susceptibility of schools within a city depends on parameters such as the quality of building materials, the engineering design, and the building technique employed. However, as the number of schools may be limited within a city, one can visit such schools and use the number of levels of the school buildings to assess some kind of susceptibility as follows:

High structural susceptibility = One-level school buildings, ground level
Low structural susceptibility = two or more storey buildings

Deficiencies in Preparedness

As in previous cases, structural susceptibility and deficiencies in preparedness will be related to the lack of protection measures on the coast such as sea walls, dykes, or similar measures which reduce the damaging potential of a tsunami on infrastructure.

Elaborating the Scenario

To elaborate the scenario of the schools within any city which could be damaged structurally, the combination of **E**xposure, **S**usceptibility and **D**eficiencies in **P**reparedness is proposed. The model displays two outcomes:

- Proposed number of schools destroyed by the tsunami; and
- Proposed number of schools damaged by the tsunami.

The calculation of these outcomes is carried out with information obtained from the city authorities associated with education.

The proposed matrix to elaborate the scenario is presented in table 15.

Table 15: Scenario of Structural Impacts – Schools in the City

Exposure		Susceptibility	Def. in Prep	Outcome	Comment
High exposure level	1	Number of schools with one-storey buildings only inside 100 metre buffer zone	**1** If there are no protection measures in place in areas where schools are located. **0** If there are protection measures in place	Number	This outcome expresses potential number of schools **destroyed**
				0	No damages expected in schools which are protected
		number of schools with several buildings which have one and two or more storeys inside 100 metre buffer zone		Number	This outcome expresses potential number of schools **damaged**
				Number	No damages expected in schools which are protected
Moderate exposure level	1	number schools with one-storey buildings only inside 100 – 200 metre buffer zone	**1** If there are no protection measures in place in areas where schools are located. **0** If there are protection measures in place	Number	This outcome expresses potential number of schools **damaged**
				Number	No damages expected
		number of schools with several buildings which have one and two or more storeys inside 100 – 200 metre buffer line		Number	This outcome expresses potential number of schools **damaged**
				Number	No damages expected
No exposure	0	Any schools		0	No damages expected.

Example 13: Potential Damages to Schools in the City of Galle

According to data provided by the Zonal School Office of Galle, there are 26 schools in Galle which serve a population of 36,983 students of all ages up to high school level. A survey carried out by UNU-EHS after the tsunami in the city concluded that two schools are located inside the 100 metre buffer zone, one being highly susceptible (C.W.W. Kannangara) and the other one with a low susceptibility, as it is composed of several multi-storey buildings (Sudharma College). Three other schools are located in the area between the 100 and 200 metre lines, which can also be assigned a low susceptibility as they are composed of various multi-buildings (All Saints College, Southlands College, and Dadalla BTS School).

Scenario (destroyed)	= 1 x 1 school with one-storey buildings, unprotected	= **1 school destroyed**
Scenario (damaged)	= 1 x 1 school with several storeys, unprotected	= **1 school damaged**
Scenario (not damaged)	= 1 x 2 schools with several storeys, protected	= **2 schools with no damage**
No damage	=	= **22 schools**

A post-tsunami damage assessment of the city carried out by UNU-EHS indicates that one of the two schools inside the 100 metre buffer zone experienced heavy damages (C.W.W. Kannangara), while the other one experienced damages to a lesser degree because it is a multi-storey facility. Two and multi-storey facilities incorporate reinforced concrete techniques that reduce susceptibility to tsunamis, while one-storey facilities may not incorporate such reinforced concrete techniques. The two schools located inside the fort within the 200 metre buffer zone did not experience any damage, as the fort has a sea wall which protects all buildings inside it. The third school only suffered minor damages to its exterior wall.

Map 5, shows on page 90, desplays the location of schools and colleges within the city of Galle.

7.1.2 Human Component

Human Susceptibility

The susceptibility of schools when it comes to people is rather high, as children can be considered a highly vulnerable group of people within any city when compared with adults.

Deficiencies in Preparedness

Deficiencies in preparedness are linked to the inexistence of sea walls or dykes, the inexistence of an early warning system, the lack of emergency planning, and the incapacity to evacuate rapidly to safe areas.

Deficiencies in preparedness = 1 if neither sea walls, dykes nor any other early warning systems are in place.
0.5 if there is an early warning system in place but no sea walls or dykes.
0 if both sea walls or dykes and an early warning system are in place.

Elaborating the Scenario for this Component

To elaborate the scenario of the schools within any city with respect to children and teenagers in schools, one would take the same approach as before. Combining **E, S,** and **DP,** the model proposes two outcomes:

- Proposed number of children and teenagers who could be killed or fatally wounded in schools; and
- Proposed number of children and teenagers injured in schools.

Calculation of these outcomes is carried out by determining the following data, which can be obtained from the education office within the city:

Total number of students in schools in the two buffer zones; and
Number and type of schools in the two buffer zones.

The proposed matrix to elaborate the scenario is presented in table 16.

Table 16: Scenario Matrix – Casualties and Injuries in Schools

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Number of students located on ground floor in schools with buildings 1, 2, or more storeys high.	**1** If there are no sea walls or levees in place in areas where schools are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of students **killed in schools.**
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of students **killed and injured in schools.**
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** students killed or **injured,** assuming they are evacuated to safe areas.
Moderate exposure level	1	Number of students located on ground floor in schools with buildings 1, 2 or more storeys high.	**1** If there are no sea walls or levees in place in areas where schools are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of students **injured** in schools.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of students **injured** in schools.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** students **injured** assuming, they are evacuated to safe areas.
No exposure	**0**	Any school, any number of students	Any degree of preparedness and protection measures		0	No students injured or killed.

The model in this case proposes that if there are no preparedness measures within the city, then one can expect fatalities in schools. If some degree of preparedness is present, then the proposed number of fatalities and injuries are the same; if the degree of preparedness is good, meaning that even schools have the benefit of the early warning system in addition to organisation and an emergency plan, then fatalities and injuries can be avoided.

Example 14: School Population in the City of Galle

A survey carried out by UNU-EHS after the tsunami in the city concluded that only one school can be considered as having only one – storey buildings within the 200 metre buffer area, while five schools can be considered as having multiple buildings, some of which can be up to four storeys high. In addition, at the time of the 26 December 2004 tsunami, there were no preparedness measures in place within the city of Galle. Table 17 presents data on these schools.

Table 17 : Data on Schools Located within the 100 Metre and 200 Metre Buffer Zones*

Schools inside 100 m buffer zone	Students	Number of floors	Students on ground floor	Protection measures?
C.W.W. Kannangara	315	1	315	No
Sudharma College	1,034	3	345	No
Sub-total for the 100 metre buffer zone	**1,349**		**660**	
Schools inside the 100 - 200 metre buffer zone				
BTS Dadalla	276	2	138	No
All Saints Central	1,057	3	352	Sea wall
Southlands	4,461	3	1487	Sea wall
Sub-total for the 100 - 200 metre buffer zone	**5,794**			
Schools outside the buffer zones, away from the shore				
21 schools	29,840			

* Data provided by the Zonal School Office in Galle.

Scenario (killed) = 1.0 x 660 students = **660 students killed**

Scenario (injured) = (1.0 x 138 x 1) + (1839 x 0.5) students = **1078 students injured**

Not injured = 36,983 – 1738 = **35,245 students**

Because the 26 December 2004 tsunami occurred during holidays, no students were attending school; therefore it is impossible to compare the outcome proposed by the model with actual impacts in this case.

Three schools are located inside the 200 metre buffer zone. Two out of 26 schools (11%) are located in the high exposure area. Another three schools are in a medium exposure area (11%) but two are inside the fort, an area well protected from tsunamis. The schools most affected by the tsunami were C.W.W. Kannangara, Sudharma, and Uswathun Colleges, which required the construction of temporary buildings to continue operations while formal reconstruction or constructions of buildings was completed. Other schools, such as Vidyaloka and Anuladevi, suffered only minor damages, and could return to normal operations quickly.

Table 18 displays the fact that basically 4 % of students and teachers are located inside the high exposure area. This means that 96 percent of the children in the city can continue their school process even in case of a tsunami.

Table 18: Data on Schools in the City of Galle*

Schools inside the 100 metre buffer zone	Number of Students	Number of Teachers
C.W.W. Kannangara	315	20
Sudharma College	1034	49
Sub-total for these 2 schools	**1349**	**69**
Schools inside the 100 / 200 metre buffer lines		
BTS Dadalla	276	19
All Saints Central (inside Fort, well protected by sea wall)	1,057	51
Southlands (inside Fort, well protected by sea wall)	4,461	159
Sub-total for these 3 schools	**5794**	**229**
Schools within 300 metres experiencing some damage		
Vidyaloka (damage to outer wall only)	1927	82
Uswathun (damage to outer wall only)	510	25
Anuladevi Balika Vidyalaya (damage to outer wall only)	1477	49
Sub-total for these 3 schools	**3914**	**156**
Total population in all schools of the city	**36983**	**1583**
Percentage of students inside the 100 metre buffer area	3.6%	4.4%
Percentage of students inside the 100/200 metre buffer area	15.7%	14.5%
Percentage of students inside the 200/300 metre buffer area	10.6%	9.8%

* Data provided by the Zonal School Office in Galle.

7.1.3 Functional Component

Functional Susceptibility

The functional susceptibility of schools is related to those aspects or processes that are required for schools to carry out their task of educating children. Relevant parameters for this susceptibility at the city scale are:

- Presence of teachers;
- Furniture in classrooms: desks, chairs, blackboards, teaching materials; and
- Water, electricity.

In this case, functional susceptibility will be assessed through the structural susceptibility, as in the case of health centers. The hypothesis would be that if the buildings are damaged in a particular school, the educational process cannot continue even if children are present.

Elaborating the Scenario Related to the Functionality of the Sector in the City

To elaborate the scenario of the schools within any city, one would use a process similar to that employed to assess the functional scenario of health facilities as expressed in the previous chapter. Deficiencies in preparedness would focus, in this case, on protection measures, such as dykes and sea walls, that would minimise potential damages.

The proposed matrix to elaborate the scenario is presented in table 19.

Table 19: Scenario Matrix – Functional Aspects in Schools

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of schools with one-storey buildings only inside 100 metre buffer zone	**1** If there are no protection measures in place in areas where hospitals are located **0** If there are protection measures in place	Number	Schools which will experience functional problems for some months.
		Number of schools with several buildings which have one and two or more storeys inside 100 metre buffer zone		Number	Schools which will experience functional problems for some weeks.
Moderate exposure level	1	Number of schools with one-storey buildings only inside 100 – 200 metre buffer zone	**1** If there are no protection measures in place in areas where hospitals are located **0** If there are protection measures in place	Number	Schools which will experience functional problems for some weeks.
		Number of schools with several buildings which have one and two or more storeys inside 100 – 200 metre buffer zone		Number	Schools which will experience functional problems for some weeks.
No exposure	0	Any facility outside 200 metre line		0	No functional problems in these facilities

Example 15: Schools Inside the 100-200 Metre Buffer Zone within the City of Galle

Table 20 presents data on these schools:

Table 20: Data on Schools Located within the 100 Metre and 200 Metre Buffer Zones

Schools inside 100 m buffer zone	Schools inside 100 - 200 m buffer zone
C.W.W. Kannangara - single-storey	BTS Dadalla - multi-storey
Sudharma College - multi-storey	All Saints Central - multi-storey
	Southlands College - multi-storey

Scenario (destroyed) = **1 school**

Scenario (damaged) = **4 schools**

The 26 December 2004 tsunami affected several schools both inside and outside the 200 metre buffer zone. In several schools, temporary wooden structures had to be put in place to serve as classrooms. In addition, plastic chairs and tables had to be used to cope temporarily with the destruction of appropriate furniture for this purpose. Uswathun College, located outside the 200 metre buffer zone, had to be fitted with such wooden structures and temporary furniture to cope with damages to its facilities.

Administrative Susceptibility

The administrative susceptibility of schools within the city is related to those aspects or processes that are required at the city level to administer efforts regarding the education process. In several countries, such processes are usually carried out by a department or office under the Ministry of Education within the jurisdiction of the city or municipal district. Therefore, this susceptibility relates to such a department or office. Relevant parameters for this susceptibility at the city scale are:

- Processes that take place in this coordination office, such as book-keeping, reporting to the provincial or national level, database management, coordination of activities involving schools within the city, coordination of teacher distribution, duty assignments, etc.

In this case, susceptibility will be assessed through the analysis of the coordinating office in terms of its location and whether the building is a single or multi-storey building. If the building is located too close to the ocean and is a single-storey building, it is very likely that relevant information kept on paper or in digital format may be lost, inhibiting the functionality for some period.

Elaborating the Scenario

To elaborate this type of scenario within any city, one has to use table 21.

Table 21: Scenario Matrix – Administrative Aspects, Education Sector

Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	One-storey building	No measures in place	High impact	Administrative functions at risk of collapsing totally
		Measures in place	Medium impact	Administrative functions at risk of collapsing partially
	2 or more - storey building	No measures in place	Medium impact	Administrative functions at risk of collapsing partially
		Measures in place	Low impact	Administrative functions not affected
Moderate exposure level	One-storey building	No measures in place	Medium impact	Administrative functions at risk of collapsing partially
		Measures in place	Low impact	Administrative functions not affected
	2 or more - storey building	No measures in place	Medium impact	Administrative functions at risk of collapsing partially
		Measures in place	Low impact	Administrative functions not affected
No exposure	Outside 200 metre line		No impact	No impacts expected with relation to the administrative process.

The model in this case proposes that some administrative processes may be affected depending on the location and type of building where the coordinating office is located.

Example 16: Zonal Education Office in the City of Galle

The Zonal Education Office in Galle is located inland, about 800 metres from the shore. In addition, it is a two-storey building, and operations are conducted on the second floor. Therefore, there is no scenario of administrative problems within the educational sector in Galle associated to the tsunami.

7.2 Technical and University Level

7.2.1 Structural Component

Structural Susceptibility

As in the case of schools, the structural susceptibility of technical institutes and universities within a city depends on parameters such as the quality of building materials, the engineering design, and the building technique employed. However, as the number of technical institutes and universities may be limited within a city, one can visit such facilities and use the number of levels of the buildings to assess some kind of susceptibility as follows:

High structural susceptibility = one-level building, ground level.
Low structural susceptibility = buildings spanning two or more storeys.

Deficiencies in Preparedness

Deficiencies in preparedness will span those measures such as sea walls or dykes, which may minimise the impact of the tsunami on the infrastructure.

Elaborating the Scenario

Elaboration of the scenario is similar to the previous cases. Combining **E**xposure, **S**usceptibility, and **D**eficiencies in **P**reparedness the model proposes these outcomes:

- Proposed number of institutes and universities destroyed by a tsunami;
- Proposed number of institutes and universities damaged by a tsunami; and
- Proposed number of institutes and universities not damaged by a tsunami.

The proposed method to elaborate the scenario is presented in table 22.

Table 22: Scenario of Structural Impacts – Universities and Institutes in the City

Exposure		Susceptibility	Def. in Prep	Outcome	Comment
High exposure level	1	Number of universities and institutes with one-storey buildings only inside 100 metre buffer zone	**1** if there are no protection measures in place in areas where universities and institutes are located **0** if there are protection measures in place	Number	This outcome expresses potential number of universities and institutes **destroyed**
				0	No damages expected in universities and institutes that are protected
		Number of universities and institutes with several buildings which have one and two or more storeys inside 100 metre buffer zone		Number	This outcome expresses potential number of universities and institutes **damaged**
				0	No damages expected in universities and institutes that are protected
Moderate exposure level	1	Number universities and institutes with one-storey buildings only inside 100 – 200 metre buffer zone	**1** if there are no protection measures in place in areas where universities and institutes are located **0** if there are protection measures in place	Number	This outcome expresses potential number of universities and institutes **damaged**
				Number	No damages expected
		Number of universities and institutes with several buildings which have one and two or more storeys inside 100 – 200 metre buffer line		Number	This outcome expresses potential number of universities and institutes **damaged**
				Number	No damages expected
No exposure	0	All universities and institutes		0	No damages expected.

The dark-shaded rows refer to the highly vulnerable technical institutes and universities. As in previous cases, the model proposes that all technical institutes and universities that have only one-storey buildings and are located inside the 100 metre buffer zone will be destroyed or heavily damaged;

whereas, those institutes and universities which have multiple-level storeys will only undergo damages but not destruction.

Example 17: Potential Damages to Institutes and Universities within the City of Galle

According to a survey carried out by UNU-EHS after the tsunami, in the city there are three vocational institutes and a branch of the University of Matara, as well as the Faculty of Medicine next to the National Hospital in Karapitiya.

Scenario (destroyed)	= 1 x 0 institutes	= **0 institutes or universities destroyed.**
Scenario (damaged)	= 1 x 3 technical institutes	= **3 technical institutes damaged.**
No damages	= 0 x 2 university campuses	= **2 university campuses unharmed.**

A post-tsunami damage assessment of the city carried out by UNU-EHS indicates that the school of nursing suffered basically no structural damage, as well as the two other institutes. In addition, the Galle campus of the University of Ruhuna is located far inland, and did not suffer any impacts from the tsunami.

7.2.2 Human Component

Human Susceptibility

The susceptibility of institutes and universities when it comes to people is low, as young adults can be considered a low vulnerable group of people within any city. Nevertheless, as stated before, if there are particular institutes targeting women only, then one should assign a higher susceptibility in this case.

School of Nursing in Galle, which has a population of nearly 1,000 female students.

Deficiencies in Preparedness

Deficiencies in preparedness would be linked to the inexistence or deficient operation of an early warning system, lack of planning, and capacity to evacuate rapidly to safe areas.

Deficiencies in preparedness	= 1	if neither preparedness nor an early warning system are in place.
	0.5	if there is preparedness but no early warning system in place.
	0	if both preparedness and an early warning system are in place.

Elaborating the Scenario of Potential Injuries and Casualties within students

To elaborate this scenario for institutes and universities within any city, one would combine **E, S,** and **DP.** The model proposes two outcomes:

- Proposed number of students which could be killed or fatally wounded; and
- Proposed number of students injured.

The calculation of these outcomes is carried out via determining the following data, which can be obtained from authorities within the city:

Total number of students in institutes and universities in the two buffer zones
Number and type of institutes and universities in the two buffer zones

The proposed matrix to assess this scenario is presented in table 23. The model in this case proposes that if there are no preparedness measures within the city, then one can expect fatalities in these facilities. If some degree of preparedness is present, then the proposed number of fatalities and injuries are the same; if the degree of preparedness is good, meaning that even institutes and universities have the benefit of the early warning system in addition to the existence of sea walls or levees, then fatalities and injuries can be avoided.

Table 23: Scenario Matrix – Casualties and Injuries in Institutes and Universities

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Number of students located on ground floor in institutes or universities with buildings 1, 2, or more storeys high	1 If there are no sea-walls or levees in place in areas where institutes or universities are located	1 (no preparedness at all)	Number	This outcome expresses the potential number of students **killed** in institutes or universities.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of students **killed** and **injured in** institutes or universities.
			0 If there are protection measures in place.	0 (good degree of preparedness)	0	**No** students **killed** or **injured,** assuming they are evacuated to safe areas.
Moderate exposure level	1	Number of students located on ground floor in institutes or universities with buildings 1, 2 or more storeys high	1 If there are no sea-walls or levees in place in areas where institutes or universities are located	1 (no preparedness at all)	Number	This outcome expresses the potential number of students **injured** in institutes or universities.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of students **injured** in institutes or universities.
			0 If there are protection measures in place.	0 (good degree of preparedness)	0	**No** students **injured** assuming, they are evacuated to safe areas.
No exposure	0	Any facility, any number of students	Any degree of preparedness and protection measures		0	No students injured or killed.

7.2.3 Functional Component

Functional Susceptibility

The functional susceptibility of institutes and universities is related to those aspects or processes that are required for such institutes and universities to carry out their task of educating students. Relevant parameters for this susceptibility at the city scale are:

- Furniture in classrooms: desks, chairs, blackboards, teaching materials; etc.
- Water, electricity.

In this case, functional susceptibility will be assessed through the structural susceptibility of such facilities. The hypothesis would be that if these facilities are damaged, the educational process cannot continue even if students are present.

Deficiencies in Preparedness

Deficiencies in preparedness will span those measures such as sea walls or dykes, which may minimise the impact of the tsunami on infrastructure.

Elaborating the Scenario

To elaborate the scenario of the institutes and universities within any city regarding functionality, one would use a process similar to that employed to assess the structural susceptibility of schools presented in the last section. As mentioned before, problems in functionality will be linked to damages and or destruction of facilities. The proposed method to elaborate the scenario is presented in table 25.

Example 18: Higher Education Centers in the City of Galle

According to a survey conducted by UNU-EHS, there are about 1,000 students in the School of Nursing located next to Mahamodera National Hospital. There are about 800 students in the other two technical institutes.

Table 24: Data on Institutes and Universities located within the 100 Metre and 200 Metre Buffer Zones

Institutes and universities inside 100 m buffer zone	Type of buildings	Total number of Students	Students on ground floor	Prepared-ness?
None	-	None	None	-
Institutes and universities inside 100 - 200 m buffer zone	**Type of buildings**	**Students**		
School of Nursing	1 and 2 storey buildings	1,000	500	None
Technical School, Galle	2 and 3 storey buildings	500	150	None
Galle Advanced Technical Institute	2 and 3 storey buildings	300	100	None
Sub-total 100 - 200 m buffer zone			**750**	
Institutes and universities outside the buffer zones	**Type of buildings**	**Students**		
Faculty of Medicine - Karapitiya	Multiple buildings, 1, 2, 3 and 4 storeys			None
University of Matara - Campus in Galle	Multiple buildings, 1, 2, 3 and 4 storeys			None

High Exposure area: 1 x 0 students x 1 = **0 students killed (no facilities in this area)**

Moderate Exposure area: 1 x 750 students x 1 = **750 students injured**

Because the 26 December 2004 tsunami occurred during a public holiday, no students were attending institutes and universities; therefore, it is impossible to compare the model with actual impacts in this case.

Table 25: Scenario Matrix – Functional Aspects in Institutes and Universities

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of institutes with one-storey buildings only inside 100 metre buffer zone	1 If there are no protection measures in place in areas where hospitals are located. 0 If there are protection measures in place	Number	This outcome expresses the potential number of institutes **destroyed**
		Number of institutes with several buildings which have one and two or more storeys inside 100 metre buffer zone		Number	This outcome expresses the potential number of institutes **damaged**
				0	No institutes damaged
Moderate exposure level	1	Number of institutes with one-storey buildings only inside 100 – 200 metre buffer zone	1 If there are no protection measures in place in areas where hospitals are located. 0 If there are protection measures in place	Number	This outcome expresses the potential number of institutes **damaged**
		Number of institutes with several buildings which have one and two or more storeys inside 100 – 200 metre buffer zone		Number	This outcome expresses the potential number of institutes **damaged**
				0	No institutes damaged
No exposure	0	Any facility outside 200 metre linie		0	No damages associated with these facilities

The model in this case proposes that if there are no preparedness measures within the city, then one can expect functional problems in institutes and universities. If protective sea walls or dykes are present, then the proposed number of facilities damaged would be reduced.

Example 19: Potential Damages to Institutes and Universities within the City of Galle

According to a survey carried out by UNU-EHS after the tsunami, in the city there are three vocational institutes and a branch of the University of Matara, as well as the Faculty of Medicine next to the national hospital in Karapitiya. None of them are protected by sea walls or dykes.

Scenario (destroyed)	=	1 x 0 institutes
	=	**0 institutes or universities facing severe functional problems.**
Scenario (damaged)	=	1 x 3 technical institutes
	=	**3 technical institutes facing some functional problems.**
No damages	=	0 x 2 university campuses
	=	**2 university campuses unharmed.**

Administrative Susceptibility

The administrative susceptibility of institutes and universities within the city is related to those aspects or processes that are required at the city level to administer efforts regarding the education process. In several countries such processes are usually carried out by personnel within these institutions. However, it is difficult to generalise any aspects concerning such susceptibility and its respective scenario at this level.

8. Government Sector

This sector encompasses all government agencies operating within the city. However, when dealing with this sector from the point of view of a city, it is important to recognise the different levels of government present in such a city. While every city has a municipal government in charge of all government activities within the city, a particular city may also be the seat for a provincial or, in selected cases, the national government. When assessing the scenario associated to this sector, it is important to set the analysis in the proper context of the particular level.

The following aspects of government will be included within this sector:

Record keeping:	Registration of births, marriages, and deaths, property titles;
Security:	Police, law enforcement within the city boundaries;
Markets:	Management of public markets, etc;
Services:	Fire-emergency services.

Susceptibility of Records

The susceptibility of the records is related to the fact that such records are kept on paper or in digital form, both of which are vulnerable because they can be destroyed when coming in contact with the surge associated with a tsunami. Therefore, such records should be considered as highly-vulnerable.

Deficiencies in Preparedness

Deficiencies in preparedness focus on the lack of physical measures, such as sea walls or dykes, and non-structural measures in place to be able to recover records should such records become destroyed or damaged. Such measures include long-term archiving in secure places, frequent back-ups of such records and archiving in different formats (paper, digital).

Scenario of Damage or Destruction of Official Records

The scenario focuses on the potential loss of or damage to such records in case of a tsunami. The following table shows how to assess such a scenario.

Table 26: Scenario Matrix – Potential Damage or Destruction of Official Records

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1 Inside 200 metre zone	Records of all types	Preparedness measures not in place	Destruction, difficulty in recovery of records	Destruction of records.
			Preparedness measures in place	Destruction, but easy recovery	Destruction or damage, but easily recoverable
No exposure	0 outside 200 metre zone			No damage	No damages because records are processed and kept in an unexposed area.

Example 20: Potential Destruction of Official Records in the City of Galle

The city of Galle operates its offices related to records (births, deaths) in the Galle Municipal building, which is a two-storey facility located in the 100/200 metre buffer zone. Many of the records were lost when they were destroyed by the tsunami, as such records were kept on the lower floor of the building. Map 6, shown on page 91, displays the location of government building within the city of Galle.

8.1 Structural Component: Police Department

Structural Susceptibility

As in the case of other sectors, the structural susceptibility of the building housing the Police Department within a city depends on parameters such as the quality of building materials, the engineering design, and the building technique employed.

High structural susceptibility = one-level building, ground level.
Low structural susceptibility = buildings spanning two or more storeys.

Deficiencies in Preparedness

Deficiencies in preparedness focus on the lack of physical measures such as sea walls or dykes, which may protect the building from being impacted by the tsunami.

Scenario of Functional Impacts to the Police Headquarters

To elaborate the scenario concerning the possibility of the Police Headquarters being affected by a tsunami, one has to use table 27:

Table 27: Structural Damages to Building Housing the Police Department

Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	**HIGH**: one-storey building	**HIGH** if there are no protection measures in place.	Large impact	This outcome expresses potential **destruction** of building
		LOW if there are protection measures in place.	Moderate impact	This outcome expresses potential **damage**, but no destruction
	LOW: 2 or more-storeys	**HIGH** if there are no protection measures in place.	Moderate impact	This outcome expresses potential **damage**, but no destruction
		LOW if there are protection measures in place.	Low impact	This outcome expresses low degree of damage.
Moderate exposure level	**HIGH**: one-storey building	**HIGH** if there are no protection measures in place.	Moderate impact	This outcome expresses potential **damage**, but no destruction
		LOW if there are protection measures in place.	Low impact	This outcome expresses potential **damage**, but no destruction
	LOW: 2 or more-storeys	**HIGH** if there are no protection measures in place.	Minimal impact	This outcome expresses minimal **damage** to building.
		LOW if there are protection measures in place.	0	No damages associated with these facilities
No exposure	Any building outside the 200 metre line		0	No damages associated with these facilities

In the city of Galle, the police headquarters are located in a two-storey building within the 100 metre buffer zone; thus, the model forecasts potential damage to the building but not destruction. A visit to the facility two months after the tsunami by UNU-EHS confirmed this fact.

8.2 Functional Component

Functional Susceptibility of Law Enforcement: Police Department

The functional susceptibility of law enforcement would include the permanent or temporary disruption of law enforcement as a consequence of:

Fatalities of or injuries to police officers;

Damage / destruction of motor vehicles and equipment of the Police Department; and

Loss of critical documents in paper or digital format (records) should they come in contact with the tsunami surge.

Deficiencies in Preparedness

Deficiencies in preparedness focus on the lack of physical measures, such as sea walls or dykes, or non-structural measures in place to be able to recover critical records and documents should these become destroyed or damaged. Such measures span long-term archiving in secure places and archiving in different formats (paper, digital).

Scenario of Functional Impacts to the Police Headquarters

To elaborate the scenario concerning the possibility of the police headquarters to be affected by a tsunami, one can use table 28.

Table 28: Functional Impacts – Police Headquarters Within the City

Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	High Police headquarters in a one-storey facility	High If there are no protection measures in place Low If there are protection measures in place	High impact	This outcome expresses potential **incapacity of Police to carry out the law-enforcement activities for several weeks.**
	Low Police headquarters in a multiple storey facility		Moderate impact	This outcome expresses potential **incapacity of police to carry out the law-enforcement activities for several days.**
Moderate exposure level	High Police headquarters in a one-storey facility		Low impact	This outcome expresses potential **incapacity of police to carry out the law-enforcement activities for several days.**
	Low Police headquarters in a multiple storey facility		Low impact	This outcome expresses potential **incapacity of police to carry out the law-enforcement activities for several days.**
No exposure	Police headquarters in any type of facility		No impact	No impact because records are processed and kept in an unexposed area and no police officers unexposed within the station can be injured.

Example 21: Police Headquarters in the City of Galle

The city of Galle operates its police headquarters in a two-storey building located inside the 100/200 metre area. Because it is located in a two-storey building, the model predicts the incapacity of police to carry out law enforcement activities during several days.

The superintendent of police mentioned in an interview that the tsunami killed one police officer and that some furniture and equipment was destroyed during the tsunami, as well as some vehicles, which had to be replaced. In addition, he pointed out the loss of important critical information stored in paper and digital forms.

Scenario of Structural Damages to Municipal Markets

This scenario related to public markets focuses on damages or destruction of such markets used by the informal sector to commercialise products, such as vegetables, fruits, fish, etc. The buildings housing these markets consist basically of open rooms; therefore, one must focus on their susceptibilities regarding structural and gender issues. Table 29 presents the matrix to elaborate the scenario of structural damages to markets. As before, deficiencies in preparedness will target sea walls and dykes, which could minimise the impact of the tsunami at the location of the markets, as well as early warning systems and emergency planning.

As it can be seen, the method proposes that one-storey buildings will face destruction if these are located within the 100 metre buffer zone, and they would be damaged if they are located in the 100/200 metre buffer zone. However, as in previous cases, the susceptibility is reduced when the market building is housed in a two- or three-storey building.

Scenarie of Human impacts within Municipal Markets

Table 30 presents the matrix to assess potential fatalities or injuries in such markets provoked by a tsunami. It is important to notice that some markets may be extremely crowded; thus, early warning and emergency planning could play a crucial role in reducing fatalities and injuries in such places, as well as protection measures such as dykes and sea walls.

Table 29: Scenario of Structural Impacts – Municipal Markets

Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	**HIGH**: markets in one-storey buildings	**HIGH** if there are no sea-walls or levees to protect markets.	Large impact	This outcome expresses potential **destruction** of markets.
		LOW if there are sea-walls or levees to protect markets.	Moderate impact	This outcome expresses potential **damage**, but no destruction
	LOW: markets in buildings 2 or more storeys high	**HIGH** if there are no sea-walls or levees to protect markets.	Moderate impact	This outcome expresses potential **damage**, but no destruction
		LOW if there are sea-walls or levees to protect markets.	Low impact	This outcome expresses low degree of damage.
Moderate exposure level	**HIGH**: markets in one-storey markets	**HIGH** if there are no sea-walls or levees to protect markets.	Moderate impact	This outcome expresses potential **damage**, but no destruction
		LOW if there are sea-walls or levees to protect markets.	Low impact	This outcome expresses potential **damage**, but no destruction
	LOW: markets in buildings 2 or more storeys high	**HIGH** if there are no sea-walls or levees to protect markets.	Minimal impact	This outcome expresses minimal **damage** to markets.
		LOW if there are sea-walls or levees to protect markets.	0	No damages associated with these markets
No exposure	Any market outside 200 metre line		0	No damages associated with these markets

Table 30: Scenario Matrix – Injuries and Casualties in Markets within the City

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Number of people located on ground floor in markets in buildings 1, 2, or more storeys high.	**1** If there are no sea-walls or levees in place in areas where markets are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **killed** in markets.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **killed** and **injured in markets**.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **killed** or **injured** assuming they are evacuated to safe areas.
Moderate exposure level	1	Number of people located on ground floor in markets in buildings 1, 2 or more storeys high.	**1** If there are no sea-walls or levees in place in areas where markets are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **injured** in markets.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **injured** in markets.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **injured** assuming they are evacuated to safe areas.
No exposure	**0**	Any facility, any number of people	Any degree of preparedness and protection measures		0	No people injured or killed.

Example 22: Public Markets within the City of Galle

The city of Galle has three public markets. The fruits and fish markets are located on the ocean shore, inside the 100 metre buffer zone. While the fruit market is housed in a two-storey building, the fish market is housed in a single-storey facility. The tsunami destroyed the fish market completely while the fruit market was only damaged. The largest public market in the city is located outside the 200 metre buffer zone, and it did not suffer structural damages as a consequence of the tsunami. Because the tsunami took place on a Sunday, none of the markets were open to the public; thus, there is no possibility of assessing the accuracy of the model at this time. Map 7, shown on page 92, displays the location of these three markets within the city of Galle.

Scenario Related to Fire Emergency Services

Table 31: Scenario of Structural Impacts – Fire Emergency Stations in City

Exposure	Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	**HIGH**: one-storey fire stations	**HIGH** if there are no sea walls or levees to protect fire stations.	Large impact	This outcome expresses potential **destruction** of fire stations.
		LOW if there are sea walls or levees to protect fire stations.	Moderate impact	This outcome expresses potential **damage**, but no destruction
	LOW: 2 or more storey buildings	**HIGH** if there are no sea walls or levees to protect fire stations.	Moderate impact	This outcome expresses potential **damage**, but no destruction
		LOW if there are sea walls or levees to protect fire stations.	Low impact	This outcome expresses low degree of damage.
Moderate exposure level	**HIGH**: one-storey fire stations	**HIGH** if there are no sea walls or levees to protect fire stations.	Moderate impact	This outcome expresses potential **damage**, but no destruction
		LOW if there are sea walls or levees to protect fire stations.	Low impact	This outcome expresses potential **damage**, but no destruction
	LOW: 2 or more storey buildings	**HIGH** if there are no sea walls or levees to protect fire stations.	Minimal impact	This outcome expresses minimal **damage** to fire stations.
		LOW if there are sea walls or levees to protect fire stations.	0	No damages associated with these facilities
No exposure	Any fire station outside 200 metre line		0	No damages associated with these facilities

Example 24: Fire Emergency Station in the City of Galle

The city of Galle operates a single fire-emergency station located outside the 200 metre buffer zone. The facility was operational at the time of the tsunami and did not suffer any damages.

9. Public Infrastructure Sector: Roads, Railroads, Ports, Airports and Religious Temples

This segment focuses on public infrastructure dedicated to transportation that is set up by the government. As such, it spans roads, railroads, ports, airports, and religious temples.

9.1 Roads Within the City

Structural Component

Roads in the context of a city serve two purposes: providing means of communication within the city for vehicles of different types and linking a city to the rest of the country. The structural scenario for roads is related to the damage or destruction of such roads in case of a tsunami. As expected, the susceptibility of roads will depend on construction materials and techniques. Particular attention has to be placed on bridges and overpasses that may be affected by a tsunami. In the context of linking the city to the rest of the country, the scenario is related to the possible isolation of a city if segments of its roads will be destroyed, inhibiting the transportation of people, goods, supplies, and resources to and from the city.

Structural Susceptibility: Bridges Within the City

As stated before, the structural susceptibility of roads and bridges depends on several parameters. However, it is only through a detailed survey that one can determine the susceptibility of each bridge. Thus, for a rapid scenario assessment, a compromise has to be accepted in terms of assuming that in the case of tsunamis, all bridges can be considered as having the same degree of susceptibility (Tang et al, 2006 c).

Structural susceptibility = equal for all bridges.

Deficiencies in Preparedness

Deficiencies in preparedness focus on the lack of physical measures such as sea walls or dykes, which may protect the bridges from being impacted by the tsunami.

Elaborating the Scenario

When elaborating the scenario on any coastal city in terms of bridges destroyed or damaged in very general terms, the model proposes two outcomes:

- Proposed number of bridges destroyed by a tsunami; and
- Proposed number of bridges damaged by a tsunami.

Table 32: Scenario of Structural Damages – Bridges in the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of bridges in this area	1 If no sea-walls or dykes are in place. 0 If sea-walls or dykes are in place	Number	This number expresses the potential number of bridges **destroyed or not functional.**
Moderate exposure level	1	Number of bridges in this area		Number	This number expresses the potential number of bridges **damaged** but still functional for limited type of vehicles.
				0	No damages to these bridges.
No exposure	1	Number of bridges in this area.		0	No damages to these bridges.

The calculation of these outcomes is carried out via determining the total number of bridges and their locations, which can be obtained from city authorities, through a visual inspection, or using road maps. The proposed method to elaborate the scenario is presented in table 32.

The elaboration of the scenario involves locating bridges in the respective buffer zones and making proper associations according to the table. The outcome of the calculation is an integer number expressing the number of bridges in coastal areas that can sustain some kind of damage due to a tsunami.

Example 25: Potential Damages to Bridges Within the City of Galle

A survey carried out by UNU-EHS indicates that there are several bridges along the main coastal road from Colombo to Galle and along the road from Galle to Matara. In addition, there are several smaller bridges inland.

High exposure area: 1 x 2 bridges x 1 (no protection) = **2 bridges destroyed**

Moderate exposure area: 1 x 4 bridges x 1 (no protection) = **4 bridges damaged**

Not exposed 1 x 16 bridges x 1 (no protection) = **16 bridges unharmed**

The tsunami severely damaged one bridge within the 100 metre buffer zone to the point that it could not be used and had to be rebuilt. To cope with this situation, a temporary "Bailey" type bridge was installed. The other bridges were basically unharmed by the tsunami and could be used without any difficulty once debris was cleared out.

The example displays one of the limitations of the proposed mode: it does not consider differences in the structural susceptibility of bridges, which would be responsible for a bridge collapsing or not. However, such susceptibilities could only be identified through a technical inspection by structural engineers, something which is out of the scope of a rapid assessment.

Structural Susceptibility of Roads

In this section, the susceptibility will be assumed as equal for all roads within the city.

Deficiencies in Preparedness

Deficiencies in preparedness will again target the lack of sea walls or dykes, which could protect the roads from damage. In this particular context, the number of kilometres of coastline exposed without protection from levees or sea walls will be used as the parameter to represent such deficiencies.

Table 33: Scenario of Structural/Functional Damages – Roads in the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	kilometres of roads situated inside the 100 metre buffer area	Any type of road	Kilometres of coastal area without dykes, sea-walls, mangrove forest or forests of similar types, etc.	Number	This outcome expresses potential number of kilometers or roads which can be **destroyed**
Moderate exposure level	kilometres of roads situated inside the 100 – 200 metre buffer area			Number	This outcome expresses potential number of kilometers or roads which can be **damaged**
No exposure	Outside 200 metre zone			Number	No damages because roads are located outside the exposed areas

The calculation of the scenario involves measuring the number of kilometres of roads which are located inside the 100 metre buffer area zone.

Elaborating the Scenario of Potential Damages to Roads

To elaborate the scenario for any city in terms of roads destroyed or damaged in very general terms, the previous method combining the three terms will be employed. The model will consider that the impact of a tsunami on a road within the city would lead to either damage or destruction. Experience in the past tsunami indicates that the pavement or concrete surface might be damaged depending on factors such as the condition of the bed of the road and its proximity to the ocean shore. The matrix to elaborate the scenario is presented in table 33.

Example 26: Potential Damages to Roads Within the City of Galle

A survey carried out by UNU-EHS indicates that there are roughly 17 kilometres of roads which are inside the high-exposure area; 18 kilometres of roads in the moderate exposure area; and over 140 kilometres of roads within the city that will not be damaged. A visit to the city after the tsunami indicated that the asphalt bed in roads was only minimally damaged in some places of the city.

9.1.1 Means of Communication to Reach the City

While it is important to elaborate the scenario associated with damages to roads within the city, it is equally important to elaborate the scenario of roads communicating the city with its surroundings and with the rest of the country. This segment of the sector spans roads and highways leading to and from the city.

Structural Susceptibility of the Road System Leading to the City

This susceptibility is related to the number of roads that connect the city and the rest of the country.

Susceptibility = equal for all roads reaching the city.

Deficiencies in Preparedness

Considering the fact that this section deals with roads leading to the city, no attempt will be made to analyse the protective measures on beaches in rural areas where roads leading to the city are located, such as sea walls and dykes.

Elaborating the Scenario

To elaborate the scenario on any city in terms of the roads connecting it with the rest of the country, the three terms **E, S, DP** are combined using simple products. The model proposes three outcomes:

- Proposed number of roads which can be destroyed in case of a tsunami;
- Proposed number of roads which can be damaged in case of a tsunami, but are still functional; and
- Proposed number of roads which will not be damaged or destroyed.

The calculation of these outcomes is carried out via determining the total number of roads leading to the city and their locations with respect to the coast, which can be obtained from city authorities or using maps.

The matrix to elaborate this scenario is presented in table 34.

Table 34: Scenario of Structural/Functional Damages – Roads Linking the City to the Country

Exposure		Susceptibility	Outcome	Comment
High exposure	1 Inside 100 metre zone	Number of roads	Number	This outcome expresses the potential number of roads **destroyed or not functional.**
Moderate exposure	1 Inside 100-200 metre zone		Number	This outcome expresses the potential number of roads **damaged, but which may still be functional.**
No exposure	0 Outside 100 metre zone		0	No damages because roads are located in a no exposure area.

Example 27: Potential Damages to Roads Leading to the City of Galle

Galle city can be reached from other cities and provinces via five main roads. Three roads connect the city with the regions inland and thus are located in areas which are not exposed to tsunamis, while two roads are part of the coastal highway of Sri Lanka, and in some segments these highways have segments within the 100 metre buffer line.

Roads which could be damaged = 1 x 2 roads = **2 roads**

Roads which cannot be damaged = 1 x 3 roads = **3 roads**

This means that the city will not be isolated in case of a tsunami, as three roads will not be affected at all. In this context, it is important to recognise that if there is a town or city which can only be accessed through one road and this road becomes impassable, then the city will be isolated during the time it takes to restore such a road.

9.2 Bus Stand and Public Bus Transportation

Human Susceptibility of the Main Bus Station of the City

One relevant segment of public transportation is related to the public bus stations. When evaluating the effects of tsunamis, the fact that such stations can sometimes be very crowded is a critical issue. The human susceptibility should be assessed considering the potential number of people which can be present at the station at the time of a tsunami.

Deficiencies in Preparedness

Deficiencies in preparedness would be linked to the inexistence or deficient operation of an early warning system, lack of emergency planning, and to the lack of seawalls or dykes which could protect the station.

Elaborating the Scenario of Casualties and Injuries in Bus Stations

To elaborate the scenario of a bus stand one has to estimate the number of people typically present in such bus stands, which can differ depending on the size of the station (which may be related to the size of the city), the day of the week, and the time of day.

As before, the calculation of the scenario is elaborated combining data regarding the average number of people in the bus stand, deficiencies in preparedness, and the location of the bus stand. The following matrix presents the scheme for the calculation.

Table 35: Scenario Matrix –Injuries and Casualties – Main Bus Station in the City

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Number of people located on ground floor in bus station with buildings 1, 2, or more storeys high.	1 If there are no sea-walls or levees in place in area where bus station are located	1 (no preparedness at all)	Number	This outcome expresses the potential number of people **killed** in the bus station.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **killed** and **injured** in the bus station.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **killed** or **injured,** assuming they are evacuated to safe areas.
Moderate exposure level	1	Number of people located on ground floor in bus station with buildings 1, 2 or more storeys high.	1 If there are no sea-walls or levees in place in area where bus station are located	1 (no preparedness at all)	Number	This outcome expresses the potential number of people **injured** in the bus station.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **injured** in the bus station.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **injured,** assuming they are evacuated to safe areas.
No exposure	0	Any facility, any number of people	Any degree of preparedness and protection measures		0	No people injured or killed.

Example 28: The Main Bus Stand in the City of Galle

The bus stand in the city of Galle is actually located just outside the 200 metre buffer zone, but in a particular place where the wave nature of tsunamis increases the exposure, because the station is located in a place where the tsunami waves arriving from opposite sides can interfere in such a way to enhance fatalities and damages. This particular station is one example that displays the limitation of the model due to its simplicity. The model predicts no damages and no injuries, but the impacts of the tsunami showed quite the contrary.

9.3 Airports

Airports, as well as ports, trains, and the road system, are employed to import and export resources within the city and to mobilise a segment of the population that needs to travel to places far away. For the purposes of rapid scenario assessment, all airports will be considered as equal in terms of susceptibility.

Structural Susceptibility of Airports Within the City

Susceptibility = equal for all airports.

Deficiencies in Preparedness

Deficiencies in this case would span the lack of sea walls or levees, which could protect the airport from damage due to a tsunami.

Elaborating the Scenario

To elaborate the scenario for the impact of a tsunami in any city in terms of the airport connecting it with the rest of the country, a similar approach to the one in the case of roads connecting the city with other cities within the country should be used. The proposed method to elaborate the scenario is presented in table 36.

Table 36: Scenario of Structural/Functional Damages – Airports in the City

Exposure		Susceptibility	Deficiencies in Preparedness	Outcome	Comment
High exposure level	1	Number of airports	1 If there are no protection measures in place 0 If there are protection measures in place	Number	This outcome expresses the potential number of airports **destroyed or not functional.**
Moderate exposure area	1			Number	This outcome expresses the potential number of airports **damaged but functional.**
				0	No damages to airports due to protection measures.
No exposure	0			0	No damages because airports are located outside the exposed areas.

Example 29: Airports in the Vicinity of the City of Galle

There are no airports located within the city of Galle. The closest airport is located away from the city in an industrial, free-trade zone 20 kilometres south-east of the city. This airport is also located several hundred metres inland, and, thus, was not affected by the tsunami.

9.4 Trains

Sri Lanka faced the worst tragedy in connection with a very crowded train being impacted by the 26 December 2004 tsunami. More than one thousand people lost their lives inside a train that was caught by the second wave of the tsunami; the train was toppled and people drowned inside. Such a tragedy is the reason for considering trains within this sector approach.

Structural Susceptibility of Rail Road Tracks

This section considers the railroad tracks by themselves. Susceptibility will be assumed as equal for all segments of railroad tracks within the city.

Structural susceptibility = equal for all railroad tracks, assumed as high within the 100 metre buffer zone.

Deficiencies in Preparedness

Deficiencies in this case would span the lack of sea walls and dykes, which could protect the railroad track from damage due to a tsunami.

Elaborating the Scenario of Damages to Rail Road Tracks

To elaborate the scenario in terms of railroad tracks destroyed or damaged in very general terms, the previous method of combining **E, S,** and **DP** will be employed. However, the model will only consider the impact of a tsunami on those tracks located within the city and not outside the city limits. In addition, the model will just imply that if a segment of the railroad track is inside the one hundred metre buffer zone, it will experience damages leading to the interruption in the train service until repairs are completed. The proposed method to elaborate the scenario is presented in table 37.

Table 37: Scenario of Structural/Functional Damages – Rail Road Tracks within the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	track	1 if there are no protection measures in place 0 if there are protection measures in place	Long-term interruption in the service	This outcome expresses potential **destruction** of segments of the tracks within the city, leading to the interruption of the service during several weeks.
Moderate exposure level	1			Short-term interruption in the service.	This outcome expresses potential **damage** to segments of the tracks within the city, leading to the interruption of the service for a few days.
				No interruption	No damage because of protection measures.
No exposure	0			No interruption	No damage because tracks are located outside the exposed areas.

The calculation of the scenario involves analysing whether some segments of the railroad tracks are located inside the one hundred metre buffer zone or not.

Example 30: Potential Damages to Railroad Lines Within the City of Galle

A survey carried out by UNU-EHS indicates that no segment of the rail tracks is located inside the 100 metre buffer zone and, thus, no destruction to the tracks is expected. This was verified after the tsunami. However, it is important to stress that the model does not take into account the type of soil conditions on which the track is laid, nor the type or age of materials employed. As in the case of bridges, only an inspection by a structural engineer could yield the precise information regarding the real susceptibility of the tracks, but this is out of the scope of a rapid scenario assessment.

Functional Component in the Case of Trains

Trains, similar to ports, airports, and major highways, connect cities. However, in the case of trains, functionality depends on the integrity of the track system spanning hundreds of kilometers, as well as the energy which trains use. Considering the experience suffered in the rail system of Sri Lanka as a consequence of extensive damages to the track system in many regions of the country, such a scenario should best be carried out at a national level scale, rather than at the level of a city.

9.5 Human Component in Train Stations

Human Susceptibility of the Main Train Station in the City

One segment of train transportation is related to the main station. As in the case of bus stations and public markets, train stations can be very crowded on certain days of the week and at certain hours. The human susceptibility should be assessed considering the expected number of people that may be in the premises at a given time.

Deficiencies in Preparedness

As in previous cases, deficiencies in preparedness would be linked to the inexistence of dykes or sea walls that may protect the main train station, deficient operation of an early warning system, and the lack of emergency planning related to rapid evacuation to safe areas.

Elaborating the Scenario of Impacts on People in the Main Train Station

To elaborate the scenario of impacts to people in the main train station, one needs to estimate the number of people typically present in such a station, which can vary depending on the size of the city and the time of day. As before, the elaboration of the scenario is carried out by combining data regarding the average number of people in the station, deficiencies in preparedness, and the location of the station with respect to the coast. The following matrix presents the scheme for the calculation.

Table 38: Scenario Matrix – Injuries and Casualties – Main Train Station in the City

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Average number of people in main train station	**1** If there are no sea-walls or levees in place in area where main train station are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **killed** in the main train station.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **killed** and **injured** in the main train station.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **killed** or **injured,** assuming they are evacuated to safe areas.
Moderate exposure level	1	Average number of people in main train station	**1** If there are no sea-walls or levees in place in area where train train station are located.	**1** (no preparedness at all)	number	This outcome expresses the potential number of people **injured** in the main train station.
				0.5 (some degree of preparedness)	number	This outcome expresses the potential number of people **injured** in the main train station.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **injured,** assuming they are evacuated to safe areas.
No exposure	0	Any number of people	Any degree of preparedness and protection measures		0	No people injured or killed.

Example 31: The Main Train Station within the City of Galle

As in the case of the main bus station, the train station in the city of Galle is actually located outside the 200-metre buffer zone, in a particular place where the wave nature of tsunamis enhances the exposure. The station is located next to a river where the tsunami waves can propagate, increasing fatalities and damages.

9.6 Ports

Ports within any city serve not only the city, but the greater region near the port spanning several hundred kilometres. However, the city also benefits from the location of a port within its limits, as the port is also used by the public and private sector within the city to import and export products and as a source of employment within the city.

Functional Susceptibility of Ports Within the City

The functionality of a port is related to its capacity to carry out the tasks of loading and unloading the cargo from ships. Several features are important when considering this function:

1. Channels to enter the docks – captain of port to steer ships into docks;
2. Cranes to load or unload the cargo;
3. Warehouses to store the cargo on a temporary basis;
4. Functionality of internal access roads;
5. Administrative functions regarding processing of shipping activities, including the handling of cargo.

Therefore, it is important to consider all these elements when carrying out the analysis. However, because such elements can vary from port to port, the recommendation is for a special team within the port authority to elaborate the scenario.

Example 32: The Port of Galle

The port of Galle experienced several situations which compromised its functionality. The doors in the warehouses were dislodged and had to be fixed. In the meantime, it was not possible to operate such warehouses in the secure manner required.

In addition, the channel leading to the docks was affected, as debris from the tsunami was deposited on the bottom of such shipping channel, reducing its capacity to allow ships of greater tonnage to enter the port. Furthermore, several ships, including a recently acquired dredge-type ship, were marooned inland and, thus, international assistance was requested to bring such a ship back into the ocean to clear the debris in the channel. Such comments justify the need to carry out not a rapid assessment, but an in-depth assessment of the functionality of a port.

9.7 Religious Temples

Structural Susceptibility of Religious Temples

The structural susceptibility of religious temples is related to their disposition to be damaged or destroyed by a tsunami. Because the construction of religious temples within each religion follows similar norms, it will be considered that all temples have the same susceptibility.

susceptibility = equal for all temples.

Assessing Structural Scenario

To assess the functional scenario of potential damages to temples, one has to combine **E, S,** and **DP.** Proposed outcomes are:

- Proposed number of temples which can be damaged or destroyed in case of a tsunami; and
- Proposed number of temples which will not be damaged or destroyed.

The calculation of these outcomes is carried out via determining the total number of temples within the city and their location with respect to the coast. This information can be obtained from city authorities. The proposed method to elaborate the scenario is presented in table 39.

Table 39: Scenario of Structural/Functional Damages – Religious Temples in the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of temples	1 If there are no protection measures in place. 0 If there are protection measures in place. number	Number	This outcome expresses the potential number of temples **destroyed or not functional.**
Moderate exposure level	1	Number of temples		Number	This outcome expresses the potential number of temples **damaged but may be functional.**
				0	No impacts due to protection measures.
No exposure	0	Number of temples		0	No impacts expected.

Example 33: Potential Damages to Religious Temples within the City of Galle

The city of Galle has twelve religious temples related to different religions. There are six temples located inside the 100 metre area, four of which are situated inside the fort in well protected areas. Another temple is located within the 200 metre buffer area and five outside the 200 metre line.

Scenario of temples facing major destruction = 1 x 2 temples = **2 temples**

Scenario of temples facing no damage = 1 x 10 temples = **10 temples**

A survey carried out by UNU-EHS after in the tsunami indicates that one temple located very close to the shore experienced major damages and is not in use. The other temple is located on a small hill next to the ocean and it did not suffer damages. Map 8, shown on page 93, displays the location of religious temples within the city of Galle.

Functional Susceptibility of Religious Temples

The functionality of religious temples is related to their capacity to allow for the execution of religious services for the population. While segments of the population are usually linked to a particular temple of their choice, having the option of attending services in different temples of the same religion allows for functionality not to be linked explicitly to one temple, but to all temples of the same religion within the city.

10. Commercial Sector

The commercial sector spans all businesses and services provided by the private sector and is traditionally divided into two groups: formal and informal sectors. The characterization of the different types of scenarios associated to this sector in a rapid fashion is complex, especially to come up with figures such as the number of businesses destroyed or damaged, as well as the number of people that could be killed or injured. The uncertainties are associated to the following facts:

- The location and number of businesses associated to the formal and informal groups varies from town to town and is usually dictated by the location of particular landmarks, such as the location of bus and train stations, as well as the location of traditional market areas, and the establishment of commercial areas along certain roads or streets within the city;
- The number of people present in such commercial areas varies from city to city.

To get an idea of the potential number of stores and businesses that could be impacted by a tsunami, a detailed survey of all stores would need to be carried out within the city. The following matrix could be employed to assess such impacts.

Table 40: Scenario of Structural/Functional Damages – Impacts in the Commercial Sector

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of stores and businesses	1 If there are no protection measures in place.	Number	This outcome expresses the potential number of stores and businesses **destroyed or not functional.**
Moderate exposure level	1	Number of stores and businesses	0 If there are protection measures in place. number	Number	This outcome expresses the potential number of stores and businesses **damaged.**
				0	No damages due to protection measures
No exposure	0	Number of stores and businesses		0	No impacts expected.

Example 34: Commercial Segment within the City of Galle

The main street within the city of Galle houses the main commercial area. This street is situated inside the 100 metre buffer zone and one can find more than 100 shops of different kinds here. Because the tsunami took place on a Sunday morning, the street was basically empty. According to comments made by shop owners, in many shops the tsunami did not provoke structural damages to the buildings, but it did destroy the front doors to the premises, ruining merchandise of all kinds stored inside and provoking financial losses to the owners.

11. Financial Sector

The financial sector spans all segments related to banking, stock market, insurance, investments firms, and related financial activities. In many cities, this sector would be characterised in terms of local and international activities. The assessment will focus on banks and similar financial institutions, as in many cities banks comprise the largest and easiest recognisable example of this sector.

11.1 Structural Component

Structural Susceptibility

As stated before, the structural susceptibility of buildings within a city depends on parameters such as the quality of building materials, the engineering design, and the building technique employed. However, it is only through a detailed survey that one can determine the susceptibility of each building considering these three parameters; thus, for a rapid assessment, a compromise has to be accepted in terms of simple parameters:

Structural susceptibility = high for buildings that are only 1-storey high.
= low for buildings that are 2 or more storeys high.

Deficiencies in Preparedness

Deficiencies in this case would span the lack of sea walls and dykes, which could protect the banks from damage due to a tsunami.

Elaborating the Scenario

To elaborate the scenario for any city in terms of banks destroyed or damaged in very general terms, one has to combine **E, S,** and **DP.** Two outcomes are proposed:

- Proposed number of banks destroyed by a tsunami; and
- Proposed number of banks damaged by a tsunami.

The calculation of these outcomes is carried out by determining the total number of banks within the city, their building type and their location, which can be obtained from several sources. The proposed method to elaborate the scenario is presented in table 41.

Table 41: Scenario of Structural Impacts – Banks in the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of banks in city located in one-storey buildings	1 If there are no protection measures in place 0 If there are protection measures in place	Number	This outcome expresses the potential number of banks **destroyed**
		Number of banks in city located in buildings with 2 or more storeys		Number	This outcome expresses the potential number of banks **damaged**
Moderate exposure level	1	Number of banks in city located in one-storey buildings	1 If there are no protection measures in place 0 If there are protection measures in place	Number	This outcome expresses the potential number of banks **damaged**
		Number of banks in city located in buildings with 2 or more storeys		0	No damages expected because buildings are low vulnerable and are located in a moderate exposure area
No exposure	0	Number of banks in this area		0	No damages expected in these banks.

The calculation of the scenario involves locating the banks inside the respective buffer zones, characterising their susceptibility, and making the proper associations according to the table. The outcome of the calculation is an integer number expressing the number of banks which may be destroyed, damaged, and unharmed.

Example 35: Potential Damages to Banks Within the City of Galle

A survey carried out by UNU-EHS indicates that at the time of the tsunami there were 13 public banks within the city and two financial institutions. Three banks were located inside the 100 metre buffer zone (Commercial bank on main street, Bank of Ceylon inside the fort, and Bank of Ruhuna behind the port). Four banks were located in the area between the 100 and 200 metre lines, three were located inside the fort (Bank of Ceylon – two branches – and Seylan Bank), and six banks and two financial agencies were located outside the 200 metre buffer zone:

High exposure area:	1 x 1 bank (one-storey buildings) x 1 (no protection) + 1 x 1 bank (two-storey building) x 1 (no protection) + 1 x 1 bank (two-storey building) x 0 (inside Fort) = **1 bank destroyed + 1 bank damaged.**
Moderate exposure area:	1 x 3 banks x 0 (inside the Fort) + 1 x 1 banks x 1 (one-storey buildings) =**1 bank damaged**
Non exposed area:	6 banks + 2 financial institutions = **6 banks + 2 financial institutions unharmed.**

A visit to the city of Galle one month and a half after the tsunami revealed that Ruhuna Bank, located inside the 100 metre area behind the port, suffered extensive functional damages and was moved to another location, while the other banks did not suffer structural damages. The banks inside the fort did not experience any damages, as they are located on a hill and there is a solid sea wall protecting the entire fort. However, one bank located outside the 200 metre buffer zone suffered damages, as some of its premises were located in the ground floor or in the basement of a three-storey building. Map 9, shown on page 94, displays the location of banks within the city of Galle prior to the 26 December 2004 tsunami.

11.2 Human Component

Susceptibility

The financial sector attracts several customers. However, in most cases, customers are adults rather than children. The susceptibility will be addressed as follows:

Susceptibility = people who are present in banks (staff and customers).

Deficiencies in Preparedness

Deficiencies in preparedness would be linked to the inexistence of sea walls or levees, deficient operation of an early warning system, and the lack of emergency planning related to the capacity to evacuate rapidly to safe areas. As in previous cases, numerical coefficients are as follows:

Deficiencies related to	=	**1**	if neither sea walls or dykes are in place to protect the banks.
Seawalls and levees		**0**	if there are sea walls or dykes protecting the banks.

And:

Deficiencies related to	=	**1**	if neither early warning system nor emergency planning are in place.
Early warning and		**0.5**	if there is an early warning system in place, but no emergency planning.
Emergency planning		**0**	if both an early warning system and emergency planning are in place.

Elaborating the Scenario

To elaborate the scenario for any city in terms of population affected or killed inside banks in very general terms one has to combine **E, S,** and **DP.** The model proposes two outcomes:

- Proposed number of people killed by the tsunami; and
- Proposed number of people injured by the tsunami.

The proposed method to elaborate the scenario is presented in table 42.

Table 42: Scenario Matrix – Casualties and Injuries Inside Banks within the City

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Number of banks inside this area times 30 persons	**1** If there are no sea-walls or levees in place in area where banks are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **killed** in banks.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **killed** and **injured** in banks.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **killed** or **injured,** assuming they are evacuated to safe areas.
Moderate exposure level	1	Number of banks inside this area times 30 persons	**1** If there are no sea-walls or levees in place in area where banks are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **injured** in banks.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **injured** in banks.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **injured,** assuming they are evacuated to safe areas.
No exposure	0	Number of banks inside this area times 30 persons	Any degree of preparedness and protection measures		0	No people injured or killed.

The selection of 30 people inside a banking facility has been made to incorporate an average number of staff at the bank and customers.

Example 36: Potential Injuries and Casualties in Banks Within the City of Galle

At the time of the tsunami, there were three banks inside the 100 metre buffer zone; two of them had no protection via sea walls or dykes and no early warning system was operational. Three of the banks located in the area within the 100 and 200 metre buffer lines were situated inside the fort, and six banks and two financial agencies were situated outside the 200 metre buffer zone.

High exposure area 1 x 2 banks x 30 persons x 1 (no sea walls or levees) x 1 (no EWS nor EP)
+ 1 x 1 bank x 30 persons x 0 (inside Fort) x 1 (no EWS or EP)
= **60 persons killed**

Moderate exposure area 1 x 3 bank x 30 persons x 0 (inside Fort) x 1 (no EWS or EP)
+ 1 x 1 bank x 30 persons x 1 (outside Fort) x 1 (no EWS)
= **30 persons injured**

Non exposed area 1 x 8 institutions x 30 persons
= **240 persons not affected**

Because the tsunami occurred during a holiday, there were no people present in banks.

Functional Scenario

This scenario is basically associated with the potential incapacities of banks and financial agencies to function due to the interruption of lifelines, or the interruption of processes which are carried out within the agencies (safe management of currency, online banking operations and online information exchange among banks within the country, wire transfers, etc.).

Susceptibility

It is to be assumed that all banks should be considered as equally vulnerable in case of tsunamis. Of course, there are differences, but it would take a detailed survey to identify such aspects.

Susceptibility = it will be linked to the destruction, damage, or interruption of lifeline systems within the bank (energy, leased telephone lines). Considering that some banks would be destroyed within the 100 metre buffer zone, it will be assumed that such banks in this segment will be more vulnerable than banks farther inland.

Deficiencies in Preparedness

Deficiencies in this case would span the lack of sea walls and dykes, which could protect the financial agencies from damage due to a tsunami.

Elaborating the Scenario

To elaborate the scenario for any city in terms of functional susceptibility in very general terms, one has to link **Exposure, Susceptibility** and **Deficiencies in Preparedness.** The model proposes two outcomes:

- Proposed number of banks which will experience high degree of loss of functionality; and
- Proposed number of banks which will experience some degree of loss of functionality.

The calculation of these outcomes is carried out via determining the number of banks and their location. The proposed matrix to elaborate the scenario is presented in table 43.

Table 43: Functional Scenario Assessment Matrix for Banks in the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of banks in this segment of the city	1 If there are no protection measures in place 0 If there are protection measures in place number	Number	This outcome expresses the potential number of banks **which will have to shut down operations for at least two weeks while life-lines are restored.**
Moderate exposure level	1	Number of banks in this segment of the city		Number	This outcome expresses the potential number of banks **that will have to cease operations for several days while lifelines are restored.**
No exposure	1	Number of banks in this segment of the city		Number	No functional problems to be associated with these institutions.

Example 37: Potential Impacts to Banking Services within the City of Galle

Functional Scenario (large impact) = 1 x 3 banks = 3 banks
Functional Scenario (moderate impact) = 1 x 3 banks
No Functional Scenario (no impact) = 1 x 6 banks + 2 financial institution = 9 institutions

According to a survey carried by UNU-EHS, one of the three banks located within the 100 metre buffer zone was transferred from one location to another (Bank of Ruhuna, originally behind the port); another bank was out of operation for nearly three weeks (Commercial Bank on main street); and the administrative building of Bank of Ceylon inside the fort did not suffer damages. However, ND bank, outside the 200 metre buffer zone in the building where the Chamber of Commerce is located, suffered major functional damages and was shut down for several weeks. Banks within the 100/200 metre buffer lines, as well as some banks outside the 200 metre buffer zone, experienced functional problems associated with loss of documentation (in paper and in computers), as well as problems with their leased telephone lines. Most of these facilities reinitiated operations within three to five days after the tsunami.

One aspect worth mentioning is the availability of funds to people after a disaster to cope with most basic needs. In the case of banks, the fact that one particular banking company may have several branches within the city may offer a better option for people to cope than a banking company which may only have one branch within a city, forcing people to travel to neighboring cities to find another branch of the same bank.

12. Industrial Sector

The industrial sector spans industries of all types and sizes. The sector focuses on processing and elaboration and a wide variety of products using basic resources, raw materials, and machinery. Because the sector is so complex due to its diversified nature, it is difficult to assess its scenarios in general terms. In the context of natural disasters, additional complications can arise within this sector when chemicals or products used by this sector are dispersed and contaminate the environment (natural-technical disasters), leading to subsequent industrial disasters, etc. Notions regarding susceptibilities which are present within this sector are described as follows.

Susceptibility of Sources of Raw Materials

These would relate to the raw materials that are required to generate products in different industries. In this case, the susceptibility is related to the predisposition of a particular industry to face a reduction in productivity as a consequence of lack of such materials. Such susceptibility can be traced to the means to transport such raw materials to the industry in case such raw materials are produced elsewhere.

Functional Susceptibility

The functional susceptibility in the case of industries is similar to that discussed in previous chapters. However, because industry sometimes demands high amounts of energy and water, the temporal disruption in such services can have a great impact on the functionality of industries even if these are located far inland.

Human Susceptibility

The susceptibility of people when it comes to industries is basically related to the workers. As adults, it is expected that the susceptibility is low when compared to that of schools and health centers in which patients are being treated. Nevertheless, as mentioned before, a natural event like a tsunami could provoke consequences within industries that could lead to fatalities.

Economic Income Susceptibility

The susceptibility of the sector spans losses associated with the destruction of facilities which are required to carry out the commercial aspects.

Deficiencies in Preparedness

Deficiencies in preparedness would be linked to the inexistence or deficient operation of early warning systems, or the lack of sea walls or dykes, as well as those related particularly to plans regarding how to shut down industrial processes prior to the arrival of a tsunami and the lack of industrial safety measures.

In the case of a rapid assessment, the diverse nature of the sector and the location of industrial facilities within any city make it difficult to assess the different types of scenarios. Therefore, it is recommended that an assessment is carried out initially identifying the types of industries that are located in the 200 metre buffer zone.

Example 38: Industries within the City of Galle	
The city of Galle has several industries located in some parts of the city, including some areas next to the coast.	
Cement Factory:	located on the south-eastern segment of the city; this is a large industry. While most of its facilities are just outside the 200 metre buffer line, it is located next to a river that can enhance damages to the plant associated with the tsunami surge.
Ceylon Petroleum	located on the south-eastern segment of the city, this is a large facility that includes storage
Company:	tanks for different types of fuels. A segment of this industry is located within the 100 / 200 metre lines, but it was not affected by the tsunami.

13. Petroleum-Based Energy Sector

The energy-related sector spans sources of energy such as petrol, coal, nuclear, hydraulic, solar, wind-powered, etc., as well as the transformation into electrical energy. However, due to the extensive use of electricity for basic needs, electricity if often grouped under the category of a lifeline. Therefore, this segment of the document will be limited to petrol-derived products. As in the case of lifelines, the elaboration of scenarios will span both the production and the distribution segments.

Damages to Sources

Susceptibility of Sources of Petroleum

Considering the fact that petrol-derived fuels start with their sources, the first segment of the susceptibility analysis would span these sources. Sources of petrol are found both in the oceans, as well as inland. In the case of tsunamis, sources are not contaminated as they are usually found very deep underground, and, thus, it is unlikely that a tsunami could have an impact inside petroleum well. Therefore, the model will assume that there is no exposure in the area where the sources are located and, hence, no scenario of contamination.

Functional Damages to Refineries, Storage Tanks, and Petrol Stations

Functional Susceptibility

The functional susceptibility in the case of petrol sources will be associated with two elements: the refineries to produce fuels such as gasoline, diesel, natural gas, and other similar combustible products; and their large storage facilities, as well as their distribution network, which in the case of gasoline would be the standard stations located throughout the city.

Susceptibility of refineries:	associated with destruction or damage to refineries;
Susceptibility of the storage process:	associated with the potential destruction or damage of storage tanks where these fuels are temporarily stored;
Susceptibility of the network:	associated with destruction or damage of fuel stations within the city.

Deficiencies in Preparedness

Deficiencies in this case would span the lack of sea walls and dykes, which could protect the facilities from damage due to a tsunami.

Elaborating the Scenario

To elaborate the scenario for any city, one again has to combine **E, S,** and **DP.** The approach proposes an outcome related to the proportion of refineries that can be damaged or destroyed by the tsunami. Calculation of the outcome is carried out determining the location of refineries, storage tanks, and the location of the network of gasoline stations located throughout the city.

In the context of refineries, the model proposes three possible outcomes:

- *Long-term disruption of processing of fuel within the city due to extensive damage to refineries if such refineries are located inside the 100 metre buffer zone;*
- *Short-term disruption of processing of fuel within the city due to minor damages to these refineries if located within the 100/200 metre buffer area; and*
- *No disruption of processing of fuel within the city for the case when refineries are located far away from the ocean.*

The proposed matrix to elaborate the scenario regarding potential impacts to refineries is presented in table 44.

Table 44: Scenario Matrix for Refineries – Functionality

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Refineries	**1** If there are no protection measures in place **0** If there are protection measures in place number	Type	This outcome expresses the possibility of **long-term** disruptions in the process of refining of fuels (weeks)
Moderate exposure level	1			Type	This outcome expresses the possibility of **short-term** disruptions in the process of refining fuels (days).
No exposure	0			0	No impacts as stations would not be affected by the tsunami due to their location outside the exposed areas.

In the context of storage tanks, deficiencies in preparedness relate again to the lack of sea walls or dykes, as well as to the lack of measures which would be taken to minimise contamination should pipelines leak stored fuel if a tsunami was to damage them. It is interesting to note that empty storage tanks may float, and, thus, can be dislodged from their bases (Scawthorn, 2006 b). Table 45 is used to identify potential damages to such storage tanks.

Table 45: Scenario Matrix – Storage Tanks

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Storage tanks	**1** If there are no protection measures in place **0** If there are protection measures in place number	Type	This outcome expresses the possibility of **long-term** disruptions in the delivery of fuel to the city (weeks) – destruction of storage tanks
Moderate exposure level	1			Type	This outcome expresses the possibility of **short-term** disruptions in the delivery of fuel to the city (days) - damage to tanks
No exposure	0			0	No disruption of delivery of fuels to fuel stations due to location of tanks outside the exposed area.

In the context of the network of fuel stations within the city, the model proposes three possible outcomes: long-term disruption of distribution of fuel within the city due to extensive damage to all or most stations; short-term disruption of the service within the city due to damage to few stations; and no disruption of the service should all stations be located far inland.

Table 46: Scenario Matrix – Distribution Network Within the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	All fuel stations	**1** If there are no protection measures in place **0** If there are protection measures in place number	Number	This outcome expresses the number of gasoline stations that could be **destroyed**
Moderate exposure level	1			Number	This outcome expresses the number of gas stations which could be **damaged**, leading to temporary disruption of the service.
No exposure	1			0	No damage as gasoline stations due to their location outside the exposed areas.

Example 39: Potential Disruption in Access to Fuel Within the City of Galle

According to a survey carried out by UNU-EHS, there are no refineries within the city and the storage tanks are located outside the 200 metre buffer zone. Therefore, with respect to refineries and storage tanks, there is no scenario of short or long-term disruption because of destruction or damage to refineries:

Scenario (long-term disruption) = 1 x 0 refineries = **no scenario of long-term disruption.**

With respect to storage tanks, one should not expect any disruption, as tanks and their adjacent hardware are located nearly 700 metres away from the ocean shore.

Scenario (short-term disruption) = 0 x 6 storage tanks = **no scenario of disruption.**

According to reports by personnel from the Ceylon Petroleum Company operating the storage facility, there were no damages to the tanks; hence, there was no disruption in the supply to the network of gas stations.

With respect to the distribution network (gasoline stations), a survey by UNU-EHS indicates that there are nine gasoline stations in the city. Three are located inside the 100 metre buffer zone, two are located inside the 100/200 metre buffer zone (one inside the fort) and four are located outside the 200 metre buffer zone.

Scenario (destroyed) = 1 x 3 stations x 1(DP) = **3 stations**

Scenario (damaged) = 1 x 2 station x 0 (DP) = **2 station**

No damages = 1 x 4 stations = **4 stations**

Within the city, the three stations inside the 100 metre buffer zone experienced destruction of the fuel pumps as these were dislodged from their bases, and storage tanks were contaminated, requiring several days to weeks to be brought back on line. The station located within the 100 and 200 metre lines inside the fort on an elevated hill was not affected, but the remaining one was. The other four stations did not suffer any damage as proposed in the model. Map 10, on page 95, displays the location of fuel stations within the city of Galle.

13.1 Human Component

Human Susceptibility

The susceptibility of fuel stations when it comes to people is rather low, as customers and employees can be considered as a low vulnerable group of people within any city. In addition, fuel stations do not usually involve masses of people, such as bus stands or train stations. Therefore, human susceptibility can be considered in general as low.

Deficiencies in Preparedness

Deficiencies in preparedness would be linked to lack of sea walls or dykes, the inexistence or deficient operation of an early warning system, and the lack of emergency planning and capacity to evacuate rapidly to safe areas.

Deficiencies in preparedness	= **1**	if neither sea walls or dykes nor early warning system are in place;
	0.5	if there is an early warning system in place, but no sea walls or dykes;
	0	if both sea walls or dykes and an early warning system are in place.

Elaborating the Scenario

To assess the gender scenario of the fuel stations within any city, one has to combine **E, S,** and **DP.** The model proposes two outcomes:

- Proposed number of people which could be killed or fatally wounded; and
- Proposed number of people injured.

It will be assumed that if the number of people present in a gas station does not exceed more than 20 persons per station on average at any given instant of time, then the following matrix is proposed:

Table 47: Scenario Matrix –Injuries and Casualties – People in Fuel Stations

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Number of stations inside this area times 20 persons	**1** If there are no sea-walls or levees in place in area where fuel stations are located	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **killed** in fuel stations.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **killed** and **injured** in fuel stations.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **killed** or **injured,** assuming they are evacuated to safe areas.
Moderate exposure level	1	Number of stations inside this area times 20 persons	**1** If there are no sea-walls or levees in place in area where fuel stations are located	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **injured** in fuel stations.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **injured** in fuel stations.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **injured,** assuming they are evacuated to safe areas.
No exposure	0	Number of stations inside this area times 20 persons.	Any degree of preparedness and protection measures		0	No people injured or killed.

The model proposes three possible outcomes: number of people potentially killed, number of people potentially injured and number of people unharmed by the tsunami.

Example 40: Potential Impacts to People in Petrol Stations in the City of Galle

According to a survey carried out by UNU-EHS, there are nine fuel stations in the city. Three are located inside the 100 metre buffer zone, two are located inside the 200 metre buffer zone and four are located outside the 200 metre buffer zone. Of the two stations inside the 200 metre buffer zone, one is located inside the fort, in a well protected area.

Scenario (killed) = 1 x 3 stations x 20 people = **60 people killed**

Scenario (injured) = 1 x 1 stations x 20 people = **20 people injured**

No Scenario (not affected) = 1 x 4 stations x 20 people = **80 people not affected**

Because the tsunami took place in the morning of a holiday, few people may have been present in petrol stations. In addition, there is no data regarding people killed or injured in such stations, as such information is not usually addressed in post-event surveys.

13.2 Economic Income Component

Economic Income Susceptibility

The susceptibility of the sector spans losses associated with the destruction of facilities that are required to carry out the commercial aspects (basically fuel stations): the contamination and, thus, loss of product (fuel coming into contact with the tsunami surge would need to be reprocessed again in some kind of refinery), the loss of cash handled in fuel stations by employees, as well as credit vouchers.

Deficiencies in Preparedness

Deficiencies in preparedness are linked to the inexistence or deficient operation of an insurance system to cover such losses, as well as the lack of an early warning system.

Deficiencies in preparedness	=	**1**	if no insurance or early warning system is in place;
		0.5	limited insurance coverage or early warning system is in place;
		0	if both insurance and an early warning system are in place.

To assess the economic income losses of the sector within any city, one has to combine **E, S,** and **DP.** Such losses would include damage or destruction of infrastructure and equipment (pumps), loss of product (contamination of fuels with the tsunami surge), incapacity to sell the product (fuel) due to destruction of network of gas stations, as well as loss of cash and standing credit vouchers. However, it is difficult to provide a theoretical framework to estimate such losses as there is insufficient data at this time.

Example 41: Economic Losses in Petrol Stations Within the City of Galle

According to interviews carried out by UNU-EHS targeting owners of petrol stations within the city, most losses were due to the destruction of credit vouchers kept in the office. Such vouchers would be accumulated and stored within the office until the end of the month prior to their processing. Owners also reported the loss of cash, as well as the need for financial and technical assistance to restore the services in many cases.

14. Telecommunications Sector

The telecommunications sector spans all segments related to communications via telephone, fax, Internet, and satellite communications. In many cities, this sector would be characterised in terms of local, national, and international activities. For this assessment, efforts will concentrate on telephones, as these are the basis for standard voice communications, fax, and Internet.

Scenario of Structural Damages

The scenario of structural damages for this sector comprises the infrastructure which is used by agencies belonging to this sector, particularly the building which hosts the administration and operations of such sector.

Structural Susceptibility

As stated before, the structural susceptibility of buildings within a city depends on parameters such as the quality of building materials, the engineering design, and the building technique employed. However, it is only through a detailed survey that one can determine the susceptibility of each building considering these three parameters; thus, for a rapid assessment, a compromise has to be accepted in terms of assigning two degrees of susceptibility related to the number of storeys of each building.

Structural susceptibility = high for buildings which are only one-storey high.
= low for buildings which are 2 or more storeys high.

Deficiencies in Preparedness

Deficiencies in this case would span the lack of sea walls and dykes, which could protect the buildings used by the telecommunications sector.

Elaborating the Scenario of Damages to Telecommunication Buildings

The model proposes two outcomes:

- Proposed number of buildings destroyed by a tsunami; and
- Proposed number of buildings damaged by a tsunami.

The calculation of these outcomes is carried out via locating the buildings that host such towers and antennas. The proposed matrix to elaborate the scenario is presented in table 48.

Table 48: Scenario Matrix – Buildings in the City that Host Towers and Antennas

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of facilities in the city located in one-storey buildings	1 if there are no protection measures in place 0 if there are protection measures in place number	Number	This outcome expresses the potential number of buildings **destroyed**
		Number of facilities in the city located in buildings with 2 or more storeys		Number	This outcome expresses the potential number of buildings **damaged**
Moderate exposure level	1	Number of facilities in the city located in one-storey buildings		Number	This outcome expresses the potential number of **damaged**
Moderate exposure level	1	Number of facilities in the city located in buildings with 2 or more storeys		0	No damages because buildings are low vulnerable and are located in a moderate exposure level
No exposure	0	Number of facilities in the city		0	No damages because buildings are located outside the exposed areas.

The calculation of the scenario involves characterising the buildings´ susceptibilities, and making the proper associations according to the table. The outcome of the calculation is an integer number expressing number of buildings that could be damaged or destroyed.

> ***Example 42: Telecommunication Facilities in the City of Galle***
>
> A survey carried out by UNU-EHS indicates that the Sri Lanka Telephone building is located outside the 200 metre buffer zone.

Structural Susceptibility of Towers and Antennas

The structural susceptibility of towers and antennas for telephone, cellular and microwave communications has to consider their weakness when being hit by large, floating debris (Ballantyne, 2006 b). However, in some cases, such towers and antennas are located on the roof of large buildings, and, thus, the contact with such debris does not take place in case of a tsunami. Therefore, the following model is proposed to characterize the susceptibility of towers.

Structural susceptibility = high for towers and antennas located in ground level; and
= very low for towers and antennas located on roofs of buildings.

Deficiencies in Preparedness

As before, these would span the lack of sea walls and dykes.

Elaborating the Scenario of Damages to Towers and Antennas

To elaborate the scenario for any city in terms of towers and antennas destroyed or damaged in very general terms, one has to combine the three proposed terms **E, S,** and **DP.** The proposed outcomes would be:

- Proposed number of towers and antennas destroyed by a tsunami;
- Proposed number of towers and antennas damaged by a tsunami; and
- Proposed number of towers and antennas not damaged or destroyed by a tsunami.

The calculation of these outcomes is carried out determining the location of towers and antennas within the city and if these towers and antennas are situated on the ground or on top of buildings.

The proposed matrix to elaborate the scenario is presented in table 49.

Table 49: Structural Scenario Assessment Matrix for Towers and Antennas in the City

Exposure		Susceptibility	Def. in Prep.	Outcome	Comment
High exposure level	1	Number of towers located at the ground level	1 If there are no protection measures in place 0 If there are protection measures in place number	Number	This outcome expresses the potential number of towers which can be **destroyed**
		Number of towers located on top of buildings		Number	This outcome expresses the potential number of towers that can be **damaged**
Moderate exposure level	1	Number of towers located at the ground level		Number	This outcome expresses the potential number of towers that can be **damaged**
		Number of towers located on top of buildings		Number	No damages expected
No exposure	1	Number of towers located on the roof of buildings or on hills			No damages expected

The model proposes that there will be no damages to towers or antennas located on top of buildings located within the 100/200 metre buffer zone, even if there are no preparedness measures in place.

Example 43: Telecommunication Towers and Antennas within the City of Galle

A survey carried out by UNU-EHS indicates that there are at least six towers and antennas used by the telephone companies in Galle (Sri Lanka Telephone Company and cellular telephone operators). One of these antennas is located in the 100/200 metre buffer zone on top of a two-storey building. The other antennas are located outside the buffer zones; hence, there is no expectation of damages to such towers within the city.

14.1 Human Component

Susceptibility

The telecommunications sector attracts several customers, but basically such customers do not visit the facilities often once the services have been established. The susceptibility will be related to the staff working in the buildings used by the telecommunications company.

Deficiencies in Preparedness

Deficiencies in preparedness are linked to lack of sea walls or dykes, the inexistence or deficient operation of an early warning system, and the lack of emergency planning and capacity to evacuate rapidly to safe areas.

Deficiencies	= 1	if neither sea walls or dykes nor early warning system are in place;
in preparedness	= 0.5	if there is an early warning system in place, but no sea walls or dykes; and
	= 0	if both sea walls or dykes and an early warning system are in place.

Elaborating the Scenario of Casualties and Injuries

- To elaborate the scenario for any employees injured or killed in these agencies in very general terms, one has to combine **E, S,** and **DP.** The proposed method to elaborate the scenario is presented in table 50.

Table 50: Scenario Matrix – Injuries and Casualties in Telecommunication Agencies within the City

Exposure		Susceptibility	Deficiencies in Preparedness		Outcome	Comment
High exposure level	1	Number of employees in facilities in this area.	**1** If there are no sea-walls or levees in place in area where these facilities are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **killed** in these facilities.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **killed** and **injured** in these facilities.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **killed** or **injured,** assuming they are evacuated to safe areas.
Moderate exposure level	1	Number of employees in facilities in this area.	**1** If there are no sea-walls or levees in place in area where these facilities are located.	**1** (no preparedness at all)	Number	This outcome expresses the potential number of people **injured** in these facilities.
				0.5 (some degree of preparedness)	Number	This outcome expresses the potential number of people **injured** in these facilities.
			0 If there are protection measures in place.	**0** (good degree of preparedness)	0	**No** people **injured,** assuming they are evacuated to safe areas.
No exposure	0	Any number of persons	Any degree of preparedness and protection measures		0	No people injured or killed.

Example 44: Telecommunication Facilities in the City of Galle

A survey carried out by UNU-EHS indicates that all facilities of the telephone company are in a non- exposure area; thus, no fatalities or injuries are expected.

14.2 Functional Component

This scenario is basically associated with the potential incapacity of the sector to provide normal telephone-based communications to their customers. Such a scenario would be associated with either the lack of electricity or the damage or destruction of the equipment used for such telecommunications. However, it is important to make a difference between telephone communications requiring copper cable to link physical telephones and those communications that are based on cellular telephones which do not need such network. Thus, the functional scenario regarding cellular communications would be linked to structural susceptibility and the supply of electrical energy to operate all equipment. In contrast, standard telephone communication relying on a network of copper wires would be more vulnerable, especially for those users in coastal areas whose functionality depends on the network and its structural susceptibility. In either case, the functional scenario could be associated to the structural scenario.

14.3 Economic Income Scenario

This scenario is associated with the potential loss of income that the telephone company has to face if telecommunications are not available within a certain period of time. The estimation of this scenario is complicated, as basic telephone services span not only local calls within the city, but calls within the country or even long-distance calls to other countries. Therefore, estimating potential loss of income associated with inability to provide the service is beyond the scope of this method of rapid assessment.

15. Concluding Remarks

The devastation caused by the 26 December 2004 tsunami in several Asian nations provoked damages and destruction patterns in many sectors in many cities, such as Galle, Matara, Batticaloa, and Hambantota in Sri Lanka. Among the lessons learned from this tsunami on issues of disaster preparedness, the fact that stands out is the spectrum of impacts and damages spanning many sectors, such as housing, life-lines, education, health, commerce, finance, energy, etc. The approach to assess tsunami scenarios presented in this document is an initial effort to systematise potential damages in such sectors and to present the results in terms of simple outcomes that can be interpreted by decision makers. The format in terms of such simple outcomes stems from the need to be able to elaborate broader emergency plans and to warn institutional authorities regarding potential impacts using figures and outcomes that they can interpret easily. However, it must be stressed again that the proposed approach is designed to look at impacts provoked only by tsunamis and does not attempt to characterise impacts related to earthquakes, which are followed by tsunamis. The combination of impacts related to such earthquakes followed by tsunamis is more difficult to model, as earthquakes may enhance the susceptibility of structures and provoke damages that may be difficult to separate from those associated to tsunamis alone.

The proposed framework to elaborate scenarios is based on the concepts of exposition, susceptibility, and deficiencies in preparedness. It has been structured in terms of tables and matrices to identify and quantify potential impacts in most sectors. The document complements the presentation of the framework with examples on how to use such matrices stemming from the city of Galle and the impacts it expe-rienced due to the recent tsunami. In this sense, it fulfills an objective of serving not only as a report of the situation in the particular case of the city of Galle, but as a tool for the elaboration of such assessments in any coastal city. The comparison between proposed outcomes and impacts provoked by the 26 December 2004 tsunami in Galle outlines the need to carry out more in-depth assessments of susceptibilities in the particular cases of lifelines (water, electricity, and sewage systems), health (hospitals), industries, and the commercial sector which are out of the scope of this simple model.

From the perspective of the city of Galle, the application of the model leads to certain conclusions that are summarised in this document. However, the fact that the tsunami took place on a Sunday morning, during a holiday, has not allowed the testing of several proposed outcomes, in particular those related to human impacts in many facilities, particularly in schools. In regards to structural damages, it can be concluded that the model is able to predict fairly well the damages observed in many sectors, although, as mentioned above, in the case of the housing district, the model provides outcomes which display discrepancies with those observed. However, in the other ten sectors, the model predictions agree fairly well with the observed impacts. In the segment related to human impacts, it has been difficult to compare the proposed outcomes with actual impacts. In some cases, the fact that the tsunami took place on a weekend and holiday made it impossible to carry out such a comparison. In other cases, there was insufficient data within the official damage reports to be able to carry out the comparison. In the case of the functional component, the proposed outcomes agree fairly well with the impacts observed in several sectors. Nevertheless, it is difficult to compare them in the case of particular sectors due to the day on which the tsunami took place. The weakest segment in the model is related to the economic component, which is very difficult to systematise as there are too many variations to be handled by a simple model. However, some guidelines and examples from the city of Galle help identify critical issues that may be important to consider, such as the issue of paper credit vouchers, which, when destroyed, have to be absorbed as losses.

Regarding potential applications, the proposed model in terms of exposure, susceptibility, and deficiencies in preparedness should allow emergency planners to identify existing weaknesses in particular sectors and to identify potential measures that can lead to the reduction in the impacts of a tsunami in the future. The splitting of impacts in components like structural damages or destruction, human impacts in terms of injuries and fatalities, functional impacts in terms of short or long-term disruption of services, and if feasible, economic impacts, is a way forward in being able to identify which measures could be set up to reduce such impacts. While the proposed model can predict outcomes in a reasonable fashion in the framework of such development sectors, its testing within the city of Galle also displays its weakness in forecasting outcomes with high precision. In this context, it is important to note that an enhanced precision in the modeling of impacts can only come with the execution of in-depth studies regarding how a tsunami wave will propagate through a specific portion of land, as well as a more precise characterisation of susceptibilities. Unfortunately, such in-depth studies are, in many cases, out of the scope of the budgets allocated by urban authorities for this purpose. Therefore, a tradeoff must be achieved in terms of the precision of the proposed results and the available funding targeted to carry out such an assessment, which can be very limited in the case of a city in a developing country. The proposed model is such an alternative; a starting point regarding this issue.

While the document may seem redundant to any reader, the 50 tables presented characterise the scenarios for the eleven sectors that have been incorporated into the framework. In this context, the document should be interpreted as providing a picture as complete as possible, rather than leave the responsibility to the reader to perform the extrapolation from a few examples within some sectors to all eleven sectors. When considering the target for this document as the coordinator of an inter-institutional emergency committee in any city, this completeness allows the coordinator to direct persons in charge of specific sectors to the explicit sections within the text.

One of the main targets when elaborating this framework has been to present the potential outcomes in terms of quantities or parameters that are simple to interpret and can be compared with impacts. As stated before, such a target is seen by the author as necessary when attempting to reach those disaster managers in developing countries who need simple tools and direct quantities to which they can relate. The use of an index with outcomes presented in terms of numerical quantities related to an unfamiliar scale may not fulfill this need; although, it seems to be common among development planners and academicians. Vulnerability assessments and risk indices developed at many levels (from local to national) have resulted in nice posters that cannot be interpreted in their full capacity by such emergency managers, only to find their places on walls for some time before being replaced by other posters. In a similar fashion, the use of qualitative approaches may also lead to a vague impression regarding how the situation really is, as descriptors such as low, moderate and high may not capture the proper picture that should be presented.

Concerning further developments to the framework, a review of the proposed outcomes and the real impacts within the city of Galle allows for the identification of several ways forward:

- There is, of course, a need to characterise more precisely the inventory of houses and buildings within the buffer zones so that the assessment can be improved in terms of precision. The complementary use of susceptibility information, derived by structural engineers related to different types of structures when it comes to tsunamis, will then allow emergency managers to forecast more precisely the potential impacts of a future tsunami. Along these lines, structural engineers should also carry out research regarding such assessments, in particular with respect to how to incorporate the shielding effect of solid infrastructure near the coast when trying to assess potential impacts behind such infrastructure.

- There is a need to characterise in a more precise way the benefits of sea walls or dykes and those related to an efficient early warning system. As it has been mentioned in the literature, Indian coastal cities protected by strong sea walls during the 26 December 2004 tsunami experienced minimal damages when compared to cities without such protection. The fort of Galle proved to be a solid measure in terms of protecting all infrastructure within its walls from being destroyed; however, minor damages related to inundation took place even inside the fort in low-lying areas because nobody had instructions to close the gates prior to the tsunami.
- The wavelike nature of tsunamis needs to be better modeled in the context of cities with harbours and bays, such as in the case of Galle. Particular places within the city experienced a larger impact due to this effect.

Regarding current technological tools related to geographical positioning and mapping, the use of GPS devices linked to a geographical information system has been employed quite successfully in this case and would be recommended; even though the process can be done using simpler methods.

In conclusion, it is important to recognise that in the context of disaster prevention, much has been advanced through the systematisation of damages observed after events. Structural engineers have been able to derive less susceptible building techniques based on the systematisation of damages observed as a consequence of earthquakes of different magnitudes. This document follows such an approach in the context of presenting a systematisation of damages spanning eleven sectors related to tsunamis, with the goal that agencies in charge of such sectors may develop measures that may reduce the impact of tsunamis in the future, leading to a more sustainable development.

List of Tables

List of Maps

Acronyms

DMC	Disaster Management Centre, Sri Lanka
EERI	Earthquake Engineering Research Institute
EP	Emergency Planning
EWS	Early Warning System
GIS	Geographical Information Systems
HIC-OCHA	Humanitarian Information Centre, OCHA
IOC-UNESCO	Intergovernmental Oceanographic Commission of UNESCO
ISDR	International Strategy for Disaster Reduction of the United Nations
OCHA	Organization for Coordination of Humanitarian Assistance
PAHO	Pan American Health Organization
PPEW-ISDR	Platform for the Promotion of Early Warning of UN-ISDR
UNESCO	United Nations Education, Science and Culture Organization
UNU	United Nations University
UNU-EHS	Institute for Environment and Human Security, UNU
UNV	United Nations Volunteers Organization
WHO	World Health Organization

References

Alwang, J.; Siegel, P. B.; Jorgensen S. L. (2001): Vulnerability, a View from Different Disciplines. In: *Social Protection Discussion Paper Series No. 115.* Social Protection Unit, Human Development Network, The World Bank.

Ballantyne, A. (2006 a): Sri Lanka Lifelines after the December 2004 Great Sumatra Earthquake. In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page 552.

Ballantyne, A. (2006 b): Sri Lanka Lifelines after the December 2004 Great Sumatra Earthquake. In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page 557.

Birkmann, J. (2006): *Measuring the un-measurable.* UNU-EHS SOURCE 5/2006. Bonn, Germany.

Brooks, N. (2003): *Vulnerability, risk and adaptation: a conceptual framework.* Tyndall Working Paper No. 38, Tyndall Centre for Climate Change Research. November 2004.

Edwards, C. (2006): Thailand Lifelines after the December 2004 Great Sumatra Earthquake and Indian Ocean Tsunami. In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page 646.

Guha-Sapir, D.; Parry, L.V.; Degomme, O.; Joshi, P.C.; Saulina Arnold, J.P. (2006): *Risk factors for mortality and injury: post-tsunami epidemiological findings from Tamil Nadu.* CRED, School of Public Health, Catholic University of Louvain, Brussels, Belgium, April, 2006. <http://www.em-dat.net/documents/Publication/RiskFactorsMortalityInjury.pdf>, 22 February 2008.

PAHO/WHO (2000): *Principles of Disaster Mitigation in Health Facilities.* Disaster Mitigation Series, Washington, D.C. < http://www.paho.org/English/PED/fundaeng.htm >, 28 October 2004.

PPEW (2006): *Basics of Early Warning.* <http://www.unisdr.org/ppew/whats-ew/basics-ew.htm>, 26 March 2008.

Scawthorn, C.; Ono, Y.; Iemura, H.; Ridha, M.; and Purwanto, B. (2006 a): Performance of Lifelines in Banda Aceh, Indonesia, during the December 2004 Great Sumatra Earthquake and Tsunami. In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page S 529.

Scawthorn, C.; Ono, Y.; Iemura, H.; Ridha, M.; and Purwanto, B. (2006 b): Performance of Lifelines in Banda Aceh, Indonesia, during the December 2004 Great Sumatra Earthquake and Tsunami. In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page 532.

Sheth, A.; Sanyal, S.; Jaiswal, A.; and Gandhi, P. (2006): Effects of the December 2004 Indian Ocean Tsunami on the Indian Mainland. In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page 467.

Tang, A.; Ames, D.; Murugesh, G.; Plant, G.; Yashinsky, M.; Eskijian, M.; Surrampalli, R.; Murthy, P.A.K.; Prasad, M.; and Ghandi, P. (2006 a): Coastal Indian Lifelines after the 2004 Great Sumatra Earthquake and Indian Ocean Tsunami. In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page 635.

Tang, A.; Ames, D.; Murugesh, G.; Plant, G.; Yashinsky, M.; Eskijian, M.; Surrampalli, R.; Murthy, P.A.K.; Prasad, M.; and Ghandi, P. (2006 b): *Coastal Indian Lifelines after the 2004 Great Sumatra Earthquake and Indian Ocean Tsunami.* In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page 608.

Tang, A.; Ames, D.; Murugesh, G.; Plant, G.; Yashinsky, M.; Eskijian, M.; Surrampalli, R.; Murthy, P.A.K.; Prasad, M.; and Ghandi, P. (2006 c): *Coastal Indian Lifelines after the 2004 Great Sumatra Earthquake and Indian Ocean Tsunami.* In: *Earthquake Spectra, Special Issue III,* Vol. 22, June 2006, page 633.

Thywissen, K. (2006): *Components of Risk. A Comparative Glossary.* UNU-EHS SOURCE 2/2006. Bonn, Germany.

Villagrán, J.C. (2006): *Vulnerability: a conceptual and methodological review.* UNU-EHS SOURCE 4/2006. Bonn, Germany.

Villagrán, J.C. (2001): La Naturaleza de los Riesgos, un Enfoque Conceptual. In: *Aportes para el Desarrollo Sostenible,* CIMDEN, Guatemala.

Watts, M.J.; Bohle, H.G. (1993): The Space of Vulnerability: the Causal Structure of Hunger and Famine. In: *Progress in Human Geography.* Vol. 17, No.1, pp. 43-67.

Wilches-Chaux, G. (1993): *Los Desastres no son Naturales.* Compiled by A. Maskrey, Tercer Mundo Editores, Botogá, Colombia.

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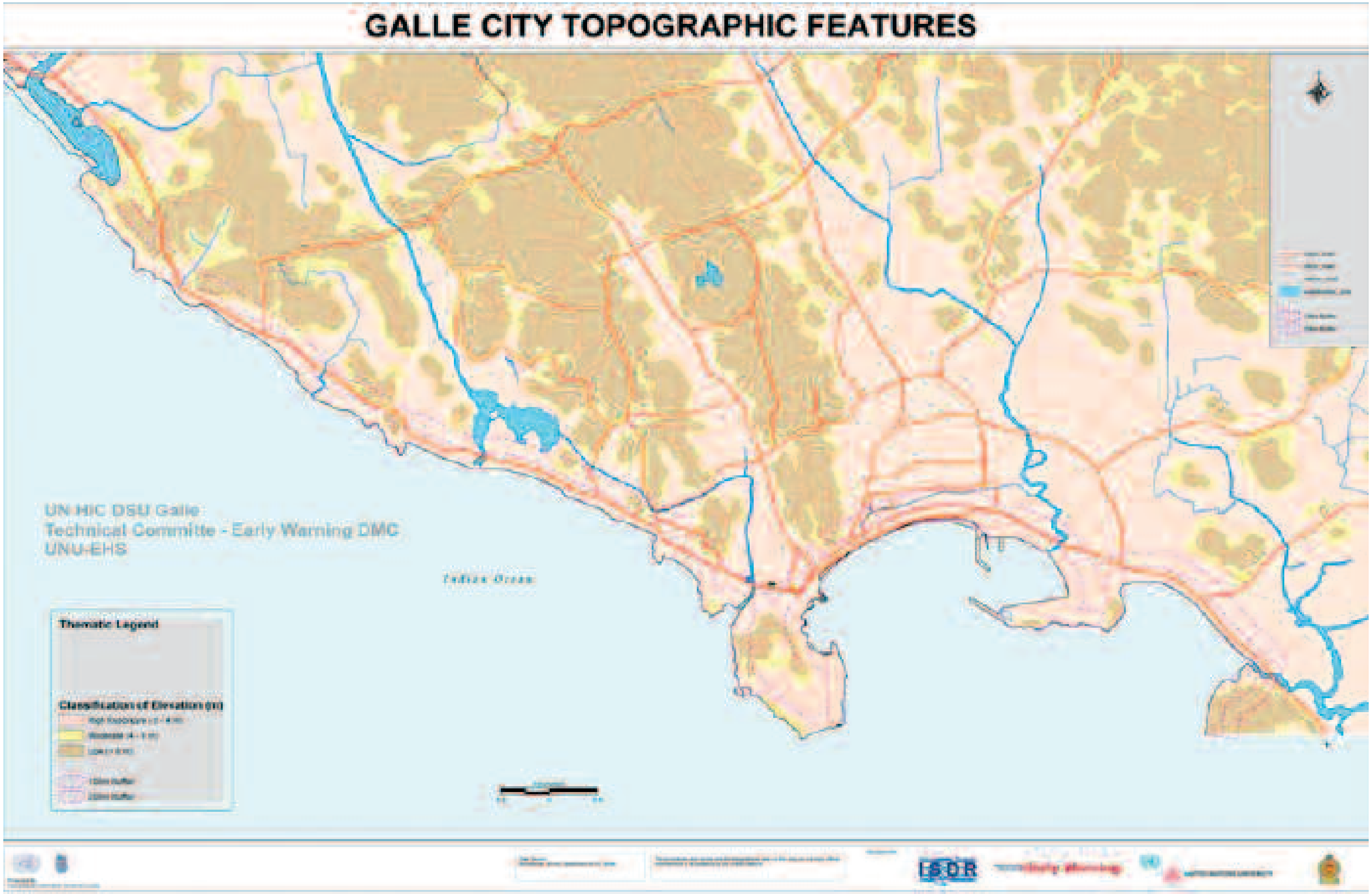
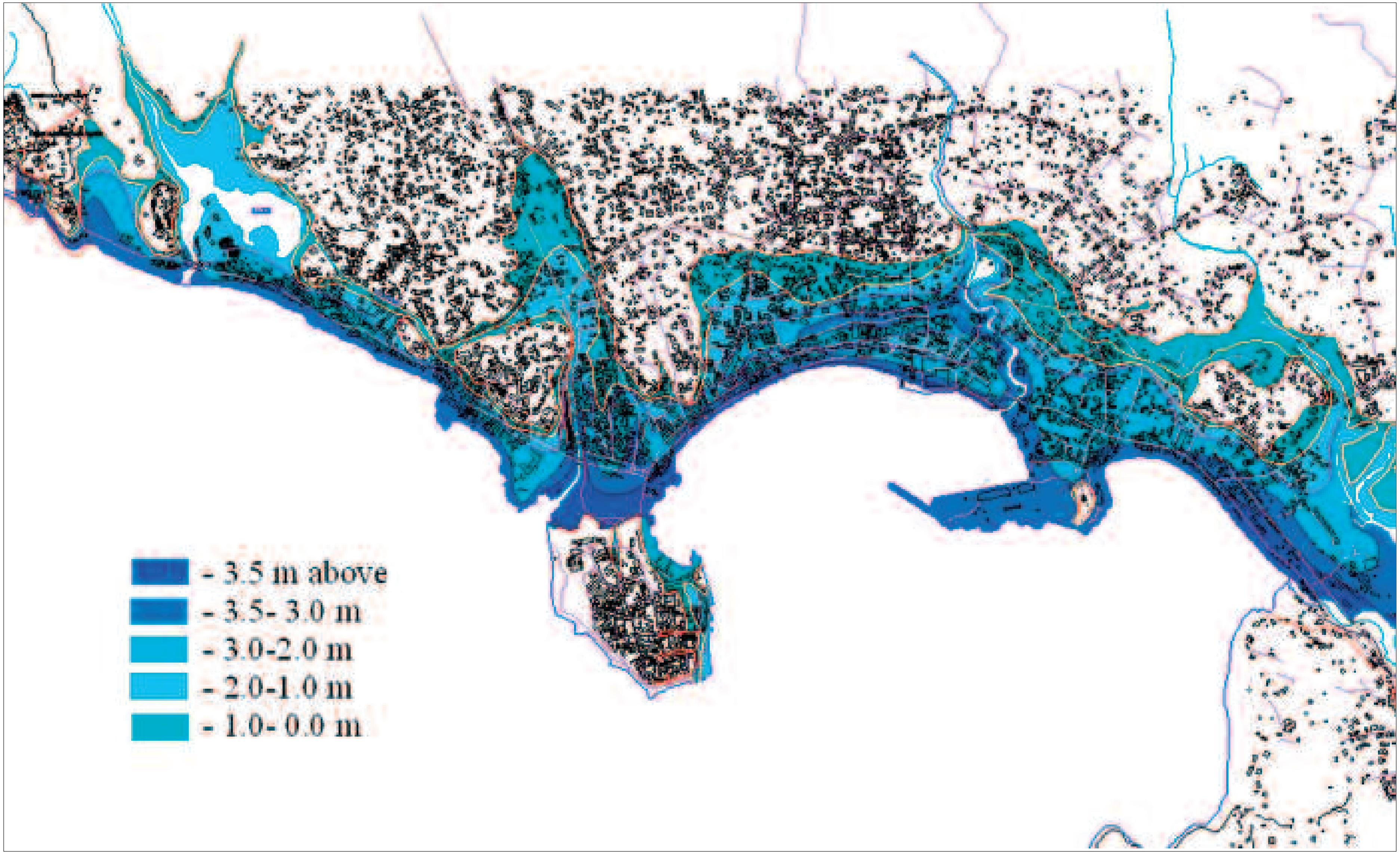
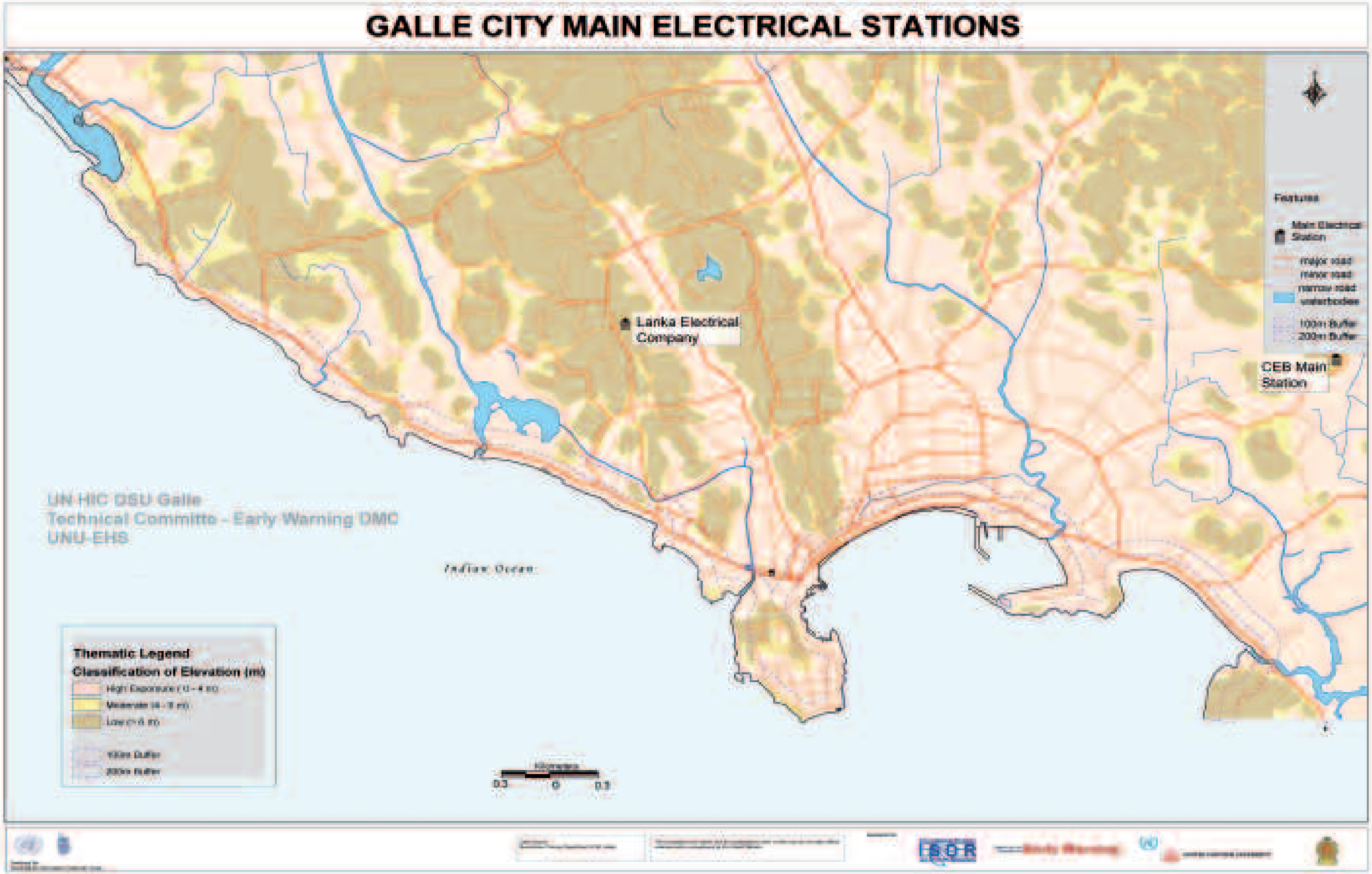


Map 1: Topographic Features of the City of Galle, Road and River Network. Demarcation of 100 Meter and 200 Meter Buffer Lines



Map 2: Inundation Levels in Galle City Associated to the 26 December 2004 tsunami
Source: S.L.L. Hettiarachchi, and N. Wijeratne



Map 3: Location of Main Electrical Stations in the City of Galle

Map 4: Location of Health Centers in the City of Galle

LOCATION OF SCHOOLS AND COLLEGES – GALLE CITY

Map 5: Location of Schools Within the City of Galle

LOCATION OF GOVERNMENT INSTITUTIONS – GALLE CITY

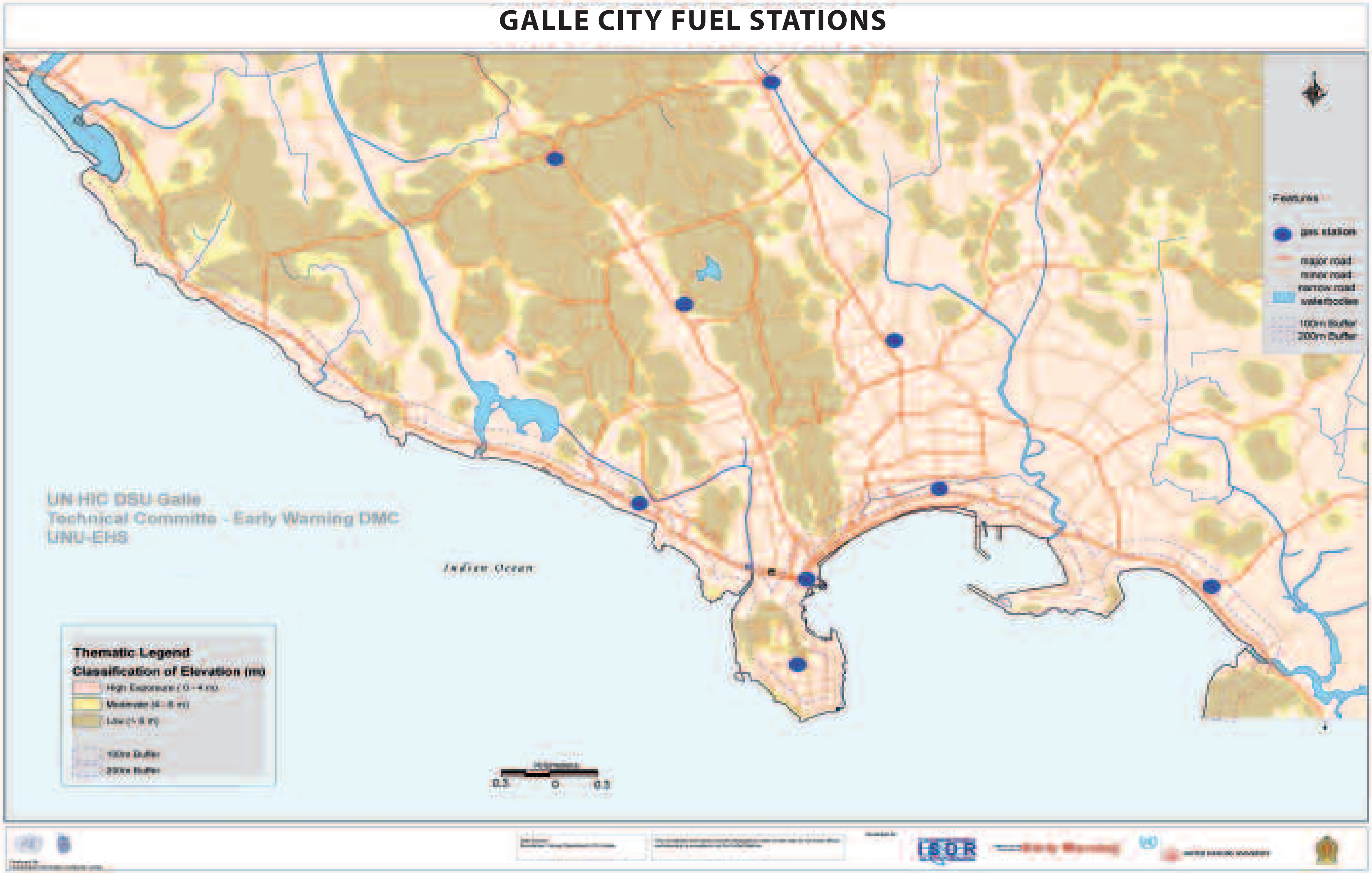
Map 6: Location of Government Buildings Within the City of Galle

Map 7: Location of Public Markets Within the City of Galle

LOCATIONS OF RELIGIOUS PLACES – GALLE CITY

Map 8: Location of Several Religious Temples Within the City of Galle

Map 9: Location of Private Banks Within the City of Galle



Map 10: Location of Fuel Stations Within the City of Galle

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UN Campus
Hermann-Ehlers-Str. 10
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Tel: ++49 (0) 228 815-0200
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