A RISK ASSESSMENT FRAMEWORK FOR LAND USE PLANNING – PART 1: INTRODUCTION, ESTABLISHING CONTEXT AND ASSESS VALUABLE ASSETS

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Abstract

Risk assessment is a crucial element of land-use planning in order to achieve a safe, sustainable and resilient society. Decisions concerning land-use may have impacts on society on long-term (several decades) which means they need to be based on a sound knowledge basis. In addition, if risks can be taken into account at an early planning stage, the opportunities will increase to find effective and cost-efficient solutions where risks can be balanced successfully with other important societal concerns. This chapter outlines a risk assessment framework, including methodological guidance, that can be used to obtain a holistic perspective on hazards, vulnerabilities and risks within a geographical area, such as a municipality, part of a municipality or a district. The chapter also provides a more detailed description and exemplification of the first two steps of the framework: Establish the purpose and context, and Assess valuable assets. These two steps provide the foundation for the subsequent steps of the framework.

Keywords: *Risk assessment, Land-use planning, Assessment framework, Establish context, Assess valuable assets.*

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1. INTRODUCTION

Risk assessment concerns the identification, analysis and evaluation of risks and it provides a foundation for how to treat risks (ISO 31000, 2018). Assessing risks, and subsequently treating risks, is a crucial element of land-use planning since an important strategic goal in most countries is to develop a safe, sustainable and resilient society. Without systematically assessing risks, there is no basis for decisions concerning how to develop land-use planning proposals that is able to treat the risks in effective and cost-efficient ways so that in the end the risks are acceptable.

Land-use planning constitutes a process for deciding how to utilize land and water in a district, municipality, region or country. It is strategic in the sense that it concerns planning for the way a community should be developed in the future (up to several decades in the future). Moreover, land use planning is one of several planning processes conducted in parallel to other types of planning, such as for example economic planning, infrastructure planning, energy planning and educational planning. In many cases, these different planning processes are highly interconnected.

There are many reasons for addressing risk in a land-use planning context. First of all, many undesired events are possible to prevent, or at least prepare for, by undertaking careful planning. As such, the process of conducting a risk assessment represents one way of contributing to a more resilient city or society[1]. Secondly, the costs of only managing these events as they happen often greatly exceed the costs of taking them into consideration at the planning stage. Finally, dealing with risks as early as possible also leads to high potential of finding efficient solutions as well as solutions that imply good trade-offs with the range of other interests that exist in a land-use planning situaiton.

In a land-use planning context, a risk assessment can be performed with two main foci. Firstly, it can be done for an existing geographical area. The purpose of conducting such risk assessment is typically to establish the baseline conditions for that area (What hazards expose the area? How is the area vulnerable to these hazards? What is the likelihood and negative consequence of undesired events?). In the subsequent detailed development of a land-use plan for the area, these baseline conditions should of course be taken into account. Secondly, a risk assessment can also be performed for a suggested land-use *plan* in order to assess the future risk profile of a proposed area. In this case, the purpose is to ensure that the risks facing the area, as it is planned, are treated in an efficient way and where other societal concerns can be cheived while keept the risks at acceptable levels. The purpose may also be to highlight, and to propose mitigation strategies, for risks that must be treated in a later stage; either in more detailed planning stage or in the building or operational stage.

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[1] See e.g. the UN campaign Making Cities Resilient http://www.unisdr.org/campaign/resilientcities/home/index, which highlights risk assessment and land use planning as important steps of reaching this goal

The aim of the present chapter is to provide an overview of a risk assessment framework that is proposed to be applicable for the area of land-use planning, including a methodological guidance for conducting the two first steps of the framework – Establish the context and Assess valuable assets, including examples. The two examples come from student groups assignments in the course Risk-based land use planning (VRSN20) givet at the Master program in Disater Risk Management & Climate Change Adaptation program at Lund University. Subsequent chapters address the remaing steps of the framwork.

1.1. Key concepts and principles

In this section the key concepts and principles used in relation to the risk assessment framework are outlined.

There are numerours ways to define risk (e.g. see SRA glossary[2] for an overview). Here we select a perspective on risk that is particularly useful in th area of land-use planning. Risk is here seen as a function of hazard and vulnerability. As indicated in the figure below, the level of risk in an area is determined by what hazards that expose the area, including their damaging potential, and how vulnerable the area is to these hazards (see Blaikie, et al. 2014). This also means that risk treatment can be performed either focusing on hazards (eliminate, reduce likelihood, reduce damaging potential, etc.) or focusing on vulnerability (add protection, increase coping capacity, etc.).

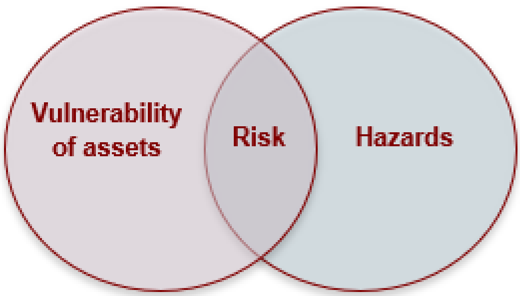

Figure 1. Conceptual illustration of risk as the function of hazards and vulnerable assets

Based on the Sendai Framework Terminology of Disaster Risk Reduction, we make use of the following definitions[3]:

- Hazard: "A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation".

[2] [SRA | Glossary | Solicitors Regulation Authority](), 2025-03-03
[3] https://www.undrr.org/terminology/capacity, 2025-03-03

- Vulnerability: "The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards".

In this framework, vulnerability is seen as including also coping capacity, which in turn can be seen as "the ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters"[4]. High coping capacity contributes to low vulnerability. Furthermore, it should be stressed that, in order for statements about vulnerability to be meaningful they should be connected to the characteristics of a *specific asset* in relation to a *specific hazard*. In other words, an asset is not vulnerable *in general* but only vulnerable in relation to specific hazards (of course there may be characteristics of an asset that makes it vulnerable to more than a single hazard). There is also a progression of vulnerability, or a systems perspective of vulnerability, in the sense that remote conditions, such as political and societal structures, power relations and ideologies are translated into the local context where unsafe conditions are manifested than in turn can be exploited by hazard occurances. Vulnerability reduction can be directed both towards towards the local unsafe conditions and towards the underlying systemic conditions. Sometimes underlying systemic conditions may be difficult to difficult to influence through land-use planning – on the other hand, if it is possible, then this may have positive influence for a range of local unsafe conditions.

Traditionally, risk assessment and management has been highly "hazard-centric" (Dilley and Boudreau, 2001); i.e. it has focussed on the natural (hurricane, flood, or earthquake), technological (industry or hazardous goods), or intentional (terrorism, sabotage) hazard that can initiate a scenario giving rise to negative consequences. However, increased attention is now being devoted to the vulnerability and coping capacity of the community and the assets that are exposed to the hazards. A reason for this is that it is sometimes impossible, or at least very difficult, to reduce the damaging potential of the hazards; instead, the only realistic option to reduce risk is to reduce the vulnerability of an area or community. In addition, efforts to reduce vulnerability can often be effective for reducing the risks related to several hazards, such as when increasing the capacity of households to be self-sustained or by increasing the capacity to distribute emergency drinking water in case of disruption in the regular water supply system (which may be caused by several different hazards).

1.2. Strategies to consider risk in land-use planning

Essentially, there are three main strategies to consider risk in a land-use planning context (which are more or less suitable depending on the type of hazard): 1) To use pre-determined safety distances, 2) to base measures, localisation etc. on a consequence-based assessments, or 3) to base measures, localisation, etc. on a risk-based assessment.

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1.2.1. Safety distances/buffer zones

Use of pre-determined safety distances (buffer zones) is historically a common approach to mitigate risk. The approach is suitable for hazards that have a specific "location", such as roads, railways, chemical plants, etc. Typically, safety distances are regulated in laws, ordinances or guidelines. The distances can be based on calculations, historical events and/or expert judgment and are typically adapted to different types of hazards. The benefit of using safety distances is that they can be applied without conducting a comprehensive risk assessment. The downside, though, is that the distances are not adapted to specific facilities but are generic and therefore also typically very conservative. From a risk management standpoint this is of course positive; however, in many cases there are other interests that prohibits the use of long safety distances, which means a more sophisticated approach that can take specific/local conditions into account are desired. Quite often, legislation opens up for the possibility to deviate from the recommended safety distances if it is possible to analytically show that an acceptable level of risk can be obtained by using shorter distances.

1.2.2. Consequence-based assessment

In this approach, sometimes also called deterministic risk assessment or scenario assessment, an assessment is made on the local conditions of e.g. an industry situated in a city or municipality. The approach is based on defining so-called worst credible scenarios or design scenarios, i.e. severe scenarios (explosions, toxic releases, flooding, etc.) that realistically could happen. Events that are deemed to be too unlikely are disregarded – although no explicit judgments of probabilities or frequencies are made. When the worst credible scenarios (typically a few) have been specified, an assessment is performed to find out their negative consequences. In order to evaluate the risk as acceptable, the negative consequences should be very low. The benefits of using this approach is that it is rather quick and simple to apply where typically only a few scenarios are assessed (i.e. it is assumed that if the negative consequences are small, and acceptable, for a severe scenario, then they will also be acceptable for a less severe scenario). A downside, though, is that it is not easy to make judgements on which scenarios that should be disregarded due to their low probability. In addition, those scenarios that are considered too unlikely to be accounted for are still scenarios that may occur. Even though the scenarios cannot be eliminated, perhaps measures should be taken to avoid disastrous consequences? Finally, another downside is that cost-benefit considerations are difficult to take into account.

1.2.3. Risk-based assessment

Unlike the consequence-based assessment, a risk-based assessment considers *both* likelihood and consequences of various risk scenarios. As such, the term Risk assessment sometimes refers exclusivelly to this approach. Risk is then evaluated considering a combination of consequences and likelihoods. This approach is the most sophisticated of the three, but also the one that is most extensive and requires the most input data. In addition, the results may not always be easy to interpret. It is also important to note that there are several degrees of sophistication within this approach when it comes to how consequences and likelihoods are estimated and described – ranging from qualitative to quantitative estimations. This will be addressed in more detail in subsequent chates that address later parts of the framework.

1.3. Purpose and outline of the framework

The framework descibred in this and subsequent chapters falls in the Risk-based category as it addresses both consequences and likelihood. Furhremore, land-use planning occurs on several levels of granularity, and the framework is developed with the comprehensive planning of an entire (or a large part of a) city or municipality in mind. Rather than providing a detailed assessment of one or a few specific risks, the purpose of this framework is to provide an overview of the large variety of risks facing the geographical area in question that may have an impact on, or that can be influenced by, land-use planning measures. By presenting this information to planners and decision-makers already at the stage of comprehensive planning, there is a higher likelihood that this information can be integrated in the planning process from an early stage, rather than entering the land-use planning process in the late and detailed phases. As such, the outcome of the risk assessments described in this framework is intended to contribute to, and improve, the detailed development planning of a city or municipality. One of the main contributions of such information is that important risks are acknowledged, highlighted, and if possible, treated before the planning has moved to a critical and detailed stage, where substantial changes are considerably more difficult to implement.

The risk assessment framework outlined in this and subsequent chapters is illustrated in Figure 2.

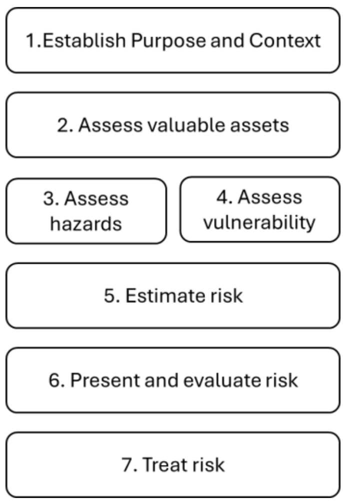

Figure 2. A risk assessment framework for land-use planning.

The framework has a generic focus in the sense that it does not specifically address certain hazards or vulnerabilities. It mainly focuses on the comprehensive planning stage (corresponding to the Swedish term "översiktsplan") rather that the more detailed development plans (corresponding to the Swedish term "detaljplan") where engineering calculations are typically performed for specific risk scenarios, such as release of toxic substances. The ideas and approaches presented in the guidelines are aimed at being scalable to planning processes at different scale levels, but the applicability of course needs to be adapted to the particular level. For example, performing a risk assessment for the land-use plan of a large city will of course be less detailed than a risk assessment for a specific neighborhood (or require much more time).

2. ESTABLISH PURPOSE AND CONTEXT

The first step of a risk assessment includes establishing the purpose of the assessment as well as describing the context in which the assessment will be conducted (cf. ISO 31000). This risk assessment framework is developed within the context of land use planning, and accordingly, this represents the generic type of setting intended. Yet, it is essential to also make a more specific description of context and purpose, as well as clearly defining the boundaries of the geographical area in question.

The purpose of the risk assessment is normally closely related to the size of the geographical area. If the risk assessment covers an entire region or municipality, the purpose is typically to give a comprehensive picture of the type and concentration of risks in the area as a whole. In this case the level of detail is low, since it is very time-consuming to conduct detailed assessments of each individual hazard and vulnerability. On the other hand, if only a small area is investigated, the level of detail can be higher and more precise information about the level of risk can be presented.

In this framework, focus will be on providing guidance to conducting a multi-hazard risk assessment for a larger geographical area, such as significant parts of, or a whole, municipality. The main challenges of conducting a risk assessment for such large geographical area relates to the ways in which a large variety of different hazards and vulnerabilities, and their interactions, can be taken into consideration within the same analysis. This calls for using a generic approach to risk assessment, such as the guidance provided in this document. For risk assessments of smaller areas, such as the area surrounding a specific industrial facility, specific guidelines on quantitative risk assessments for that particular context are more appropriate. In such cases the risk assessments are typically performed with respect to a single or a few hazards, such as transport of hazardous materials or large-scale industrial facilities.

Although an important part of establishing the purpose and context of a risk assessment is to define the system boundaries, it is still necessary to remember that there may be important factors to take into consideration that lie outside the studied geographical area. For example, if an industrial facility is located close to the boundary of the studied area, this is something that needs to be taken into consideration in the risk assessment, since this facility may affect the planning of the studied area.

More generally, it is important to recognise that the studied area forms a part of a larger community, and for this reason it is essential to know how the studied area connects with its surrounding areas. This means that a general inventory of a larger part of the community or city may be valuable before the risk assessment is initiated. In addition, since a risk assessment is performed at a particular planning scale, e.g. as a basis for developing a plan for a part of a municipality, there are normally existing plans at a higher hierarchical level (e.g. municipal level) that may contain information of relevance, such as risk policies, information concerning hazards, future plans that will affect risk levels, etc. Therefore, understanding and establishing the relation with higher-level plans is also a crucial aspect of defining the context.

Another distinction that needs to be considered is whether the risk assessment is performed for the current conditions of the relevant geographical area or for some future plan proposal. The former type of risk assessment aims to map out the baseline risk characteristics of the area that needs to be taken into account when developing a plan for future land use. This type of risk assessment is performed at an early stage of a land use planning process in order to guide the development of a future plan. This assessment is likely to not be particularly detailed since much of the current land use will probably not be relevant for the planned future land use. Therefore, this risk assessment should be seen as more of an inventory of relevant hazards and vulnerabilities than an in-depth assessment. The latter type of risk assessment aims to analyse the risks of a proposed future land use in order to ensure that risks are kept at acceptable levels or, if not, to suggest suitable risk reduction measures that can be implemented without unacceptable negative effects on other interests related to the future land use. This type of risk assessment should be performed in conjunction with the development of the future plan and/or when a land-use plan has been proposed.

In addition to defining the system boundary, it is also important to explicitly articulate what the risk assessment will be used for and what level of detail it needs to have (which often may be determined by the type of input available and the resources at hand). Moreover, and closely related to the use of the risk assessment, it is important to reflect on who the intended receivers of the assessment and its results are. For example, are the receivers a broad and varied group of stakeholders with different levels of understanding of risk assessments? Or do all the receivers have a thorough understanding of risk assessment? This question should be taken into consideration in relation to the process of conducting the assessment, and in particular, in relation to how the results are presented and recommendations are formulated.

Questions to ask in the step Establish purpose and context:

- What is the purpose of the assessment, what will the results be used for?
- What are the geographical boundaries of the area under investigation? How does the area connect to its surroundings?
- What level of detail of the results is required?

Why is this step important?

- Without a clearly defined purpose and system boundary it is not possible to determine what information that should be included and the level of detail of the risk assessment
- If the results from a risk assessment is not presented in a way that takes into account the knowledge and understanding of the receivers, it is unlikely that the results will be used as input to the land-use planning process

Example of the step Establish purpose and context (from a risk assessment of Mumbai)

The local planning authority of Mumbai has requested a risk assessment of an area in the South of Mumbai, specifically, Girgaon. The purpose of this document is to provide a risk assessment by adopting a multi-hazard approach, and to provide the Mumbai planning authority with recommendations regarding risk reduction measures. The report focuses on several risks that Girgaon is exposed to, and how different assets are affected by these risks. It provides a full picture of what types of risks are prevalent in Girgaon, and which assets are the most vulnerable to each of these risks. The focus of this assessment is on future developments to reduce risks, as climate change changes the risk field and is assumed to cumulatively have an impact on Girgaon and Mumbai as a whole. Ultimately, this risk assessment can be used by the Mumbai planning authority to identify which risk reduction measures are most pressingly needed in Girgaon in order to protect the most valuable assets in the area. Girgaon is a sub-city scale region of around 2 km^2. The geographical boundaries of the area include the beach and main railway station, and follows two big main roads as a demarcation. Since the area is relatively large, the level of detail that the assessment provides is limited. Therefore, the report focuses on the larger impact of risks, and on how risks may interplay with one another. Moreover, Girgaon is a densely-populated area with large socio-economic differences. These factors make a risk assessment all the more important, as it increases the vulnerability of assets within the area to risk.

3. ASSESS VALUABLE ASSETS

Risk concerns the possibility of losing something that we humans value (see e.g. the definition of risk suggested by Klinke and Renn, 2002). Accordingly, it is not possible to talk about risk unless we do this in relation to something that we see as valuable. This value may be more or less taken for granted in many contexts. For example, when we discuss risk in relation to road traffic, it is primarily human health and life that we see as our valuable asset. However, in other contexts the valuable asset may not be equally clear and there may be many different values (such as property and environmental values). Furthermore, different stakeholders may hold different views regarding what is valuable. For this reason, an important step of a risk assessment constitutes the identification of the things we see as valuable as well as their prioritisation since all values are typically not seen as equally important. In addition, some less important values may have to be neglected since the limited time and resources available may restrict the scope of the assessment.

3.1. Identify valuable assets

On a generic level, it is possible to identify some broad categories of valuable assets. In the context of land use planning, human life is undoubtedly one such important value. However, this is not the only important value worth protecting. For example, additional aspects include environmental values, economic assets and critical infrastructures providing essential services to a community. This list of generic values can typically be deducted from laws, statutes and policy documents, etc. Examples of valuable assets in the context of a land use risk assessment include:

- People
- Societal functions
- Economy
- Built environment
- Natural environment
- Social values and democracy
- Sovereignty of the state

This list represents generic values that are deemed necessary to protect through a variety of different means. In addition, these categories are to some extent overlapping. Furthermore, some of them may be difficult to address directly in the context of land use planning (e.g. the dimension Social values and democracy), which could lead to less emphasis being placed on that particular value.

Regardless how assets are categorised, such categories should only be seen as an aid to cover a broad set of values. Each of these generic values can be specified in more detail in relation to the geographical area under investigation. For example, the category People can be decomposed into the sub-categories Children, Elderly, Disabled, etc. In the same way, the category Built environment can be decomposed into Hospitals, Rescue services, City hall, Roads, etc. In this way, a detailed list of valuable assets, preferably with a physical manifestation, can be created for the specific geographical area.

3.2. Prioritise valuable assets

The above specification of values in relation to the geographical area under investigation may render a long list of valuable assets. For practical reasons, this entire list may not be possible to take into account in a risk assessment, and it is likely that all aspects are not considered equally important to protect. In order to obtain a manageable number of valuable assets, this list must be arranged in order of priority where some less important assets may have to be neglected (depending on the level of detail and resources available for the assessment). It is important to note that there is no universally accepted order of priority of such list (since this is a subjective choice), although human lives typically are placed at the top. In order to give legitimacy to the way valuable assets are ordered in relation to each other, it can be fruitful to use a participatory approach where many different stakeholders have the ability to influence the selection and prioritisation of values, and to explicitly present the motivation for the ordering of different values. Additionally, legistlation within the area of land-use planing may put requirements on what valuable assets to take into account in a risk assessment. The outcome of this step should be a list of valuable assets specific to the particular geographical area of concern and arranged in order of priority.

3.3. Present valuable assets

Presenting the valuable assets is recommended since it may facilitate the subseuent hazard and vulnerability assessment, i.e. by making it easier to identify areas where hazard exposure coincide with valuable assets. One way of presenting valuable assets is to pinpoint them on a map, for example in a GIS (Geographic Information System) software. This is usually a comprehensible way of conveying important information. For some values, such as the location of hospitals and other critical functions in the community, this is fairly straightforward. However, for other values, such as clean air, the valuable asset is more or less ubiquitous, and thus more difficult to illustrate.

- **Questions to ask in the step Assess Valuable Assets:**
  - What values or assets are important to protect by land use planning measures in the geographical area under investigation?
  - How are these values prioritised in relation to each other?
  - Can any of the identified assets be excluded to limit the scope of the assessment?
- **Why is this step important?**
  - Risk represents a potential loss, but something is not considered a loss unless it represents something we value. Therefore, an important step of a risk assessment is to specify what we value.
  - In order to produce a comprehensive risk assessment and still account for practical limitations relating to time and resources, it is necessary to arrange different valuable assets in order of priority

Example of the step Assess Valuable Assets (from a risk assessment of Palm Beach)

Specific assets were identified as needing protection in disasters. They are grouped in categories and ranked in order of importance. This analysis prioritizes protecting human life and other identified valuable assets located in Palm Beach. For this reason, people are at the centre of the risk assessment, with transportation infrastructure and tourist/cultural attractions being additional valuable parts of society that enable a high quality of life.

People

In disasters, it is crucial that people's lives are protected. Residents as well as visitors should be safe during and after an adverse event, and this means protecting residential areas. In addition, commercial activity and the livelihoods of residents should be safeguarded.

Transportation Infrastructure

Transportation infrastructure is a significant component of a functioning society. To ensure that residents can receive resources during or after a disaster, transportation pathways should be monitored and fortified. The most important assets are the two bridges leading off Palm Beach Island, and the accompanying avenues that lead to them. Flagler Memorial Bridge & Royal Poinciana Way along with Royal Park Bridge & Royal Palm Way are critical drawbridges that connect the island to the mainland. The third most important transportation asset is N & S County Road. This state road runs vertically down the length of the island and serves as a collector road for neighborhoods and businesses. Lastly, S Ocean Boulevard is of great importance. This boulevard borders the ocean and provides a barrier for coastal erosion during a storm. Without this barrier, homes and businesses could be threatened.

Tourist & Cultural Attractions

Palm Beach Island is known for being a popular tourist destination. It has many cultural attractions that bring in significant amounts of revenue. The Breakers Hotel, situated precariously along the beach on the east side of the island, is a well-known luxury resort that attracts tourists. Its continued preservation is important for the economic viability of the area. In addition, the Flagler Museum and the public Palm Beach accesses also provide economic stimulus and enhance the quality of life for residents and visitors on the island. Lastly, the Society of the Four Arts is a museum, art gallery, and entertainment space with cultural significance.

<u>Example of the step Assess Valuable Assets (the presentation part - from a risk assessment of Mumbai)</u>

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A RISK ASSESSMENT FRAMEWORK FOR LAND USE PLANNING – PART 2: HAZARD ASSESSMENT

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Abstract

Risk assessment is a crucial element of land-use planning in order to achieve a safe, sustainable and resilient society. A critical part of a risk assessment is the hazard assessment where natural, technological and intentional hazards are identified and characterized. Key characteristics of hazards include Magnitude/intensity, likelihood, spatial extent, geographical location, duration. speed of onset, speed of closure, damaging mechanism, secondary hazards, hazards trends and cause. By characterizing hazards thoroughly, the subsequent vulnerability assessment and risk estimation will be facilitated. This chapter provides methodological guidance and exemplifications on how to conduct the hazard assessment

Keywords: *Risk assessment, Land-use planning, Hazard assessment.*

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1. INTRODUCTION

As outlined in the chapter *A risk assessment framework for land use planning – Part 1: Introduction, establishing context, and assessing valuable assets*, risk assessments are key to developing sound land-use proposals. A critical element of such an assessment is the identifiation and assessment of hazards. According to Sendai Framework Terminology of Disaster Risk Reduction[1]a hazard refers to "A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation". The aim of this chapter is to outline and provide methodological guidance on how to carry out a hazard assessment as part of the broader risk assessment. It also exemplifies the output from such an assessment. The examples come from student groups assignments in the course Risk-based land use planning (VRSN20) givet at the Master program in Disater Risk Management & Climate Change Adaptation program at Lund University.

It is important to note the distinction between the concepts of hazard and risk. The hazard itself represents a *potential* for damage, but it is not described directly in relation to something we value (i.e. an asset). For example, there is a high likelihood of an earthquake of great magnitude occurring at the seabed of the Atlantic Ocean due to tectonic plate movements. This represents a significant hazard. However, as long as such earthquake does not affect something we define as valuable, this event does not represent a risk. In other words, a hazard in itself does not represent a risk until it is threatening something that we as humans value (i.e. some sort of asset), which is conceptually illustrated in Figure 1.

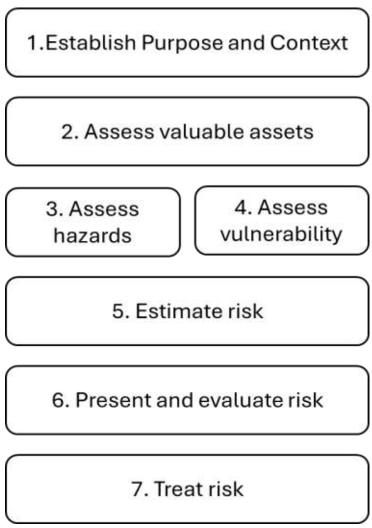


Figure 1. A risk assessment framework for land-use planning

[1] https://www.undrr.org/terminology/capacity, 2025-03-03

In a risk assessment, the identification and assessment of hazards is conducted in separation from the identification of assets (and their vulnerability), and in the subsequent risk assessment step these elements are combined to assess the level of risk.

2. IDENTIFY HAZARDS

The first step of a hazard assessment involves the identification of hazards that have the potential of affecting the geographical area under investigation. Focus of this framework is placed on hazards that are relevant from a land use planning perspective, i.e. if its likelihood or its potential negative consequences (when it interacts with some vulnerable set of assets) can be affected by the design choices made in the land use planning process. Although this includes a wide variety of hazards, some hazards are less relevant such as spread of diseases, lifestyle-related hazards such as smoking and obesity, etc. For a further discussion on this topic, see Fleischhauer (2008).

There are multiple, complementing ways of conducting this step, such as analysing what has happened in the past (e.g. by reviewing newspaper articles), analysing statistical records/datanases, browsing webpages of relevant authorises and agencies, consulting existing risk assessments and other relevant reports, using checklists for hazard identification, carry out brainstorming sessions, conducting workshops or interviews with people working at the local authorities, emergency responders, city planners, infrastructure providers, or other specialist competencies in the community. In addition, research concerning future hazard trends It is also highly relevant to talk to the general public about hazards and past events that have affected the community. Ideally, these different approaches should be used in combination to ensure a broad, multi-hazard identification.

Many different types of hazards may affect a community and each hazard that may affect the geographical area under consideration should be listed. In order to structure this list, different ways of grouping or categorising hazards are possible. One example of such set of categories is the following one, which classifies hazards according to their main cause[2]:

- Natural hazards, such as floods or storms;
- Technological hazards, such as industrial accidents or infrastructure breakdowns;
- Social hazards, such as riots or social unrest and;
- Intentional hazards, such as terrorism or sabotage.

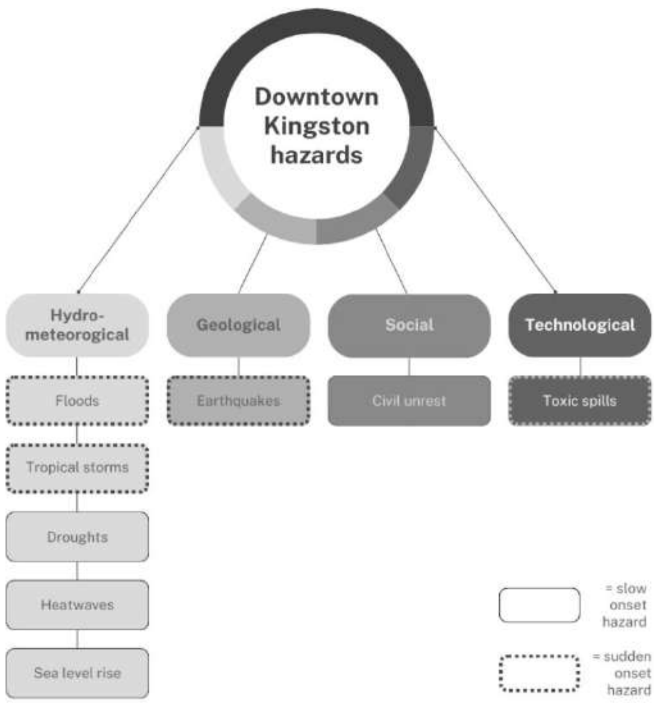
This list represents one possible classification of hazards, but it is important to note that hazards can be categorised in many other ways (many other categorisations have been

[2] Note that in addition to using such a checklist for structuring hazards, it could also be a basis for the identification of hazards.

suggested in the literature) and with greater level of detail, such as dividing natural hazards into atmospheric, hydrologic, geologic and biologic. Another way is to categorise hazards according to the kind of consequences they may give rise to, e.g. health hazards, security hazards, environmental hazards, etc.

In essence, it is always possible to identify hazards that fall in more than one category. A reason for this is that hazards are typically not only caused by a single (e.g. natural) factor. Of course, sometimes the cause may be entirely natural, such as in the case of volcano eruptions, earthquakes and meteorite impacts. But more commonly there are multiple contributing factors that give rise to a hazard. One example is the fact that human-induced climate change gives rise to increased frequency and intensity of floods and hurricanes. In addition, a technological hazard may be triggered by a natural hazard, for example a mudslide triggering a chemical leak. Since there are numerous ways of classifying hazards, it is more important to try to cover as many hazards as possible than trying to define the optimal way of classifying hazards (and the classification should only be seen as a way of structuring the identification process).

<u>Example of the step Hazard identification (from a risk assessment of Kingston)</u>



Example of the step Hazard identification (from a risk assessment of Iztacalco)

HAZARDS IDENTIFIED	TYPE	SPATIAL EXTENT	SPEED OF ONSET
Earthquake / Seismic Events	Geological	National	Sudden
Volcanic Eruption	Geological	National	Sudden
Land Subsidence	Geological	Regional	Slow
Tsunamis	Geological	Global	Sudden
Pluvial, fluvial and lake flooding	Hydrometeorological	Local	Slow
Slope Instability	Geological	Local	Slow
Sinking / Subsidence	Geological	Regional	Slow
Heatwaves and Droughts	Hydrometeorological	Global	Slow
Hailstorm	Hydrometeorological	Regional	Sudden
Dust storm	Hydrometeorological	Regional	Sudden
Extreme Rains	Hydrometeorological	Local	Sudden
Thunderstorms	Hydrometeorological	Local	Sudden
Droughts	Hydrometeorological	National	Slow
Electric Fire and Explosion	Technological	Local	Sudden
Air Accidents	Technological	Regional	Sudden
Explosive Substances	Technological	Local	Sudden
Communicable Diseases	Biological	Regional	Slow

3. PRIORITISE HAZARDS

In the same way as for the identification of valuable assets in the previous chapter, there may be pragmatic reasons for making a selection of a few hazards that are investigated in further detail. This prioritisation thus results in a number of prioritised hazards that are used in the subsequent steps of this framework. The basis for such prioritisation can be on the damaging potential but also to what extent the hazard or the vulnerablity of assets with respect to the hazard can be managed by land-use planning measures.

4. CHARACTERISE HAZARDS

The list of hazards created in the previous step includes a broad set of hazards that may potentially affect the community. Each hazard in this list needs to be described and assessed based on its unique characteristics, since different hazards may affect a community in different ways. For example, an earthquake does not affect a community in the same way as a flooding. Understanding of a hazard's key characteristics is also necessary since it will be a basis for assessing the vulnerabilities to the hazard, i.e. it is necessary to know how a hazard will materialize in order to know to what extent a community is vulnerable to it.

Many different characteristics can be used to describe hazards, including for example their frequency, magnitude, geographical impact and speed of onset. Moreover, all hazard characteristics may be described using different levels of detail, which influences the precision and uncertainty of the outcome of the risk assessment.

Note that the estimation of negative consequences is *not* part of the hazard characterisation step of the present framework. The reason is that the extent of the consequences depends on the vulnerabilities of the valuable assets to the particular hazard. Since the vulnerability assessment constitutes the next step of this framework, the consequence estimation cannot be conducted until after the vulnerability assessment step. However, it is important to note that in some risk assessment guidelines, consequence estimation is performed *before* the capacity and vulnerability assessment. The estimated consequences is then seen as representing some immediate, proximate or potential comsequences of the hazard and the capacity and vulnerability assessment concerns how these immediate consequences may or may not give rise to additional more long-term effects. However, when using such approach it is unclear what aspects of vulnerability and capacity that should be taken into account in the estimation of "immediate" consequences – e.g. what vulnerability characteristics should be accounted for? Since there is no clear answer to that question, the choice here is not to perform consequence estimations in the hazard characterisation step but rather in the risk analysis step where the hazard and vulnerability assessments are integrated.

Below, a number of type of hazard characteristics will be described. Note that all the characteristics may not be relevant for all hazards and there may be additional characteristics in some contexts. Furthermore, the different characteristics can be described in one, or a combination, of different ways including:

- Verbal description, e.g. the hazard is related to a sudden speed of onset.
- Qualitative categories, e.g. the magnitude of the hazard is 1) low, 2) medium or 3) high.
- Semi-quantitative categories, e.g. the duration of the hazard is 1) up to a day, 2) 1-5 days, 3) 5-10 days or 4) 10-20 days.
- Quantitative, e.g. the frequency of a category-5-earthquake is 1 in 1000 years.

The choice of how to describe the various characteristics should be adapted to the purpose of the risk assessment and the resources and information available.

Usually, there is a relation between two or more hazard characteristics. For example, such a relationship usually exists between the frequency and the magnitude of a hazard occurance; the frequency of a particular hazard occurance with a high magnitude (i.e. high flood water levels) is typically low, while the frequency of a hazard occurance with a low magnitude is higher. Another example relates to the relationship between spatial extent and duration; a long duration typically implies a large spatial extent. Moreover, the relationship between different hazard characteristics can be plotted in different ways. While the accuracy of such charts depends on the data available, a rough estimate can normally be generated, which at least gives an indication of this relationship. Input for creating a magnitude-frequency chart can be based on historical data as well as expert judgments.

4.1. Magnitude (intensity/severity)

The magnitude of a hazard refers to its "strength" or "power". Magnitude can be described in different ways depending on the hazard in question, such as the rise of sea water level for flood hazards, the category of wind speed on the Saffir-Simpson wind scale for a hurricane, magnitude on the Richter scale for an earthquake hazard or equivalent TNT to express the power of an explosion. In a hazard assessment, it is useful to describe the range from lowest level of magnitude (with a potential to cause damage) to the highest one (with a likelihood that is not negligible).

4.2. Likelihood

Each hazard with a certain range of magnitude can be associated with a likelihood. Likelihood is here seen as covering the more specific, but not entirely synonymous, terms frequency and probability. In the present context it is common to use frequency for hazards that can be described as repeatable/recurring events, such as flood or hurricane. Frequency is a description of expected number of occurrences of the hazard of specified magnitude within a certain time period (in this context, typically one year). Estimation of frequency is normally done in a quantitative way. This is especially the case where historical records exist that can provide a well-founded basis for the estimation. However, many hazards are extremely rare, and their frequency estimations can therefore be challenging and associated with large uncertainties. In such cases, qualitative or semi-quantitative ranking scales could be used.

For events that are more "unique" in character, e.g. the launch of a particular Mars rocket or terrorist attack to a particular key asset, it is not possible to use the concept of frequencies (i.e. it is not meaningful to talk about how many times the rocket will fail per time unit since it is a one time off situation). Instead it is more relevant to talk about probability (i.e. what is the probability of the rocket failing at the particular launch?). It should be stressed that the difference between a frequency and a probability is somewhat subtle and often statements about frequency and probability are mixed in the same assessment, which in this case is typically not an issue[3]. See Kaplan (1997) and Aven and Reiners (2013) for a more thorough discussion of these concepts including different ways of interpreting the concept of probability.

Furthermore, estimating the likelihood of intentional hazards can be very challenging as historical records may tell very little about what the likelihood will be in the future since there are numerous contributory factors that may affect likelihoods, such as political factors, conflicts, etc.

[3] Note that information about frequency (e.g. 1 event every 100 year) can be converted into for example a probability of occurrence next year. For small frequencies the probability estimation is simply "the same" (i.e. frequency of 1 event per 10000 years) is the same as probability of 1/10000 during next year) but it is not the case for large frequencies (i.e. 1 event per year is not the same as probability of 1).

It is also important to note that in many cases, the frequency or historical records for a particular hazard only exists for the national level. If this is the case, an adjustment to the area under consideration needs to be carried out in the risk assessment step.

4.3. Spatial extent and geographic location

Hazards have different spatial extent, ranging from local (e.g. industrial accidents) to regional (e.g. drought), national (e.g. erosion) and even global scale (e.g. asteroid impact). The geographical impact of a hazard is important to describe since it gives an indication of how badly a community may be affected; does the hazard present a potential danger only to a specific building or may the entire community be affected? In this way, the geographic impact is important for determining the level of risk (which is conducted in the Risk Assessment step).

Moreover, most hazards do not occur in random places; rather, they are usually more likely to hit some areas than other. Obvious examples include floods, that would primarily affect lowland areas. This is one of the reasons for studying what has happened in the past in the area under consideration; it is not unlikely that the same hazard will occur again in the same location in the future. Furthermore, some hazards are bound to particular locations in the area of concern, such as the impacts of industrial accidents are limited to areas rather close to the facility.

4.4. Duration

The same type of hazard may vary in terms of its duration. For example, a flooding may peak and retreat in only a few hours, or it may have a long duration. Depending on the duration, the resulting damage may be more or less severe. Therefore, information about the typical duration is highly important as a basis for estimating the level of risk (conducted in the Risk Assessment step).

4.5. Speed of onset and speed of closure

Some hazards may have a sudden beginning without any possibilities of alerting the population, such as an earthquake or a road accident involving transportation of hazardous material, while others are slowly evolving hazards, such as hurricanes where there are possibilities to obtain weather forecasts or information on sea level rise which constitutes a long-term transformation.

The speed of onset gives important information in relation to the possibility to prepare and respond to a threatening hazard. Is it reasonable to expect forewarnings of an imminent hazard that may spark protection measures or will it strike the community without prior signs of upcoming danger?

Depending on the speed of onset, in combination with the capacity and vulnerability of the assets in the geographical area, the risk may therefore be high or low. In a similar way as a hazard may have a slow or fast onset, the closure (i.e. the ending) of the hazard occurance can also be fast or slow. Slow speed of onsets and/or slow closure is sometimes referred to as creeping crises which may imply certatin challanes for its management (see e.g. Boin et al., 2020).

4.6. Damaging mechanism

The damaging mechanism refers to the way in which the hazard affects the asset, e.g. heat radiation, pressure waves due to explosions, or toxic effects. In some cases this is obvious, but in other cases this mechanism is complex and need to be investigated as a basis for being able to suggest relevant risk-reducing measures in the final step of the risk assessment.

4.7. Secondary hazards

In some cases a hazard event may trigger another hazard event, i.e. a secondary hazard. This could be a natural event, e.g. hurricane or tsunami, triggering a technological event, e.g. oil spill, nuclear power plant accident or infrastructure disruption. Sometimes these types of hazards are called NaTech hazards (i.e. Natural event that triggers a technological event). Secondary hazards may also be technological hazards that trigger another technological hazard, such as an explosion in an industrial facility that triggers a toxic release in another facility nearby, or, although less frequent, a technological hazard triggering a natural hazard.

It is important to consider whether the identified hazards have the potential for triggering secondary hazards since the total negative consequences of such an event may become considerably larger. Since there may be uncertainties with respect to whether a particular hazard would trigger a secondary hazard or not, this characterisation should ideally be done using some type of likelihood description.

4.8. Hazard origin or cause

Understanding why a hazard may occur, i.e. what it is caused by, may be important in the subsequent process of trying to reduce its likelihood. More specifically, by understanding causes it may be possible to implement preventive barriers, such as measures to prevent erosion. At the same time it should be noted that, in a land use planning context, it is common that not much can be done to reduce the likelihood of a hazard event since this is outside the influence of the land use planning process. For example, reducing the likelihood of incidents in an existing industrial facility is not primarily a matter for land use planning but rather a matter for other legislations.

4.9. Hazard trends

Land use planning typically considers a long timescale, during which the characteristics of many hazards may change in various ways. For example, some hazards may become more or less frequent over time, or they may change in nature in some other way, such as quicker speed of onset once they occur. For example, it is likely that hazards related to climate change may increase in the future (such as the likelihood for flooding and hurricanes). This information constitutes an important input when consequences are estimated and when risk-reducing measures are suggested since land-use planning decisions must be taken with respect to how the future will look (although this is highly uncertain).

5. PRESENT HAZARDS

The outcome of the previous step is essentially a hazard sheet for each hazard with descriptions for each relevant characteristic when it comes to the particular area of interest. However, there may also be reasons for presenting this information in such way that hazards can be more easily compared and contrasted. There are at least two reasons for doing this. First, it could facilitate the identification of hazards with many commonalities, and these hazards can be grouped in the subsequent steps of the risk assessment. Secondly, it could facilitate the screening of insignificant hazards, e.g. hazards that “score low” on all or most characteristics above. Such hazards may not be relevant for further consideration in the risk assessment.

There are numerous different ways of presenting hazard information in e.g. tables, graphs or on maps. Essentially all the characteristics described above could be presented in order to contrast the different hazards (e.g. which ones have the largest spatial extent, which have the highest frequencies or which have the shortest speed of onset). One way of presenting this information is by using spider web diagrams (which is possible if information about the hazard characteristics are expressed using at least qualitative categories). One diagram is outlined for each hazard where its “score” on the characteristics, or on a chosen set of characteristics, are noted on the multi-dimensional axes in the diagram to form a “spider web”. Different hazards can then be compared to find similarities, differences, significant hazards (large areas) and insignificant hazards (small areas).

In the land-use planning context the geographical aspect is of course also of great concern since one of the primary ways to reduce risks is to avoid locating vulnerable assets in areas where there is a high concentration of hazards. Presenting hazard maps is therefore a key element of this step. In a very basic hazard map those hazards that are related to a particular location are simply mapped out – such as industrial facilities, roads for transportation of hazardous material, or areas with large flood hazards. If more information exists about the hazards, this information can be added (such as safety distances or individual risk contours around facilities).

Questions to ask in the step of Hazard Assessment:

- Which hazards (that are relevant for land use planning) may affect the area of interest?
- What are the main characteristics of these hazards, including magnitude, frequency, spatial extent, etc.
- How can hazard information be presented?
- Can hazards be grouped according to similar features?

Why is this step important?

- In order to obtain a comprehensive risk assessment, all hazards that may give rise to damage of vulnerable assets in the area under consideration need to be identified
- Since each hazard may affect the area in different ways (and call for different types of risk-reducing measures), it is important to describe the characteristics of each hazard

Example of the step Hazard chacterization (from a risk assessment of Palm Beach)

HURRICANES	
Hurricanes are low-pressure systems rotating in a continuous closed circulation which form following atmospheric disturbances over warm water in the Atlantic Ocean. They produce heavy rainfall, strong winds, and ocean surges which cause widespread damage upon landfall (NOAA, 2020).	
Magnitude	**Relative Annual Loss: VERY HIGH** The Saffir-Simpson Scale categorises hurricanes according to wind-speed: CAT 1 = 119-153kph CAT 2 = 154-177kph CAT 3 = 178-208kph CAT 4 = 209-251kph CAT 5 = 252kph+ (PBC, 2021, p. 3) Palm Beach is exposed to all categories of hurricanes, with an expected annual loss (i.e., damage to personal and public property) of $864,000,000 USD (FEMA, 2021).
Frequency	**Relative Annual Frequency: HIGH** By examining historical data relating to 70 hurricanes affecting Palm Beach on record, FEMA (2021) estimates an annual frequency of 0.3 hurricanes per year. Hurricane season runs from June 1 to November 30 (FEMA, 2022).
Spatial Extent	The impacts of hurricanes will vary depending on geography: ▪ Hurricanes will affect multiple municipal and state jurisdictions along the coast. ▪ All affected areas are susceptible to wind damage. ▪ Low-lying areas are particularly susceptible to flooding because of extreme rainfall and storm surges.
Onset	Hurricanes are sudden-onset hazards with significant warning time due to slow formations (over several days) before landfall. They allow authorities to warn the public, coordinate evacuations, and take appropriate preparedness actions.
Trends	Climate change directly impacts ocean temperatures, air humidity, and wind patterns which determine the formation of hurricanes. According to NASA (2022), a warming ocean will lead to more energetic hurricanes – resulting in slower-moving systems, increased rainfall, and stronger winds – that will increase in intensity.

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A RISK ASSESSMENT FRAMEWORK FOR LAND USE PLANNING – PART 3: VULNERABILITY ASSESSMENT

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Abstract

Risk assessment is a crucial element of land-use planning in order to achieve a safe, sustainable and resilient society. After having conducted the steps of establishing purpose, assessomg valuable assets, and assessing hazards, the next important step is the vulnerability assessment. Vulnerability assessment in this context refers to analysing the conditions of a geographic area or planned area that increase the susceptibility of an individual, a community, assets or systems to the impacts of hazard. Factors can be physical, social, economic or environmental. This chapter provides methodological guidance and examples on conducting the vulnerability assessment step.

Keywords: *Risk assessment, Land-use planning, Assessment framework, Vulnerability Assessment*

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1. INTRODUCTION

As outlined in the previous two chapters *A risk assessment framework for land use planning – Part 1 and Part II*, risk assessments are key to developing sound land-use proposals. After conducting the first three steps of the framfework, the next step is to conduct the vulnerability assessment step (see figure 1 below). The present chapter aims to provide methodological guidance on how to conduct the this step and to exemplify the output from such an assessment. The examples come from student groups assignments in the course Risk-based land use planning (VRSN20) givet at the Master program in Disater Risk Management & Climate Change Adaptation program at Lund University.

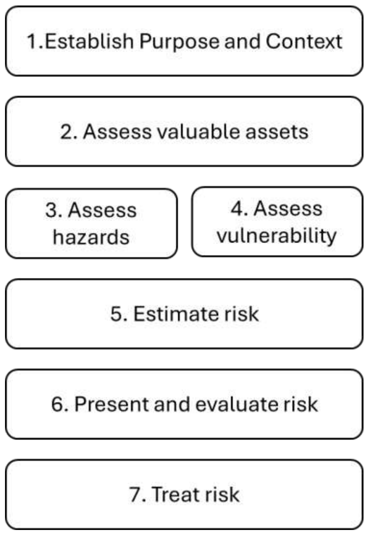

Figure 1. A risk assessment framework for land-use planning

The hazards identified in the Hazard Assessment step, see the chapter *A risk assessment framework for land use planning – part 2: Hazard assessment* may pose a threat to the assets identified in the step Assess Valuable Assets. However, all assets are not exposed to all hazards, nor are they vulnerable to the hazards in the same way. In a vulnerability and capacity assessment, the assets' susceptibility to hazards (i.e. their vulnerability) as well as their ability to withstand those hazards (i.e. their capacity) are assessed. This is done for all assets exposed to each particular hazard. The vulnerability and capacity assessment should, for example, take physical, environmental, economic, as well as social factors into consideration. This step also includes an analysis of the causes behind their vulnerability/capacity.

Many definitions of the term vulnerability exist, and in this framework, vulnerability is defined as "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards"[1]. Furthermore, the term capacity is defined as "the ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters"[1]. While this step is simply called vulnerability assessment, it also includes the assessment of capacity.

Sometimes the term capacity is used to simply denote the flip side of vulnerability. Although the concepts of capacity and vulnerability essentially are opposites, a high level of vulnerability does not always correspond to a low level of capacity, and vice versa. One of the subtle differences between the concepts is that vulnerability typically refers to an internal feature or property (a susceptibility to harm), while the term capacity typically also takes external factors into consideration (the possibility of receiving assistance to manage or reduce harm). Moreover, the term vulnerability often describes a passive state (either an asset is susceptible to harm, or it is not), while the term capacity describes an active feature (the ability to actively manage harm).

1. ASSESS EXPOSURE

The first step of the vulnerability and capacity assessment is to determine whether a specific asset is exposed to a specific hazard. Unless there is such exposure, an assessment of vulnerability or capacity is irrelevant.

This step is conducted by analysing exposure for each asset in relation to the hazards, one at the time. As a way of facilitating this step, the hazard map can be compared with a map showing assets for the geographical area under consideration (if such maps have been created in previous steps). In any case, the results from this step can be illustrated in a table, see Table 1 below. In the table, exposure is indicated with an "X", but it could also be graded e.g. as High, Medium, Low, None.

Table 1. Outline of an exposure table

		Hazard						
		Flooding	Fire	Explosion	Hurricane	Social disorder	Etc.	Etc.
Asset	People	X	X		X	X		
	Buildings		X	X		X		
	Etc.							
	Etc.							

[1] https://www.undrr.org/drr-glossary/terminology, 2025-03-05

Example of the step Assess exposure (from a risk assessment on Manchester)

		Hazard		
		Flooding	Terrorist attacks	Heatwaves
Exposed Asset	People	• Homeless people are particularly vulnerable to flooding in the city centre as they often shelter by tunnels and walls along the canals. • Residents and property owners, particularly those living or working close to canals/rivers or living on canal houseboats in Castlefield area. • Commuters, workers and students who work or study in the city centre. • Tourists/ anyone else who is in the city centre at the time of a flood.	• All people in the city centre are vulnerable to terrorist attacks, however those from marginalised communities or religious and social minorities may be more possible targets of terrorism (Piazza, 2011) • Based on previous terrorist attacks in Manchester, people who live or work in busy central areas such as round Piccadilly Gardens, Market Street and the AO arena are vulnerable to terrorist attacks (Mancosu, and Pereira, 2021).	• All people in the city centre are vulnerable to heatwaves but especially those who are in less ventilated buildings, work outside or are located in busy, crowded areas. • Old people and children are also more vulnerable to heatwaves (CDC, 2022)
	Critical infrastructure	• The city's three largest train stations Manchester Picadilly, Oxford Road and Victoria are all near to canals. There are also multiple smaller train stations such as Deansgate and Salford Central close to the river. • University buildings and research facilities • Hospitals and other health centres. • Bus and tram stops throughout the city. • Central fire and police stations.	• All critical infrastructure in the city is vulnerable to terrorist attacks, this however especially includes the large train stations, hospitals and health centres which are more likely targets of terrorism in the UK (Segell, 2006; Cauwer et al., 2016).	• Critical infrastructure such as hospitals, public transport and universities cannot function if it is too hot for staff to work and hence are vulnerable to heatwaves.

2. DESCRIBE FACTORS INFLUENCING VULNERABILITY AND CAPACITY

From the analysis performed in the previous step, showing which assets are exposed to which hazards, the next step is to describe how the assets are vulnerable (or have capacity to withstand or manage) these hazards. This information can be included in a similar (extended) table as table 1.

Vulnerabilities and capacities can be internal (such as fire drills enhancing the capacity to evacuate quickly in the case of a fire) as well as external (such as the availability of resources from rescue service to reduce the impact of a fire). Vulnerabilities and capacities can also be both active (such as the availability of water sprinkler systems in a building) and passive (such as the existence of fire walls).

As mentioned above, the vulnerability and capacity assessment can use predefined categories as a point of departure, such as:

- Physical
- Environmental
- Economic
- Social

However, it is important to note that such categories should only be used if they are seen as valuable to structure the assessment (the categories have no value per se, and there are many alternative ways of categorising vulnerabilities and capacities).

In the example illustrated in Table 2, factors influencing the vulnerability or capacity are merely described as positive or negative (+ or -). It is also possible to use a more refined grading system, such as indicating a scale between -3 to +3. Independently of the chosen grading system, the factors should also be described qualitatively so that the judgements made are motivated. In addition, such information can be used as a basis for risk reduction measures.

For some combinations of hazards and assets, the vulnerability can be described in qualitative terms. Such example is shown below. However, for many combinations of hazards and assets, a quantitative or semi-quantitative assessment is more feasible. An example would be a probability distribution that describes the probability of building collapse as a function of an increasing hazard magnitude (e.g. increasing Richter scale or TNT equivalent). It is important to note that the vulnerability or capacity of an asset in relation to a specific hazard may be influenced by multiple factors. Moreover, some of these factors may have a more direct influence, while others are more indirect. For example, the vulnerability to flooding is influenced by the type and location of residential buildings. These factors are, in turn, typically influenced by the socioeconomic status of the residents (who may have little choice to find affordable housing in safer areas). This progression of vulnerability from unsafe conditions directly determining the vulnerability to a specific hazard to the more remote "root causes", such as economic, demographic and political processes, are further discussed by Blaikie et al. (2014). Typically, indirect factors are harder to influence (especially in a land-use planning context) and the causal relationship is less clear.

Table 2: Factors influencing vulnerability or capacity of assets in relation to hazards

		Hazard		
		Flooding	Fire	Etc.
Asset	People	+ Proximity to rescue service, warning systems installed - Limited mobility of elderly living in low-land areas	+ Proximity to rescue service - Old residential buildings with poor fire protection	
	Buildings	+ … - …	+ … - …	
	Etc.			

\+ refers to a positive influence in terms of reducing vulnerability or increasing/strengthening capacity.

\- refers to a negative influence in terms of increasing vulnerability or reducing capacity.

Example of the step Describe factors influencing vulnerability (from a risk assessment of Mumbai)

People

Research indicates that people are highly susceptible to heatwaves, leading to increased mortality rates, particularly in Girgaon, where the climate is characterised by high heat and humidity (Kravchenko et al., 2013). The combination of these factors can result in severe heat-related medical conditions, including heat stroke, cramps, exhaustion, and dehydration, amplifying the impact on individuals with chronic diseases (ibid., 2013). The body's natural cooling mechanisms are diminished in high heat and humidity environments, making it challenging for individuals to cool down, leading to dehydration, organ stress, and potentially fatal consequences (Akerman et al., 2016). Vulnerability to these effects may be influenced by age, health status, and socio-economic conditions. The elderly and individuals with pre-existing health conditions face increased vulnerability due to challenges in regulating body temperature, while socio-economic factors play a role in determining access to cooling infrastructure and healthcare resources.

Urban floods in coastal cities like Mumbai, particularly during monsoons, pose a complex threat to the population due to various factors, including high-intensity rainfall, insufficient drainage systems, and tidal influences (Eldho et al., 2018). The associated health risks during floods include structural hazards like trauma, burns, and electrocution, along with exposure to carbon monoxide, infectious agents in contaminated water, and potential respiratory issues due to mould growth (National Institute of Environmental Health Sciences, 2021).

People's vulnerability in flooding is closely tied to their geographical location, access to flood-resistant shelters, and awareness of evacuation routes. Residents in low-lying areas like Girgaon may face higher vulnerability, therefore existing flood shelters in the area must be complemented by well-maintained evacuation routes to demonstrate greater capacity to cope with such events.

Building collapse presents a significant threat to people, especially in densely populated and partly unregulated areas such as Girgaon. Girgaon's numerous informal settlements and unregulated construction amplify the risk of building collapse, emphasising the need for improved building regulations and safety measures. Factors influencing vulnerability in building collapse include the structural integrity of buildings, adherence to building codes, and residents' awareness of evacuation protocols. Vulnerable populations may include those residing in poorly constructed or dilapidated buildings.

Critical Infrastructure

Critical infrastructure faces significant vulnerabilities during heatwaves, presenting widespread challenges across sectors. Transportation systems, including roadways, runways, and railways, are especially susceptible, with potential buckling under high heat leading to cascading effects, including heat-induced power outages and threats to public health (Cybersecurity & Infrastructure Security Agency, n.d.). Elevated temperatures also affect power lines, reducing efficiency and overwhelming load shedding capacity, while overheating of building materials amplifies energy needs for cooling during power outages (ibid., n.d.). Research highlights the pronounced impact of heat on rail infrastructure, causing tracks to buckle and disrupting train operations (McEvoy, Ahmed & Mullet, 2012). Vulnerabilities in critical infrastructure during heatwaves are linked to cooling requirements of energy systems, potential strain on water supply for cooling, and the impact of high temperatures on transportation networks.

Critical infrastructure in urban areas, as exemplified by the Mumbai flood event in July 2005, faces heightened vulnerability to urban floods, resulting in cascading impacts across various sectors. Widespread flooding severely damaged essential facilities, hindering healthcare services, causing significant losses to the Maharashtra State Electricity Board, and disrupting transportation (Singh & Kumar, 2013). These urban system's vulnerabilities to floods are influenced by proximity to water bodies, adequacy of flood protection measures, and the robustness of sewage and waste disposal systems. Infrastructure in low-lying areas may face increased vulnerability, but capacity exists in the form of an early warning system.

Critical infrastructure is susceptible to building collapse, especially during significant events like earthquakes. In Mumbai, the perceived earthquake threat is relatively lower, particularly in the Girgaon area with predominantly 3-5 storey detached buildings (Shah, 2021). Despite assumptions that collapses might not cause substantial damage due to the buildings' detached nature, critical infrastructure vulnerabilities may arise from dependencies on specific structures for energy generation or transportation hubs in buildings susceptible to collapse.

<u>Example of the step Describe factors influencing vulnerability (from a risk assessment of Medellin)</u>

<u>Human Life and Health: Vulnerabilities</u>

The hillside location, poor construction and resultantly poor living conditions of people residing in the informal settlements in Llanaditas accounts for a vulnerability in the occurrence of a flood, landslide or earthquake (IUCA, n.d.). Moreover is the lack of updated population statistics an issue for human life and health, especially for the mapping of groups such as the elderly and people with disabilities (ibid.). Existing evacuation plans for the area are not up to date, and there is a lack of knowledge on how to act in the case of a flood, a landslide or an earthquake (ibid.).

The pressure and release (PAR) model identifies a process generating vulnerability, consisting of root causes, dynamic pressures and unsafe conditions (Wisner et al., 2004). Based on the PAR model, issues like the lack of education about hazards and the absence of an official early warning system (EWS) in Llanaditas can be seen as unsafe conditions for residents (IUCA, n.d.; Velásquez, 2022). As there is no official EWS in Llanaditas, residents instead have to rely on self-monitoring conducted by community members (Monsalve, 2023). Contributing to these unsafe conditions are dynamic pressures such as the lack of economic resources and political incentives to implement risk reducing measures (IUCA, n.d.).

Social, cultural and economic vulnerabilities in Llanaditas are exacerbated by social disruption in Colombia, causing internal displacement and illegal entry of migrants to Llanaditas (Diaz et al., 2023). Consequently, the expansion of informal settlements increases, causing deforestation and digging on the hillside, which in turn triggers landslides (Kalsnes & Capobianco, 2022). Furthermore, an increased population density is adding to the vulnerability to hazards like floods, landslides and earthquakes (Velásquez, 2022). According to Sepúlveda Murillo et al. (2019) the majority of the population in Llanaditas are low-class citizens and face financial vulnerability.

The lack of financial capacities often leaves residents with no option but to live with their relatives or friends until they can afford to move out or find housing, causing a continuous cycle of financial strain to the sole family breadwinner (ibid.). Existing housing conditions, including the poor sewerage system and lack of proper sanitation utilities, predispose the residents in Llanaditas to various health vulnerabilities; transmitted diseases such as cholera, diarrhoea, dysentery, typhoid, and polio (Agudelo-Suárez et al., 2022). The population's consumption of contaminated water and poor sanitation are linked to an inability to maintain hygienic conditions due to insufficient garbage collection, poor industrial and hazardous waste management as well as wastewater management and disposal (ibid.).

<u>Human Life and Health: Vulnerabilities</u>

The people in Llanaditas reside in close proximity to several health clinics and are considered to have significant community capital to prepare for, adapt to and recover from disasters (Velásquez, 2022). Community capital indicates high levels of trust, good relationships between community members and a willingness to engage in community activities and is hence an important aspect of societal resilience (Cutter et al., 2010).

Starting in 2018, a project was initiated in the El Pacífico neighbourhood in Llanaditas with the aim of empowering local neighbourhoods through participation, education and political action for disaster risk management (IUCA, n.d.).

In collaboration with local councils, corporations and the Institución Universitaria Colegio Mayor de Antioquia in Medellín, the project started a Community School for Risk Management in which risks, vulnerabilities and capacities could be identified. A Community Plan for Risk Reduction was developed for El Pacífico in 2019 (ibid.), following a pre-existing plan developed for Llanaditas in 2016 (Velásquez, 2022).

Through the 2019 Community Plan for Risk Reduction, which covers the El Pacífico neighbourhood in Llanaditas, various strategies and measures have been implemented for disaster preparedness and adaptation (IUCA, n.d.). The local community has been active in mapping risk levels and vulnerable groups in the area, developing evacuation routes with colours and arrows for hazards, and conducting 'human monitoring' by repeatedly checking hazard-prone areas such as the La Rafita ravine (Monsalve, 2023). Community initiatives in the area have also included 'green measures' which work with nature as an ally rather than a threat (Wamsler, 2014), such as planning to develop a

3. EVALUATE AND PRESENT VULNERABILITY AND CAPACITY

This step aims at drawing conclusions from the vulnerability and capacity assessment. In particular, it is important to evaluate the previous steps with regards to the following questions:

- Is it possible to identify vulnerabilities or capacities that are common to many assets? This information is valuable in relation to suggesting risk-reducing measures, since the same measure can reduce vulnerability or increase capacity for several assets.
- Is it possible to identify hazards that affect several different assets? And vice versa, is it possible to identify hazards that hardly influence any assets at all (and therefore may be disregarded in the subsequent step of the risk assessment)?
- Is it possible to identify assets that are particularly exposed and/or have a particularly high degree of vulnerability/low degree of capacity?
- Is it possible to identify factors that may change over time, i.e. trends that may increase vulnerability or decrease capacity (e.g. demographic or political trends influencing the vulnerability or capacity of assets)?

The results from a vulnerability and capacity assessment can be illustrated in a map, showing where those assets that are particularly exposed to hazards are located. This map can be created with the map showing assets from the step involving identification of vulnerable assets as a point of departure.

Questions to ask in the Vulnerability Assessment step:

- Which assets are exposed to which hazards?
- What is the vulnerability and capacity of each asset in terms of their (in)ability to withstand or manage these hazards?
- Which assets are particularly vulnerable and which hazards are exposing several assets?

Why is this step important?

- In many situations, the hazard itself cannot be altered. For example, the occurrence of an earthquake cannot be avoided. Therefore, measures need to be taken to increase the capacity and reduce the vulnerability of the assets. In order to take such measures, adequate information about the vulnerability and capacity, as well as factors influencing these aspects, is necessary.

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A RISK ASSESSMENT FRAMEWORK FOR LAND USE PLANNING – PART 4: RISK ESTIMATION

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Abstract

Risk assessment is a crucial element of land-use planning in order to achieve a safe, sustainable and resilient society. After conducting the first four steps of the framework, the next critical steps of the risk assessment is the conducting the risk estimation. In the risk estimation, the vulnerability assessment is combined with the hazard assessment to described risk scenarios, and make risk estimations, which includes likelihood estimation, consequence estimation and uncertainty description. This chapter provides methodological guidance and examples on conducting the risk estimation step.

Keywords: *Risk assessment, Land-use planning, Assessment framework, Risk estimation.*

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1. INTRODUCTION

As outlined in the chapter *A risk assessment framework for land use planning – Part 1: Introduction, establishing context, and assessing valuable assets*, risk assessments are key to developing sound land-use proposals. A critical step, after the steps Establish purpose, assess valuable assets, assess hazards, and assess vulnerabilitis, are the risk estimation (see figure 1 below). The present chapter aims to provide methodological guidance on how to conduct risk estimation and to exemplify the output from such an assessment. The examples come from student groups assignments in the course Risk-based land use planning (VRSN20) givet at the Master program in Disater Risk Management & Climate Change Adaptation program at Lund University.

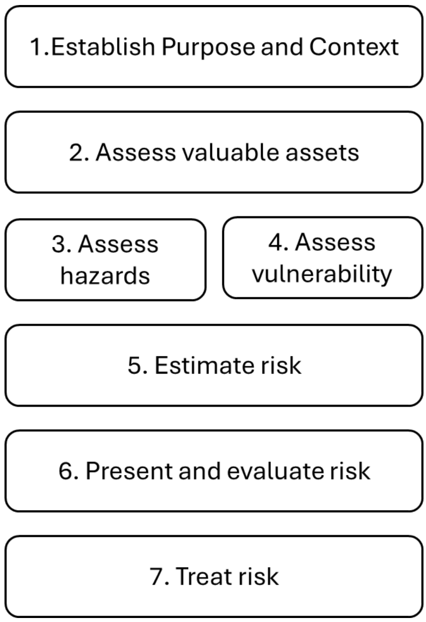

Figure 1. A risk assessment framework for land-use planning

The purpose of this risk assessment framework is to provide the basis for assessing and estimating risk in a particular geographical area, in order to use this information in the context of land-use planning. At this stage of the risk assessment, all the steps conducted so far are merged together to estimate the level of risk in the geographical area and to draw conclusions about the implications this entails.

For large geographical areas comprising multiple hazards and valuable assets, it is not feasible to synthesise information about each hazard and the vulnerability/capacity of each asset in a detailed manner. Accordingly, it is necessary to develop a manageable number of representative risk scenarios. A representative risk scenario is a scenario that represents a group of underlying more detailed scenarios and where the consequences of the representative scenario correspond to *the average consequences* of the underlying group of scenarios. The reason for using the average consequences is to arrive at a representative, rather than conservative, picture of risk. Note, however, that when estimating the likelihood of the representative scenario, the likelihood of the whole group of underlying scenarios must be aggregated – otherwise the risk level will be grossly underestimated.

An example of a representative risk scenario can be a large release of toxic gas close to a shopping mall. This is a scenario that represents a variety of specific toxic gas release scenarios. The variety of scenarios arises from the fact that the amount of gas may vary, the timing of the accident may vary, the exact location of the accident may vary, etc. But the available time to conduct the risk assessment typically does not allow for specific scenarios to be modelled for each possible variation. Instead, a single representative scenario, corresponding to a scenario of average consequence severity, is used to represent all the underlying possibilities.

1. DESCRIBE RISK SCENARIOS

In the Vulnerability Assessment step, the basis for creating scenarios has already been conducted by linking hazards to (one or several) assets. In this step, the most relevant scenarios are chosen and each scenario is described in terms of its specific hazard characteristics (in many cases, the same information used in Hazard Assessment step can be used if this is considered representative). In the same way as the hazard is described with regards to various hazard characteristics, the assets exposed to this particular hazard need to be described in terms of their vulnerability and capacity.

In the process of constructing scenarios, the following principles should be used as a point of departure (see Kaplan et al. (2001) for more details on these principles):

- The scenarios should cover all possible (negative) events that may happen in the area under consideration that exceeds some minimal level of impact, i.e. the consequences should not be negligible
- Each scenario should be described by using a sufficient level of detail (i.e. the hazard characteristics and the vulnerability/capacity of the assets should be portrayed)
- The different scenarios should be mutually exclusive (i.e. they should not be overlapping)

In addition, the process of constructing scenarios includes some important choices or considerations.

1.1. Description of the way a hazard materialises to give rise to consequences:

- A particular hazard may affect one or several assets in different ways. This is because some hazards may include a very large variety of possible outcomes; both the fact that the hazard may affect a community in different ways (varying degree of severity, speeds of onset, durations, etc.) and that the exact same hazard event may lead to different outcomes depending on variation in the vulnerability characteristics (many people happens to be present close to an explosion, the emergency response is successful or not, etc.). For this reason, it is necessary to decide if each hazard should be assessed by using one or several scenarios. As a starting point, it is recommended that the initial assessment includes one or a few (representative) scenarios related to each hazard. The goal is to be able to make sufficiently precise consequence estimations. In a more detailed assessment (e.g. in the detailed planning of the geographical area under consideration), a larger number of scenarios may be included. In any case, it is essential that the total list of scenarios is not greater than it is possible to analyse each one of them to create an aggregated picture of the risks facing the geographical area under consideration.
- For each scenario, the hazard should be described by using the different hazard characteristics outlined in the Hazard Assessment step.

1.2. Description of the way the assets are exposed to the hazard in the specific scenario

- The hazard may affect one or several of the assets, and by using the information presented in the Vulnerability Assessment step, each specific scenario can be described. Sometimes several assets are affected at the same time (e.g. by flooding, hurricanes or earthquakes), while other hazards only affect one particular location (and asset) at the time (e.g. transportation accidents).
- If several assets may be affected by the same hazard, but not in the same scenario – it is necessary to decide whether it is possible to create one representative scenario (e.g. explosion occurring in any of the six shopping malls), or if it is necessary to create multiple scenarios (explosion occurring in shopping mall A, explosion occurring in shopping mall B, etc.).

2. ESTIMATE CONSEQUENCES

In this step, the negative the consequences arising in the scenarios are estimated. When multiple hazards and assets are assessed in the same risk assessment, more than one consequence dimension is normally necessary, e.g. loss of human lives (number of fatalities), economic loss (Million Euros) or disruptions in societal functions (number of people without electric power). Naturally, the dimensions used are related to the choice of assets described in the step Identify Valuable Assets.

When choosing consequence dimensions it is also important to think about the time perspective. Traditionally many risk assessments focus on the short time perspective – e.g. instant fatalities. However, there may also be reasons for looking at consequences in a longer time perspective – which is typically more accentuated in vulnerability assessments. This may, for example, relate to questions about how society is apt to cope with the fatalities resulting from an explosion – are there enough health care facilities? Is there enough psychological support for long-term treatment of victims, etc.?

In addition to the choice of consequence dimensions, the type of scale also needs to be selected[1]. At the most rudimental level, consequences can be described qualitatively (i.e. using words). Furthermore, consequences can be described using a quantitative ranking scale where a fixed set of categories are used (e.g. 1. Small consequences, 2. Medium consequences, etc.), which enables ranking of scenarios.

However, it may be difficult to communicate a risk assessment that has adopted this scale since the interpretation of e.g. "small" may vary between different persons and in different contexts. An even more sophisticated way of describing consequences is using a semi-quantitative scale, which is similar to a qualitative ranking scale with the difference that each category is also described with a quantitative interval (e.g. 10-100 fatalities, 100-1000 fatalities, etc.).

Finally, the most sophisticated scale is the quantitative one, which correspond to using an "exact" quantitative description, e.g. 113 fatalities or 15M SEK economic loss. Which scale to use depends on the purpose, although it is generally recommended to at least use a semi-quantitative scale. Sometimes an analyst may feel tempted to use an imprecise scale in contexts where there are large uncertainties concerning consequences.

However, it is preferable to try to use a scale that is precise (i.e. that cannot be interpreted in many different ways) but to communicate that some of the estimations are very uncertain. Of course, in more detailed assessments, e.g. in the context of a detailed development plan ("detaljplan"), a quantitative scale is typically necessary.

It is important to note that the construction of the categories, in case a qualitative ranking or semi-quantitative scale is used, must be adapted to the particular case and size of the area in question. For example, a catastrophic consequence in the context of a risk assessment for a school would probably be one fatality. However, in a risk assessment for natural hazards in an entire country, a catastrophic consequence could e.g. be 20 fatalities.

If several consequence dimensions are deemed relevant it is necessary to decide whether separate scales should be used for each dimension or whether a single joint scale, which combines the different dimensions, should be used. Regardless which alternative is chosen, different consequence dimensions need to be compared in the final assessment in

[1] This section is equally relevant for likelihood estimations.

order to provide an aggregated analysis of the risks facing the geographical area. This requires that value judgments are made concerning the "weight" of a fatality compared to a serious injury, or an economic loss, etc.

In order to make the consequence estimation, all the relevant information from the hazard and vulnerability assessment should be used. The point is to try and foresee how a hazard (with some specified hazard characteristics, such as very quick speed of onset, long duration, etc.) interacts with the relevant vulnerability characteristics (area with weakly constructed buildings affected, no early warning system, etc.) to give rise to a specific severity of the consequences. In detailed risk assessments, such as those performed in the context of a detailed development plan ("detaljplan"), various calculation and simulation tools are typically used to estimate consequences. At a more overall level, though, the consequences are typically estimated based on expert judgments. However, although expert judgments are being used, it is nonetheless of great importance that the reasoning behind such judgements is transparent and logical with reference to the underlying hazard and vulnerability characteristics.

Finally, as discussed in the previous sections, a particular scenario is always representing a group of more detailed scenarios. Therefore, an average value of the consequences across the group of scenarios should be used in the consequence estimation. If the average consequences is a very poor representation of the consequences of each more specific scenario, then the scenario should be broken down into more detailed scenarios (i.e. it may be necessary to iterate between this and the previous step).

3. ESTIMATE LIKELIHOOD

Similar to consequence estimations, likelihood estimations also require a selection of type of scale. The options are equivalent to those previously described above related to consequence scales (qualitative, qualitative ranking scale, semi-quantitative, quantitative). When it comes to quantitative estimations, two different concepts are typically used: probability and frequency.

Three information sources are typically used as a basis for likelihood estimations. The most desirable type of information is relevant statistics (e.g. data on past incidents etc.). Often statistics may not be directly applicable to the particular geographical area and then it must be adapted to the local conditions. For example, if national statistics are being used it has to be "scaled down".

It is also necessary to consider whether the particular area is represented well in such national statistics. In estimating likelihood it is also necessary to take into account how the scenarios have been modelled. For example, if several scenarios are used to represent flooding, then the total likelihood of flooding must be divided over the sub-scenarios (which can be done by using e.g. event trees).

Finally, since the underlying data is often limited, it is typically necessary to also make use of expert judgments to estimate likelihoods. In this context, it is of great importance that the judgements are made in a transparent and well-documented way.

Example of the step Risk description, consequence and likelihood estimation (from a risk assessment of Mumbai)

Heatwave scenario and frequency

According to de Bont et al. (2024), the frequency of heat waves in Mumbai is 3.6 times/ year with an average temperature of 31.5°C. This report assumes that the same number applies to Girgaon. However, due to the low amount of vegetation in Girgaon and the possible increased local heat island effect, the frequency is increased to ***3.6-4 times per year****.*

Heatwave consequences

Defining consequences of heatwaves in terms of fatalities causes difficulties because extreme heat can cause indirect mortality through underlying physiological pathways (de Bont et al., 2024). This report estimates the number of deaths caused by heatwaves by using increased daily mortality:

- *Average all-cause daily deaths in Mumbai = 251 deaths (de Bont et al., 2024)*
- *Average increase in daily mortality during heat waves = 3.4% (de Bont et al., 2024)*
- *Average duration of heatwave = 4 days (de Bont et al., 2024)*
- *Average additional deaths Mumbai during heatwave event = 3.4% / 100% · 251 · 4 = 35 deaths*
- *Average additional deaths Girgaon = 0.94% of 35 =* ***less than one additional death***

Since this report considers heatwaves and a building collapse as mutually exclusive events, it can be assumed that a heatwave would cause ***no monetary losses to the built environment.*** *However, critical infrastructure suffers more easily from heatwaves. To make a rough estimation of financial losses on critical infrastructure in Girgaon, the following equation is used:*

- *Total GDP loss India: 5.4 % (Al Jazeera, 2023).*
- *Percentage of 2023-2024 GDP that is critical infrastructure: 3.3% (Invest India, 2023)*
- *Total GDP India: 4.11 trillion USD (IMF, 2024)*
- *Total surface India in sq km: 2,973,190 (The World Bank, 2024).*
- *Critical infrastructure loss India = total GDP India · % of GDP from critical infrastructure % income loss due to heatwaves = $4.11 trillion · 0.033 · 0.054 = $7.32 billion*
- *Critical infrastructure loss Girgaon = crit. inf. loss India / Total area India · Total Area Girgaon = $7.32 billion / 2 973 190 km2 · 2 km2 = $4 927*
- *Critical infrastructure loss Girgaon per heatwave event = crit. inf. loss Girgaon / number of heatwave events/year = $4 927 / 4 = $1 232*

However, Girgaon is an area with a lot of critical infrastructure compared to the Indian landscape in general, so this paper triples this number to account for this and the uncertainties involved in this calculation. The range of ***financial losses for critical infrastructure is $1 232 - 3 695 due to a heatwave.***

4. DESCRIBE UNCERTAINTY

There are many sources of uncertainty related to describing and characterising hazards, vulnerabilities, risk scenarios and making estimations of consequences and likelihood. These uncertainties may come from poor underlying data, subjective judgments conducted by the analyst/experts, uncertainty related to whether all relevant scenarios are covered in the assessment or to what extent the models used provide valid outputs.

It is important to acknowledge uncertainties, to be transparent about them and communicate them to potential stakeholders and decision-makers. The reason is that uncertainties may affect the decisions made following a risk assessment. Large uncertainties may warrant additional, more detailed, analyses to be made, or additional data collection efforts. Alternatively, if this is feasible, it may give rise to a need for additional risk reduction measures or application of a precautionary approach to risk management. Describing and analyzing uncertainties may also provide direction to how to most effectively reduce the uncertainty in an assessment.

There are many ways of describing uncertainties. If the risk assessment is conducted quantitatively, uncertainties in e.g. probability of consequence estimations (or at least some of the uncertainties) may be quantified by intervals or probability distributions. If the assessment is more qualitative, then uncertainties in estimations can be discussed qualitatively or classified using some ordinal scale (e.g. small, moderate, large). Again, a transparent approach is highly important.

Example of the step Uncertainty description (from a risk assessment of Palm Beach)

The risk ranking includes uncertainties, because the intervals were estimated in accordance with the hazards assessed in the area specific to project constraints and do not represent the severity based on evidence. Due to limited data availability, the risk rating is based on assumptions. Assumptions are made about the population numbers, including tourist numbers, which will vary according to season and weather. Furthermore, it is assumed that people are evenly distributed throughout the island, and that the whole area is affected from the sudden onset hazard. Since the mean of annual data is taken, the frequency and population number are uncertain. In addition, a critical factor to the number of fatalities is the early warning time before a hazards strikes, so people are more likely to evacuate the island before transportation routes might become impassable.

Moreover, the resulting consequences of the worst credible case scenario are based on estimations and comparisons to similar hazards in different areas. Yet, hazards and areas differ, and the consequences cannot be compared only on basis of the hazard type, but depend on factors like time of occurrence, the building structures and existing infrastructure, and hazard intensity, which are not addressed detailed enough within this risk assessment. Also, climate change might have an impact on the frequency of the hazards, so further predictions are needed. In addition, it is uncertain if all scenarios and potential consequences of the hazards are assessed.

Questions to ask in the step Risk Estimation:

- What is the level of risk in the area under consideration?
- Which risks are high, and which risks are low?
- Which risks are acceptable, and which risks are not?

Why is this step important?

- The ultimate goal of a risk assessment in a land-use planning context is to determine the level of risk facing a particular geographical area. By combining the previous steps, this step results in such assessment.

Example of the step Risk estimation (from a risk assessment of Kingston)

Scenario 1: Category 5 Hurricane occurs

This scenario describes a sudden escalation in storm intensity, generating a Category 5 hurricane that is stationed over Kingston. The winds likely destroy most informally and some formally constructed houses. Flying debris obstructs roads and flattens energy and communication infrastructure, causing isolation and blackouts in the neighbourhood. Heavier flying objects constitute further hazards, and the operations in the port are halted. Some bridges collapse while much of the vegetation is uprooted or snapped. Branches and trunks fall on roads, cars and houses. Not all Downtown Kingston's population is able to evacuate. Shelters are not sufficient to accommodate the entire population. Additionally, though precipitation is limited, storm surges cause coastal flooding, exacerbating wind impact and hindering response efforts through flooded built infrastructures.

Likelihood

Based on historical data and previous research, it is likely that about one to four major hurricanes will impact Jamaica per year, with sea level rise and other climatic and anthropogenic factors also shaping these events and the triggering of floods (CSGM, 2017; National Water Commission, 2024; Rouleau et al., 2020; Vision 2030 Jamaica, 2017). According to climate modelling projections, the number of Category 5 hurricanes are expected to double (UNCTAD, 2017). Therefore, the frequency used for this scenario is 1 every 10 years.

Consequences

Economic losses/built infrastructure: Due to damages to built infrastructure, Kingston suffers high economic losses per hurricane (Vision 2030 Jamaica, 2017). Hurricane Ivan, a category 5 event in 2004, caused damages of USD 360 million in Jamaica (World Bank Group, 2021). Through dividing the damages proportionately according to the population size and accounting for inflation, for Downtown Kingston the estimated loss for the scenario is 5 million USD.

People: The most deaths registered in the 21st century were for Hurricane Ivan (17 people in whole Jamaica), though 14% of the country's population were directly affected by the hurricane (ECLAC, 2004). 5 deaths and 100 injuries in Downtown Kingston could be assumed as a consequence due to the scenario's hurricane landfall over the city.

Nature: Hurricane Ivan has caused damages to coastal areas with beach erosion and damages to mangrove forests located in front of the neighbourhood (PIOJ, 2004)

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A RISK ASSESSMENT FRAMEWORK FOR LAND USE PLANNING – PART 5: PRESENT, EVALUATE AND TREAT RISK

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Abstract

Risk assessment is a crucial element of land-use planning in order to achieve a safe, sustainable and resilient society. After conducting the first five steps of the framework, the next critical steps of the risk assessment is the risk presentation, evaluation and treatment. These steps concern putting together all risk information from previous steps and make it comprehensible for decision makers and stakeholders to enable them to make wise choices about risk acceptance and risk reduction measures. This chapter provides methodological guidance and examples on conducting the risk presentation, evaluation and treatment steps.

Keywords: *Risk assessment, Land-use planning, Assessment framework, Risk presentation, risk evaluation, risk treatment*

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1. INTRODUCTION

As outlined in the chapter *A risk assessment framework for land use planning – Part 1: Introduction, establishing context, and assessing valuable assets*, risk assessments are key to developing sound land-use proposals. Two critical steps of a risk assessment in a land-use planning context is Risk presentation and evaluation, and Risk treatment (see figure 1 below). The present chapter aims to provide methodological guidance on how to conduct the these two steps and to provide examples of how the steps can be conducted. The examples come from student groups assignments in the course Risk-based land use planning (VRSN20) givet at the Master program in Disater Risk Management & Climate Change Adaptation program at Lund University.

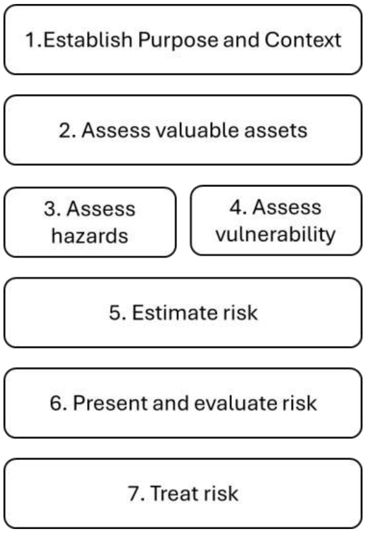

Figure 1. A risk assessment framework for land-use planning

2. PRESENT AND EVALUATE RISK

The output from the last step is basically a list of scenarios (including descriptions of relevant hazard characteristics, assets and vulnerability characteristics) with their likelihood and consequence estimations. This information needs to be organized in such way that it will be possible to gain insight regarding risk levels, what aspects that contribute most to this level of risk (related to either hazards or to vulnerability), as well as to make judgements regarding risk acceptance. Key questions that can be posed in this step include:

- Which hazards are most important to address in terms of reducing their magnitude, likelihood, etc.?

- Which assets are most important to address in terms of improving protection or reducing vulnerability (either by reducing the exposure or increasing the capacity to withstand hazard events)?
- Are there areas with high concentration of hazards and/or vulnerable assets that should be targeted for intervention (i.e. risk-reducing measures)?
- Are the aggregated (combined) risk levels in the area acceptable?

2.1. Risk presentation

There are several ways to present risk. Some require quantitative information whereas others are possible to use also for qualitative or semi-quantitative information. In general, different ways of presenting risk complement each other by highlighting different aspects of risk. Therefore, a general recommendation is to use several ways of presenting risk. For example, risk can be presented by focusing on hazards (e.g. what are the magnitude and likelihood of the scenario/scenarios associated to a particular hazard). This information gives insights about which hazards that should be prioritized and addressed by risk-reducing measures. However, there may be certain assets or vulnerability characteristics that are resulting in the consequences becoming larger in a variety of scenarios; and this would not be apparent if risk is only presented by focusing on the hazards.

<u>Non-quantitative analyses (more common in comprehensive planning, e.g. "översiktsplan")</u>

- Risk matrix – scenarios can be plotted in a risk matrix to gain an overview of significant scenarios and less significant scenarios. When using this method it is important to realize the limitations related to the risk matrix – see Duijm (2015) for a summary and discussion of these limitations.
- Priority list for hazards – by summing the product of likelihood and consequences for all scenarios (if many) related to a particular hazard it is possible to estimate a "risk score" that can be used to set a priority list for hazards.
- Hazard, vulnerability and risk maps – hazards, vulnerabilities and risk can be plotted on maps in several different ways. If information about the geographic distribution of hazard exposure and vulnerability levels exist it is possible to plot such information on a map and also to combine into risk levels. Note that this is typically done for single hazards, such as earthquakes, although multi-risk mapping is also possible.

<u>Quantitative analyses (more common in detailed development planning, i.e. "detaljplan")</u>

- Location-specific individual risk – one type of risk map is to plot risk levels for different geographic locations which require estimations to be expressed in a quantitative way.

- FN-curves displaying societal risk– can be used to express societal risk and overcomes some of the limitations of the risk matrix. However, this way of presenting risk may be difficult for non-experts to understand, and should therefore be accompanied by a thorough discussion about implications.

2.2. Risk evaluation

Risk evaluation can be done in several ways, both qualitatively and quantitatively, depending on how the risk analysis has been performed. Even though risk evaluation is performed quantitatively, e.g. by comparing an FN-curve to a risk acceptance criterion, it is recommended that the evaluation is accompanied with qualitative considerations, since the quantitative evaluation does not capture the full range of complexity and the wide set of considerations that must be made. For example, it is possible to apply the risk evaluation principles suggested in SRV (2003): 1) Principle of plausibility, 2) Principle of proportionality, 3) Principle of fairness, 4) Principle of disaster avoidance. There are also other several qualitative frameworks for risk evaluation suggested, e.g. Klinke and Renn (2002).

Evaluating quantitative risk estimations (such as location-specific individual risk, and FN-curves) require some risk acceptance criteria to compare with. In Sweden, there are no such criteria stipulated in law although some counties have proposed criteria to use in a land-use planning context, e.g. RIKTSAM (County Adminstrative Board Skåne, 2007). In this context, a number of aspects must be considered carefully having to do with whether the risk acceptance criteria are adapted to the context of application:

1. Is the criterion adapted to the scale of application (primarily relevant for societal risk)? A large area, such as an entire municipality, is of course associated with higher societal risk than an equivalent small area simply because it will include more hazards and more assets, thus implying larger societal risk (although the individual risk is the same). The issue is the same when looking at societal risks along a route where hazardous goods are transported. Risk levels for a longer route will of course be higher than risk levels for a shorter route.
2. If there are several hazards/risk sources, should each be evaluated separately or should the aggregated risk levels be evaluated? The risk acceptance criteria suggested by DNV (1998) which has been widely used in Sweden, is adapted to the situation of a single risk source (e.g. an industry) exposing the surroundings to risk. How these criteria can be extrapolated to a multi-risk land-use planning context is not straightforward.
3. There must also be a match between the risk analysis and the risk acceptance criteria regarding what risk types should be included in the evaluation. Is it only industrial/technical risks or should other risks, e.g. traffic accidents, life-style risks, natural hazards, etc. be included?

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Questions to ask in the risk presentationa and evaluation step:

- What is the level of risk in the area under consideration?
- Which risks are high, and which risks are low?
- Which risks are acceptable, and which risks are not?

Why is this step important?

- The ultimate goal of a risk assessment in a land-use planning context is to determine the level of risk facing a particular geographical area. By combining the previous steps, this step results in such assessment.

Example of the step Assess Valuable Assets (from a risk assessment of Kingston)

RISK MATRIX		Consequences				
		Minimal (no deaths or serious injuries; less than 0.1 million USD)	Small (no deaths and/or 1–9 severely injured; 0.1-0.5 million USD)	Medium (1–2 dead and/or 10–20 severely injured; 0.5 - 2 million USD)	Significant (3-5 dead and/or 21 –50 severely injured; 2 - 5 million USD)	Very significant (> 5 dead and/or >50 severely injured; over 5 million USD)
Likelihood	Very low (roughly 1 in 10 000 years)					
	Low (roughly 1 in 1000 years)					
	Medium (roughly 1 in 100 years)					
	High (roughly 1 in 10 years)				S1	S2, S3
	Very high (roughly 1 per year)					

Example of the step Assess Valuable Assets (from a risk assessment of Palm Beach)

Risk Description	Description	Probability	Impact asset 1	Impact asset 2	Impact asset 3	Risk rating
Risk 1 – Hurricane (worst case)	S3 – hurricane category 5 during daytime	Very high	Very high	Very high	Very high	**Critical**
Risk 2 – Severe Thunderstorm (worst case)	S1 – severe thunderstorm during daytime	Very high	High	Very high	Severe	**Critical**
Risk 3 – Heatwave (worst case)	S2 – heatwave lasting more than three days	High	High	Very low	Very low	**Moderate**

3. RISK REDUCTION

Based on the risk assessment presented in the previous step it is possible to identify a number of risks that may require measures to reduce their likelihood or impact. The information compiled in all previous steps provides valuable input to the selection of risk-reducing measures. The risk assessment step provides information on which risks that are highest, and gives an indication of which risks that are in most urgent need of risk-reducing measures. In addition, the hazard assessment step gives information about the way hazards may affect a community, while the vulnerability assessment step includes important information about the ways in which the assets are vulnerable (and have a capacity) to the various hazards.

Risk-reducing measures can be directed both towards the hazard and the vulnerable asset. Selection of risk-recuing measures should be conducted to obtain as effective and efficient risk-reduction as possible. In this regard, it is important to consider whether a specific measure may reduce the potentially negative impacts from multiple hazards, or strengthen the capacity of multiple vulnerable assets. Risk-reducing measures are possible to categorise as follows:

- Generic measures – i.e. measures that affect multiple hazards and/or vulnerable assets
- Hazard-specific measures – i.e. measures that are directed towards one/many hazards
- Asset-specific measures – i.e. measures that are directed towards one/many assets

It is likely that a risk assessment will not be able to cover all potential future hazard occurrences and events – some events are simply not possible to foresee. Therefore, it is important to try to suggest measures that can also protect a community from surprises rather than only for those events that have been identified and included in the analysis.

Land use planning involves multiple interests and perspectives. When risk-reducing measures are suggested, it is important to take these interests and perspectives into consideration in order to achieve a solution that is satisfactory for all stakeholders. For example, it is usually necessary to take both aesthetical and economic perspectives into consideration when risk-reducing measures are suggested. Consequently, it is necessary to consider both the positive as well as negative effects of the suggested risk-reducing measures. While positive effects include the way the risk levels are affected by the suggested measures, negative effects include costs, restrictions on the use of valuable land, etc.

Finally, it is important to realise the need for good risk communication. Typically, risk assessments and risk-reducing measures must be communicated with stakeholders who have limited knowledge about the concept of risk. In addition, often the persons making decisions about risk acceptance and risk reduction are not the same as those assessing the risk. Therefore, it is of great importance that the risk, uncertainty and suggested risk reducing measures are communicated in a way that is understandable for all stakeholders. If it is concluded that the risk level is unacceptable, it must be clear how the suggested risk reducing measures give rise to a risk level that is acceptable. Or the opposite, if the risk level is found to be acceptable, it has to be clear on what grounds the conclusion rests. A transparent, open and honest risk analysis, risk evaluation and risk treatment is crucial in implementing successful risk consideration in land-use planning.

Questions to ask in this step:

- What risk-reducing measures are most suitable?
- Should risk-reducing measures be directed towards the hazards, the vulnerable assets, or both?
- How do the suggested risk-reducing measures interrelate with other interests and perspectives?

Why is this step important?

- The risk assessment step may show that some risks are not acceptable, which calls for relevant risk-reducing measures. These need to be selected in such way to obtain an overall satisfactory solution, taking consideration of all relevant interests and perspectives involved in land-use planning processes.

Example of the step Risk reduction (from a risk assessment of Kingston)

Expanded and resilient infrastructure

Expanded and more resilient public infrastructure aims to reduce vulnerabilities towards risks of Scenarios 1 and 2 in the assessment area, while improving living standards.

Recommendation 1 under this section is: Establish 100% coverage of solid waste collection in the assessment area.
Motivation: Implementing a functioning solid waste collection system for the whole assessment area, including informal settlements, could alleviate clogged gullies, thus reducing flooding and disease spread in polluted waters after hydrological hazard scenarios.
Synergies: Coupled with a gender-sensitive job creation programme in waste collection and recycling, this recommendation can also support a more circular economy. It is recommended that the new waste and recycling management employees also have time set aside to raise awareness about waste and pollution in schools.
Drawbacks: Initially high costs; new informal settlements are expected to keep appearing; waste collection system's functionality potentially undermined by weak governance and corruption.

Recommendation 2 under this section is: Upgrade gullies while rerouting electricity and telephone wires underground.
Motivation: Road drainage and gullies need to be more frequently unclogged and updated to reduce the risk of flooding and ensure the operability of roads (UN & IDB, 2007). The infrastructure elements vulnerable to hydrometeorological hazards would be better protected underground in order to reduce risks of blackouts and road blockages because of utility poles falling during hurricanes and floods.
Synergies: This recommendation partially draws on the Ocean Cleanup initiative (Ocean Clean Up, 2024) which in 2023 placed 12 interceptors in Downtown gullies (figure 8). Interceptors are floating barriers that can collect waste before it reaches the ocean. The updated infrastructure needs to be simultaneously earthquake-resilient, thus reducing infrastructure's vulnerability to seismic hazards.
Drawbacks: High costs; substantial changes needed in the whole waste management system before gully clogging can be sufficiently solved.

Recommendation 3 under this section is: Review EWS and use KCT as a test-bed for bilingual risk communication.
Motivation: A common obstacle to risk communication is language barriers, and official information in Jamaica is provided in English (Coppola, 2020; Koyfman, 2019; JIS, n.d.). A review of Kingston's early warning systems (EWSs) should be conducted to gather gender-, income and age-segregated data on the percentage of the population reached by EWS, as well as their knowledge of evacuation options and languages.
Synergies: Dual-language risk communication could reach the part of the population speaking Patois and minimise linguistic separation of communities. The port and the KCT could be used as a testbed for developing the bilingual EWS, considering KCT's large workforce and its exposure to multiple hazards.
Drawbacks: Gathering data necessary for appropriate EWS review is time-consuming and costly; underlying power structures and cultural norms may cause biases in data.

4. REFERENCES

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