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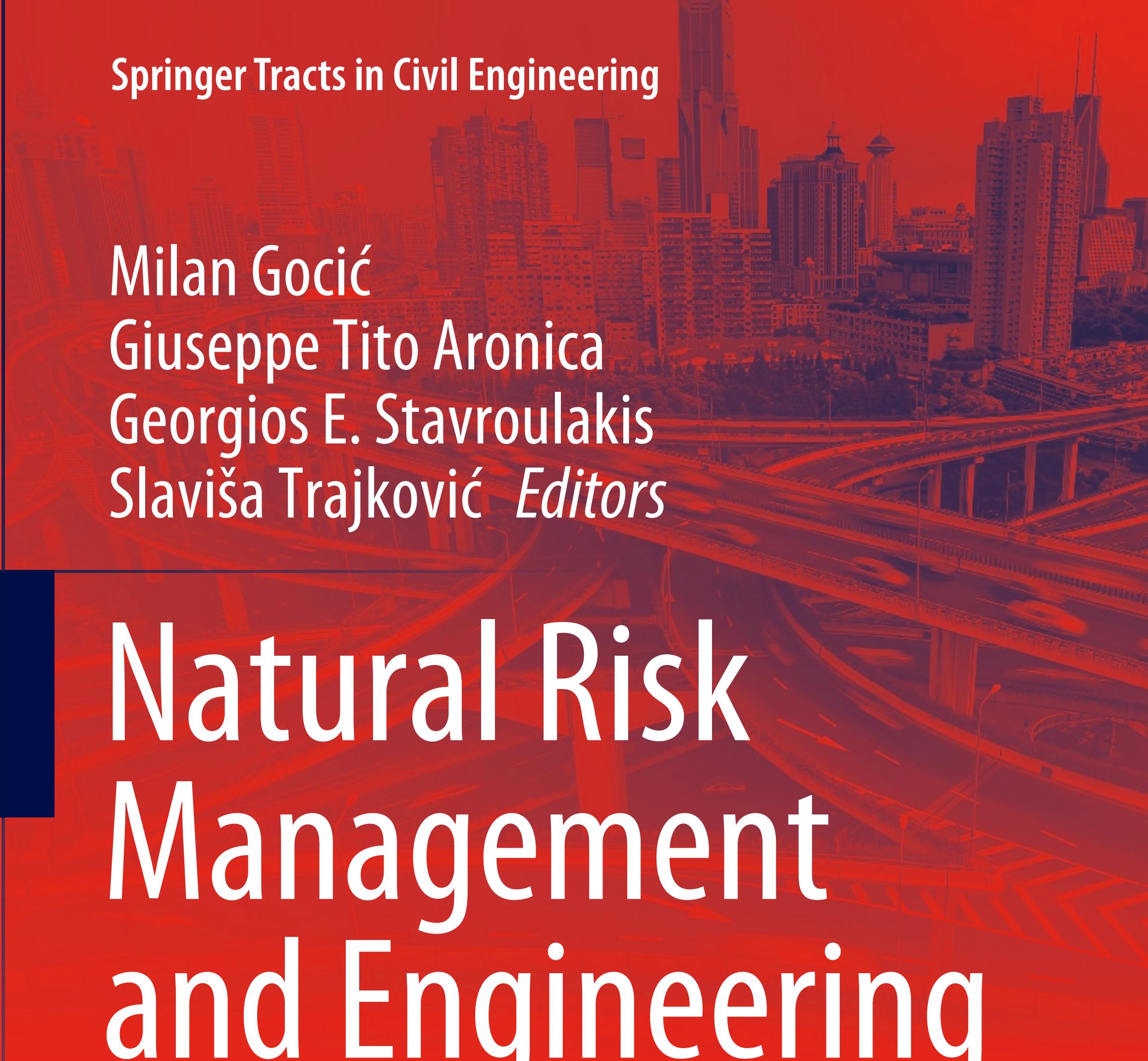

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Natural Risk Management and Engineering

NatRisk Project

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Preface

Management of natural disasters became the greatest global challenge and an indispensable requirement for sustainable development and is set as a goal both in Europe 2020 and the Agenda 2030 for Sustainable Development United Nations. While some natural disasters cannot be foreseen and/or prevented, much can be done to diminish and alleviate their human and economic consequences, using guiding principles, priority actions and prevention tools defined in Yokohama Strategy for a Safer World, Hyogo Framework for Action and Sendai 2015–2030. Disaster risk prevention and management considerations are included in a number of key EU policies.

The project **Development of master curricula for natural disasters risk management in Western Balkan countries** (NatRisk) is an Erasmus+ CBHE KA2 action in the field of higher education, co-funded by the Erasmus+ Programme of the European Union.

The project goal is the development and implementation of the advanced and modern master curricula in line with Bologna requirements and national accreditation standards that enable the education of specialists in the field of natural disasters risk management. The new master study profiles that include comprehensive aspects of natural disasters risk management will be the result of analysed shortcomings of the current system for natural disasters risk management in Western Balkan partner countries. Different aspects of natural disasters risk management request an interdisciplinary approach and cooperation between experts from various scientific fields.

This book of chapters is part of the project and consists of different contributions related to natural disasters risk management under various aspects from engineering to socio-economic.

In detail, chapters deal with risk assessment tools and quality methods, the different approaches for civil–military collaboration in natural disasters risk management, leadership models, theories or philosophies and their usefulness for managing successfully crisis deriving from natural disasters. Further, the main aspects of natural disasters and risk management in Bosnia and Herzegovina, in

Kosovo, in the River Ibar and in the South Morava river basins were discussed and presented.

All the contributions come from scientists, experts and academics which were deeply involved in all the project activities and in the educational processes outlined in NatRisk project goals.

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Chapter 1
Risk Assessment Tools and Quality Methods

Gabriella Farkas, András Horváth and Georgina Nóra Tóth

Abstract Nowadays the risk management is one of the most important activities at every organization. Whether it is a process (e.g. natural disaster control) or product (e.g. a drone, which can be used for detection or rescue processes) it is necessary to discover and critical analyze the all potential risks. The risk assessment process can be divided into three determined steps: risk identification, risk analysis, risk evaluation. All process steps must be performed using the best and most suitable method so we can be sure of achieving the best results. These methods are most effective if we have enough experience and data from the past. Therefore it is important to present the methods which can be used for data collection and data analysis. We can not eliminate the risk factors in the risk assessment process but it helps us to be able to quantify and to reduce their effect with preventive actions. Our goal is to summarize these methods and techniques which can be used to analyze and evaluate risks based on our experience.

Keywords Risk assessment · Quality tools · Risk analysis · Evaluating methods

1.1 Introduction

An unwanted event whether the consequences of a natural disaster, an industrial accident, a machine or equipment failure can be interpreted on a wide scale from discomfort to the most serious. Human life, the natural environment can be in danger sometimes with property damage. In risk assessment is important we can distinguish between hazard and risk. In case of natural hazard the consequences can be flooding, earthquake, environmental pollution we usually examine the possibility of event occurrence. The risk analysis should take into account all factors (possible events) that lead to an undesirable event taking into account the likelihood of their occurrence. In our study the emphasis is on risk management and approaching the methods we can use to effectively implement it. The methodology of risk assessment has always

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been present in our lives in which we used it consciously or we experienced it. The risk-based thinking is in the management systems a fundamental principle therefore the techniques and methods are given more importance.

Terms and Definitions of Risk Management

The purpose of this chapter presents the terminology and the process of the risk management. For that we use the explanations and approaches of the relevant standards (ISO/IEC Guide 73; ISO 31000:2018; IEC 31010:2019). These standards contain the basic terms and the risk management process and techniques as well. According to the standard (ISO 31000:2018) the risk is the effect of uncertainty on objectives. The effect could be positive or negative which is especially important in the management systems. Goals can have different aspects such as health and safety or environmental aims and they can apply at different levels. These levels could be product, project, process or strategic. The standard contains some useful notes about the risk definition these are the follow.

- Risk is often characterized by reference to potential events and consequences or a combination of these.
- Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.
- Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood.

Risk Management Process

Risk management means the coordinated activities to direct and control an organization with regard to risk (ISO 31000:2018). The risk management process contains six stages and an indispensable part (Communication and consultation) which is a necessary activity with external and internal stakeholders during the process.

By establishing the context an organization can define the external and internal parameters and takes into account when managing risks. The external parameters are for example economic, natural environment or key drivers and trends having impact on the aims of the organization or people and so on. The internal context means the internal environment in which the organization seeks to achieve its aims (Klüppelberg et al. 2014).

Risk assessment (the red box) involves ***risk identification***, risk analysis and risk evaluation (Fig. 1.1). Firstly it need to be identified the all risks. Therefore the organization should identify sources of risks, impacts of the risks and their causes, their potential consequences. The output of this step is a list of risks based on those events that might create, prevent, enhance, accelerate, degrade, or delay the achievement of targets (Fig. 1.2).

Risk analysis includes understanding of the risk. The result of the risk analysis is the input to risk evaluation and to decisions on whether risks need to be treated. This step involves to identification the source of the risks and determination the positive or negative consequences and estimation of the likelihood of occurrence. Furthermore,

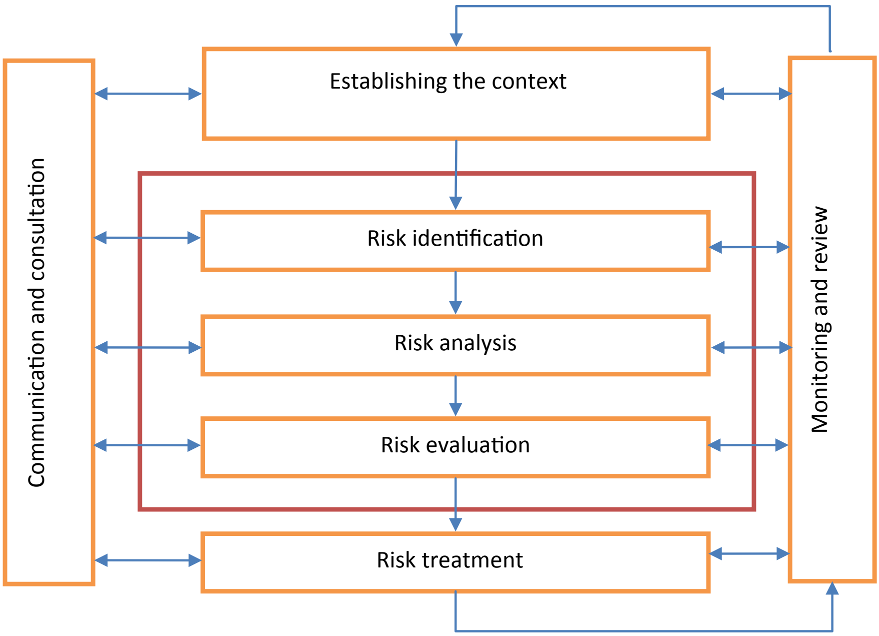
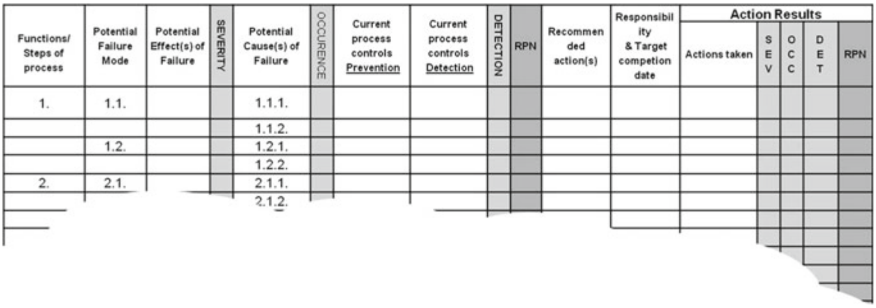


Fig. 1.1 Risk management process (ISO 31000:2018) (Color figure online)



Functions/ Steps of process	Potential Failure Mode	Potential Effect(s) of Failure	SEVERITY	Potential Cause(s) of Failure	OCCURENCE	Current process controls Prevention	Current process controls Detection	DETECTION	RPN	Recommended action(s)	Responsibility & Target competion date	Action Results				
												Actions taken	SEV	OCC	DET	RPN
1.	1.1.			1.1.1.												
				1.1.2.												
	1.2.			1.2.1.												
				1.2.2.												
2.	2.1.			2.1.1.												
				2.1.2.												

Fig. 1.2 FMEA table (Tague 2015)

it contains information about the severity of the consequence. Based this information the risk levels can be defined.

The last step of the risk assessment is the ***risk evaluation*** which purpose is to assist in making decisions. These decisions based on the outcomes of risk analysis about which risks need treatment and the priority for implementation. Decisions should take account of the wider context of the risk and the tolerance of the risks borne by parties other as well. Very important requirement of the standard is that decisions should be made in accordance with legal, regulatory and other requirements.

Risk treatment based on the output of risk analysis and contents many options for treat risks.

The ISO 31000 standard involves the following options for treat risk:

- keep away from the risk by deciding not to start or continue with the activity that gives rise to the risk;
- taking or increasing the risk in order to pursue an opportunity;
- removing the risk source;
- changing the likelihood;
- changing the consequences;
- sharing the risk with another party or parties (including contracts and risk financing); and
- retaining the risk by informed decision.

Both monitoring and review should be a planned part of the risk management process and include periodic or ad hoc checking.

1.2 Methods and Materials

1.2.1 Risk Management Tools and Techniques

There are many techniques were published which can be used in the field of risk assessment. But some of the strongly applicable for identify the risks but not applicable to evaluate the risks. In this chapter there will be some methodology which can be strongly used for overall the risk management process and some additional which are very popular and useful in just one step. Hereinafter three methodology would be presented which strongly applicable for overall risk management process (FMEA, HAZOP, Environmental risk assessment). After that there are some well-known techniques are shown which can be used in just one or two steps the process.

Failure Mode and Effect Analysis (FMEA)
The FMEA method developed by the US Military and few years later applied that in the NASA. After that in 1977 the Ford motors applied this methodology in the automotive industry. Nowadays it is widely used methodology. There were some descriptions about the FMEA method in the Automotive industry which content different steps of the FMEA and requirement of the evaluation (QS 9000, VDA) (Baynal et al. 2018). Currently there is just one handbook published by AIAG and VDA in 2017, which harmonizes descriptions about the methodology and requirements. This is a systematic risk assessment method which uses tree structures to identify the potential failures of a system, sub-system or components and causes of the failures and effects. After the analysis it can helps to evaluate them and suggest recommended actions. It can be used in teamwork (Ben-Daya et al. 2009). FMEA can help to find:

- all potential failure modes of the various parts of a system;
- the effects of these failures;
- the mechanisms of failure;
- how to avoid the failures, and/or relieve the effects of the failures.

There are three method of FMEA:

- Design FMEA;
- Process FMEA;
- FMEA-MSR (Monitoring and System) Response.

The FMEA applicable for

- system;
- sub-system;
- component.

The three methods followed by six-step process (FMEA Handbook 2017):

1. Scope definition and project planning
2. Structure analysis
3. Function analysis
4. Failure analysis
5. Risk analysis
6. Optimization.

The risk evaluation based on three viewpoints. ***S*** is the severity of the failure which depends on the effect of the failure. ***O*** is the occurrence of the causes of the failure which depends on the probability of occurrence and Detection (***D***) which means how to easy to find the cause of the failure. Based these values the handbook involves tables for the evaluation. It can help to define the Action priority (High, Moderate or Low) and suggest recommended action with deadline and responsibilities. But other evaluation table can be defined if it fits better with the examined system (FMEA Handbook 2017).

Hazard Operability—HAZOP

HAZOP is a structured and systematic examination of a product, process, procedure or system. It is a preventive tool which can help to identify risks to people, equipment, and environment objectives. This process is a qualitative methodology based on use of guide words. The HAZOP developed to analyse chemical process systems but has been extended to other types of systems and complex situations. It can be applied in teamwork and its time-consuming technique (IEC 31010:2019; Dunjó et al. 2010; Kletz 2018). Before the examination need to identify and collect the guide words (For example: No or not, Higher, Less, as well as, Part of, Reverse Opposite, Other than etc.) and define meaning the words. These words can help to reveal the potential risks. For this method the reference document is the IEC 61882:2016 standard.

Environmental Risk Assessment

The process of the environmental risk assessment is as follows:

- Problem definition: this step includes locate the extent of the assessment by defining the scope of target populations and relevant hazards.
- Hazard identification: this includes identifying all possible sources of injury to the target population from hazards. Usually the hazard identification relies on practiced knowledge and relevant literature;
- Hazard analysis: this contains understanding the nature of the hazard and the interaction with the target.

The following example for an environmental risk assessment with the diagram is from the IEC 31010:2019. "For example, in considering human exposure to chemical effects, the hazard might include acute and chronic toxicity, the potential to damage DNA, or the potential to cause cancer or birth defects. For each hazardous effect, the magnitude of the effect (the response) is compared to the amount of hazard to which the target is exposed (the dose) and, wherever possible, the mechanism by which the effect is produced is determined. The levels at which there is No Observable Effect (NOEL) and no Observable Adverse Effect (NOAEL) are noted. These are sometimes used as criteria for acceptability of the risk" (IEC 31010:2019) (Fig. 1.3).

Cause-and-Effect Analysis
The cause- and effect analysis is also known as Ishikawa or fishbone diagram. This diagram was developed by Dr. Kaoru Ishikawa at the University of Tokyo in 1943 (Tague 2015). With these tool can be analyse a complex problem or a risk. This technique is one of the seven quality tools. The shape of this diagram is like a fish skeleton (Fig. 1.4). It contains a central line ("spine"), and in the end of this line there is a problem, and involves several branches (categories). The type of categories depends on the problem (Man, Machine, Environment, Material etc.). In one category many potential causes can represented (Figs. 1.5 and 1.6).

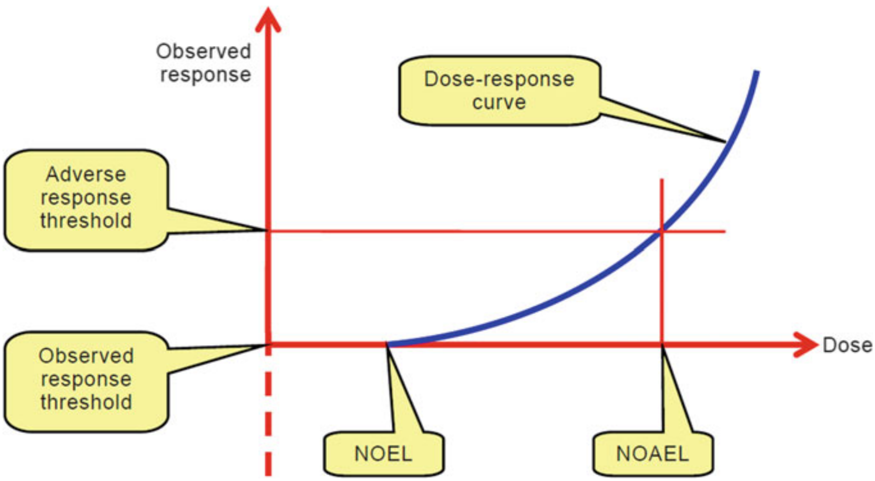


Fig. 1.3 Dose-response curve (IEC 31010:2019)

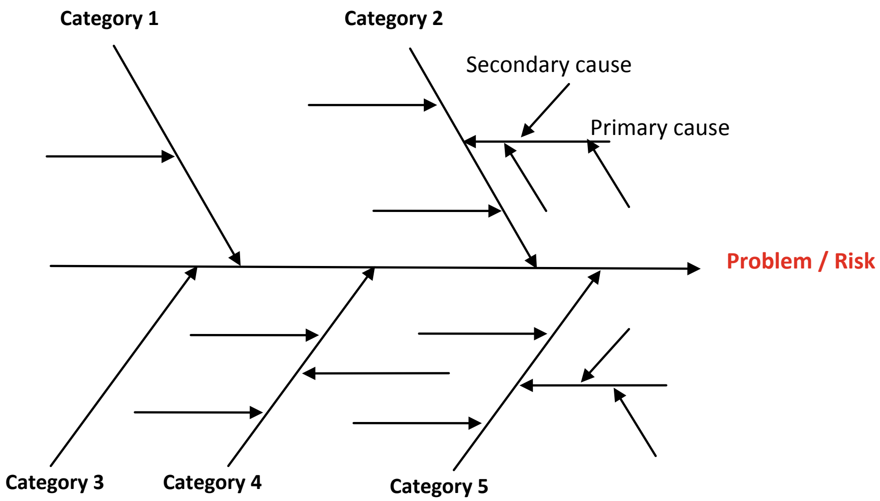


Fig. 1.4 Fishbone diagram (Tague 2015)

The basic steps of the analysis:

- Identify the occurrence of malfunctions or problems.
- Find the reasons: e.g. with brainstorming and consider the theoretical and practical facts.
- Define categories (4M–9M) related to the problem.
- Group the individual causes by category and write down the most important causes (primary causes).
- Finding the root causes e.g. with 5 Why method (secondary causes).

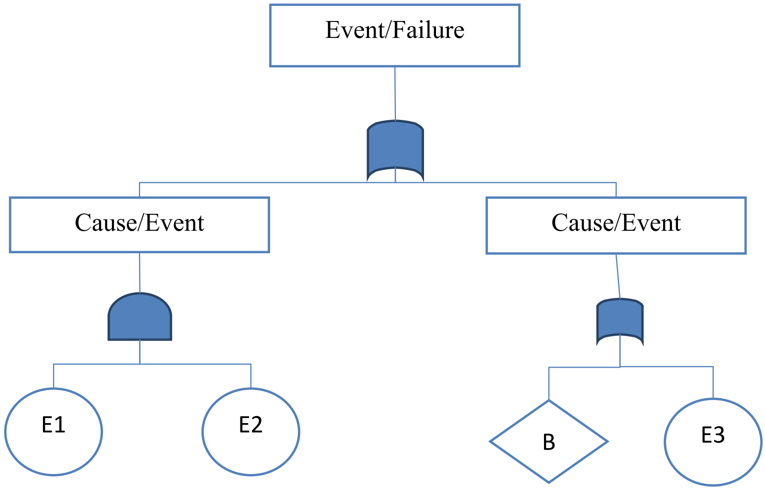
This method can be use for identify risks or analyse the consequences. The fishbone diagram provides a systematic indication of the cause (problem) and the underlying causes, thereby facilitating the resolution of the problem. Using to get to the root causes of a problem this should help to promote effective actions (IEC 31010:2019).

Fault Tree Analysis

This method widely used and apply a hierarchical structure. It can use logical gates to show the relationships between the factors/items. The factors identified in the tree can be events that are related with component hardware failures, human errors or any other relevant events which induces the unwished event.

The basic steps of the fault tree analysis:

- Identify the failures or problems (top event).
- Collect the causes of the problems, they will be the events.
- Find the adequate gate symbols to show the relationship between the events.
- Determine the probability of the events with Boolean algebra.
- Analyze the relations and the results of the probabilities and propose actions to prevent and avoid the potential failures.



	And gate
	Or gate
	Events
	Base event
	Events not analyzed at this time

Fig. 1.5 Fault tree and the gate symbols (ISO 31010:2019)

Nowadays this method is widely used in the different fields, e.g. in the analysis of accidents and complex systems. In the FTA can be calculate and analyze the probability of the failures therefore it is easier to determine preventive actions to eliminate the risks and the failures and their effects (IEC 31010:2019; Modarres 2016).

Event Tree Analysis (ETA)

The ETA is a graphical method for analyse an event series. It considers the functioning/not functioning of the various systems. The main goals are to mitigate the consequences of the failures. It can be applied both qualitatively and quantitatively.

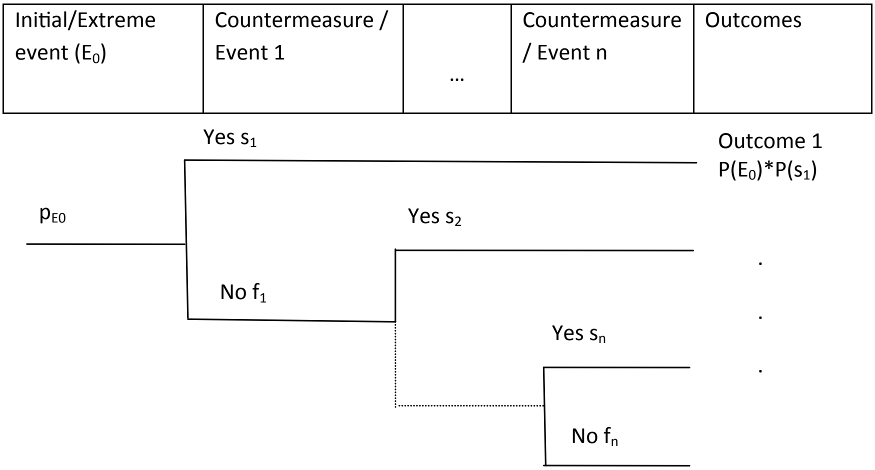


Fig. 1.6 ETA diagram (ISO 31010:2019)

The basic steps of the event tree analysis:

- Firstly, the initial event should be selected (Critical event).
- The goal is mitigating outcomes with function of the system.
- For each function or system, a line is drawn to represent their success or failure.
- Probability values can be calculated.

This method can help to model different pathways from the initiating event and analyse the system (IEC 31010:2019; Modarres 2016).

Decision Tree

A decision tree represents decision alternatives and outcomes in a hierarchical structure. It is similar to an event tree. It starts an initial decision and can be displayed different pathways and outcomes. Events or the state of the system and results depend on the decisions. This analysis provides the opportunity to select the optimal decision path. The decision tree is used in managing project risks.

On the Fig. 1.7 there is a decision tree which contains three levels. The nodes represent the states of system, and the arrows are the decisions. Below the leaf points can be found the results.

The basic steps of the decision tree analysis:

- Firstly, the initial decision should be selected.
- As the two hypothetical way proceed, different events will occur, and different predictable decisions will need to be made.
- The probability of the events can be estimated with cost.
- The probability of pathway and total cost per branch can be calculated.
- The pathways can be compared, and the optimum can be chosen.

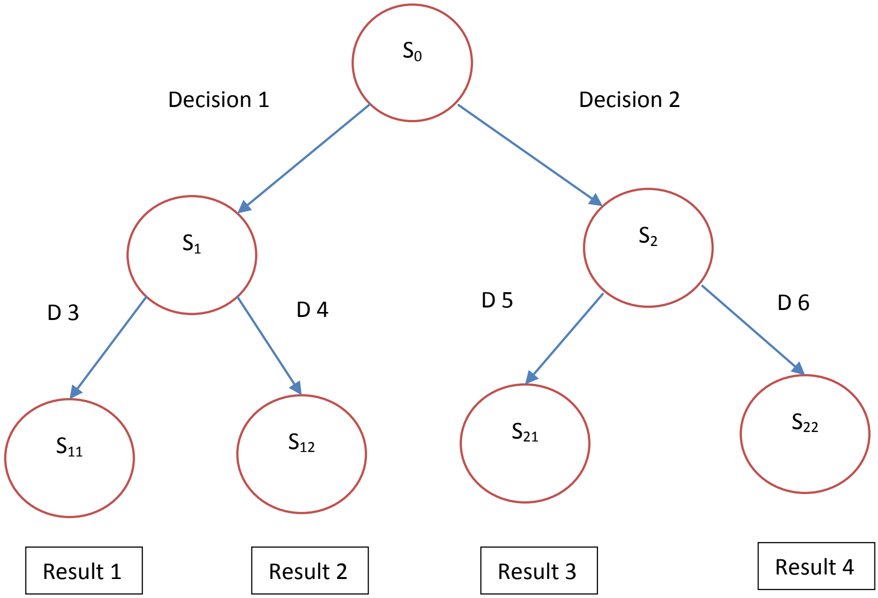


Fig. 1.7 Decision tree (ISO 31010:2019)

This is a method which is used a hierarchical structure for creating a decision map and helps to find the best decision series. It is suitable for qualitative and quantitative analysis (IEC 31010:2019).

Bow-Tie Analysis

The bow-tie analysis combined a fault tree analysis (FTA) and an event tree analysis (ETA). The centre of the bow-tie is a critical event and on the left side can be seen the FTA and on the right side the ETA. The FTA can help to analyse the history of the event (causes) and to define preventive controls. The ETA gives an overview of the consequences and help to place control actions to mitigate the effects.

The basic steps of the bow-tie analysis:

- A critical event is determined (Central event).
- The causes of event occurrence should be analysed.
- Define preventive controls which relate to each cause, draw to the left side of the bow-tie.
- The consequences can be determined, and controls can be defined to mitigate the effects of the consequences.

This method is so simple but spectacular for analyse a critical event and it helps to prepare for prevention and treatment (IEC 31010:2019) (Fig. 1.8).

Consequence/Probability Matrix

The consequence/probability matrix is an easy to use tool for analysing and evaluating the risk, defining levels. In Fig. 1.9 there is a matrix with two dimensions

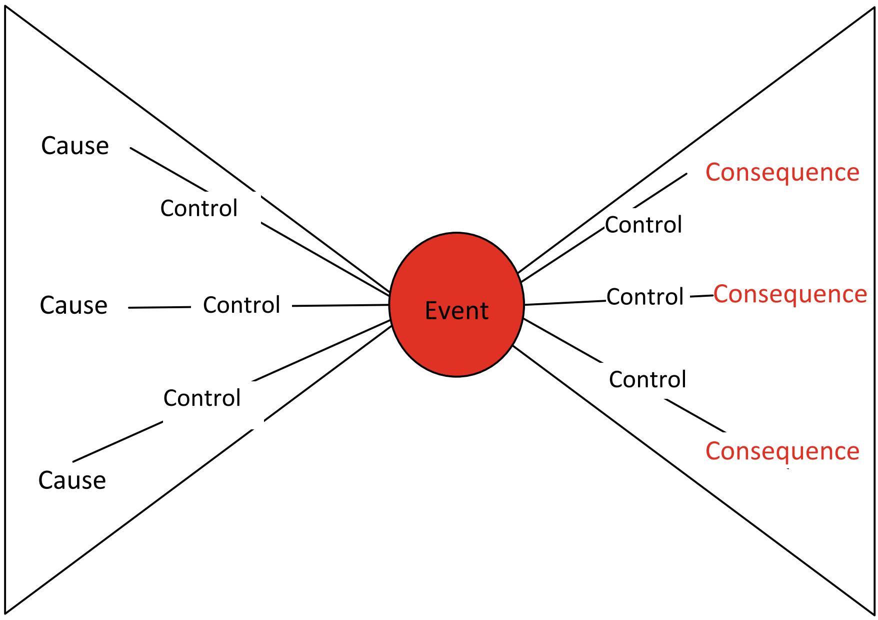


Fig. 1.8 Bow-tie analysis (ISO 31010:2019)

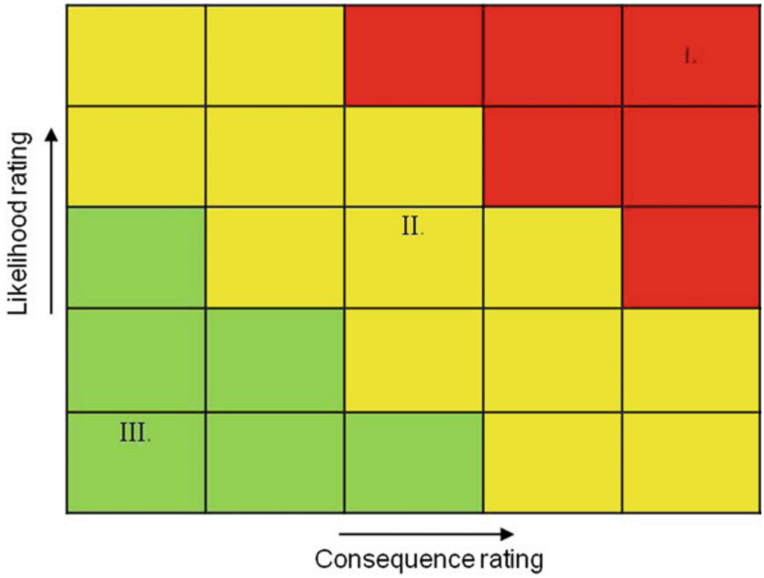


Fig. 1.9 Consequence/probability matrix (ISO 31010:2019)

[Consequence rating (1–5), Likelihood rating (1–5)]. And three risk levels can be seen [I.-critical level (red), II. Moderate level (yellow), III. Low level (green)]. The definition of the levels depends of the creator or other requirements, but it is flexible.

The basic steps of the event tree analysis:

- Possible risks should be collected.
- Occurrence and the severity of the consequences can be identified.
- Levels of risks can be defined.
- Serious risks can be chosen and treated.

A consequence/probability matrix can be used to rank risks, sources of risk or risk treatments based on the level of risk. It is generally used as a selection tool when many risks have been identified, and we would like to focus on serious risks (IEC 31010:2019).

1.2.2 Useful Quality Tools and Techniques

In this chapter we summarize the quality tools and methods that can help organizations and experts analyze problems or determine the most appropriate way to solve a problem. Many methods have been developed to address quality issues that can be applied well regardless of the area of application and the operation of the organization. In many cases the most difficult task is to select the method that is most effective for the task (analysis) to be solved. To do this you can get help with the thematic knowledge of methods that are adapted to the nature of the problem. Standards and professional books mostly outline the areas of application to which the given quality tool can be applied, making their use more efficient and facilitating the decision-making process. We describe the aims, fields of application, process and main steps of the methods. The main steps of the creative creation process go into the field of conscious methods of problem solving. Knowledge of these methods is essential for quality professionals as they need to apply their daily work in order to perform their tasks more effectively.

The seven basic tools are well-chosen methods based on the graphical tools of industrial statistics and creativity technology (Table 1.1). These provide effective support for quality improvement and quality control. Quality improvement means a company-wide quality improvement. It is a continuous activity that affects all departments of the organization and in which each employee is involved.

The process of solving the problem with the PDCA cycle shows that each step of the process can be well matched to each stage of the Deming circle (Juran and De Fao 2010). The design step (P) involves identifying the problem or problem, selecting the most important problems. To do this the current processes must be assessed; data collection, data analysis and causal analysis must be carried out. Implementation (D) involves designing and implementing the solutions. Control (C) involves all activities that evaluate the effectiveness of the implemented solutions. During the intervention (A), the accepted proposals and measures are incorporated to reduce and prevent

Table 1.1 Relation between the steps of the problem solving and the recommend tools

PDCA cycle	Steps of the problem solving	Recommend tools and techniques
P Plan	Determination of the problem	Brainstorming Affinity chart (K-J method) Fishbone diagram Pareto diagram
	Data collection	5W + 1(2)H Data collecting card Histogram Pareto diagram Control charts
	Data analysis	Histogram Pareto diagram Scatter diagram Graph Control charts
	Cause analysis	5Why Fishbone diagram Cause and effect analysis
D Do	Determination of the recommend actions	Flowcharts
C Check	Evaluation of the results	Data collecting card Histogram Pareto diagram Control charts
A Act	Standardization	Documentations Procedures Manuals

the recurrence of the problem. Its effectiveness is based on continuity. In line with the PDCA principle, the problem-solving process does not end and the "perfection" continues at a higher level.

In case of problem solving are the tools, procedures and methods applied appropriately to the task taking into account the material and personal conditions. Problem solving is always more efficient and effective if we work with colleagues in a team.

Data Collection

The aim of data collection is to have objective data for the right decision, judgment and action. Unclearly opinions are often untrustworthy and may lead to mistake. The "quality" of the data (source, credibility, correctness) is more important than the quantity. The data should be grouped according to the purpose of the desired judgment and the expected action. The goals of data collection can be:

- overview of the current situation,
- managing problems,
- workflow control,
- changing activities,
- decision on acceptance or rejection.

The way the data is processed depends on the nature and appearance of the data.

Data Collection with 5W+ 2H Method

We can use this method when we need to collect data shortly to identify exactly the problem. According to the method, we systematically ask questions about a process or a problem, the purpose of which is to collect data. The question words are (Tague 2015):

1. Who?—e.g. Who does this?
2. What?—e.g. What are essentials?
3. When?—e.g. When can it happen?
4. Where?—e.g. Where is this can it happen?
5. Why?—e.g. Why do we do it?
6. H: How?—e.g. How is it done?
7. How much?—e.g. How much does it cost?

This is a simple method and it can be widely used (e.g. project planning, reviewing the completed project, creating a report or presentation).

Histogram

The histogram is a bar chart (Fig. 1.10) in which we can represent the frequency distribution of the data. This diagram can be used to show a large number of data and it is easy to visualize different statistical parameters (range of values, average, standard deviation).

The basic steps of the procedure:

- Data collection: number of data should be at least 50 or 100 or more.
- Determination of the bars: recommend number of the classes (B) can be choose according to the number of the data points (N) ($N = 50$–$100 \rightarrow B = 5$–9; $N = 100$–$250 \rightarrow B = 7$–11).
- Calculation of the width of bars: First it is necessary to calculate the total range of the data: R = largest value − smallest value after that the width of each bar: $W = R/B$.
- Creation of the frequency table which must contain: number of the bars, limits of the bars (or classes), frequency of each bars (absolute value or relative value).
- Completion of the histogram chart.

In the following we would like to introduce this procedure by an example. Examining the evolution of precipitation in the last five years the task is to illustrate the distribution of the frequency of precipitation using a histogram. Follow the steps of the procedures:

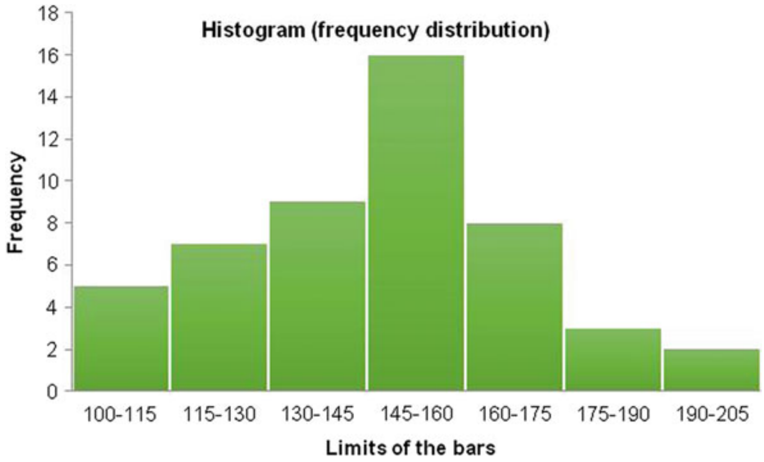


Fig. 1.10 Histogram

Table 1.2 Annual rainfall in Hungary years: 2013–2017

Annual rainfall (mm)	Year				
	2013	2014	2015	2016	2017
Békéscsaba	501	740	562	635	519
Budapest	588	665	599	569	579
Debrecen	545	456	432	744	569
Győr	610	748	553	617	571
Kecskemét	509	703	532	566	592
Kékestető	922	881	766	870	989
Keszthely	689	876	599	771	633
Miskolc	774	726	570	712	708
Paks	647	671	602	697	606
Pápa	635	757	573	645	553
Pécs	687	918	616	788	672
Siófok	607	846	519	704	533
Szeged	545	842	442	644	438
Szolnok	490	692	453	607	522
Szombathely	708	877	511	742	658

Data based on Hungarian Central Statistical Office https://www.ksh.hu/

Table 1.3 Frequency table

Classes number	Limits of the classes (mm)	Frequency f_i How many elements fall in each classes?	Relative frequency $g_i = \frac{f_i}{N} * 100$ (N = 75) (%)
1.	432,543	12	16.0
2.	543,654	31	41.3
3.	655,766	19	25.3
4.	767,878	9	12.0
5.	879,990	4	5.3

- Collection of the relevant data (Table 1.2).
- Determination of the bars: In this case the number of the data points N = 75 and the chosen number of the bars is B = 5.
- Calculation of the width of bars: Based on the data R = 989 − 432 = 557. The width of each bar: W = R/B so W = 557/5 = 111.42 therefore we use W = 111.
- Creation of the frequency table which contains: number of the classes, limits of the bars (or classes), frequency of each bars (absolute value or relative value) (Table 1.3).
- Completion of the histogram chart (Fig. 1.11).

The histogram is the great tool to show graphically the statistical characteristics and it promotes error-correcting and error-prevention intervention based on our personal experience in the early stages of data processing. Histogram analysis may include:

- form of the diagram,

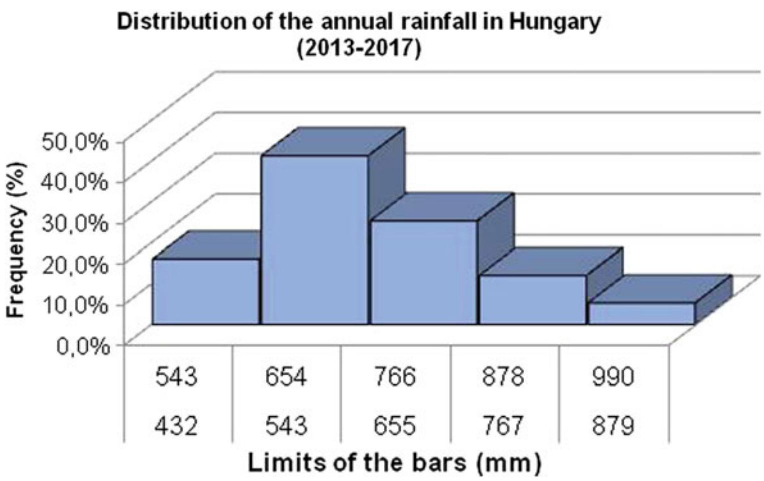


Fig. 1.11 Histogram (distribution of the annual rainfall in Hungary)

- the correct choice of class intervals,
- examining the shape of the histogram,
- for comparison with specification limits.

Pareto Diagram

Pareto analysis helps you find the most important thing of the many problems. Pareto principle (rule 80:20) means 20–30% of the causes are responsible for 70–80% of the causes. In practice:

– 80% of the errors are caused by a 20% defect,
– 20% of workers produce 80% of scrap labour,
– in a shop 20% of the goods bring 80% of the revenue.

In general it means that a small proportion of the causes of a problem is responsible for most of the effects. We often use it when we want to detect errors. In quality management we apply it when the task is to separate the "vital few" and "trivial many" problems (Juran and De Fao 2010). The Pareto diagram is a graphical representation of Pareto analysis (Fig. 1.12). It can be used to separate the factors according to the frequency of each factor. The diagram is a tool for implementing Pareto analysis which is a bar graph representing the data in an arrangement by size (number of defective pieces, time, cost, etc.).

The basic steps of the procedure:

- Data collection and selecting the most important components.
- Discover how the importance of a problem is proportional to the amount of problems.
- Find out to what extent the situation has improved after we have made improvements in each area.
- Completion of the Pareto chart.

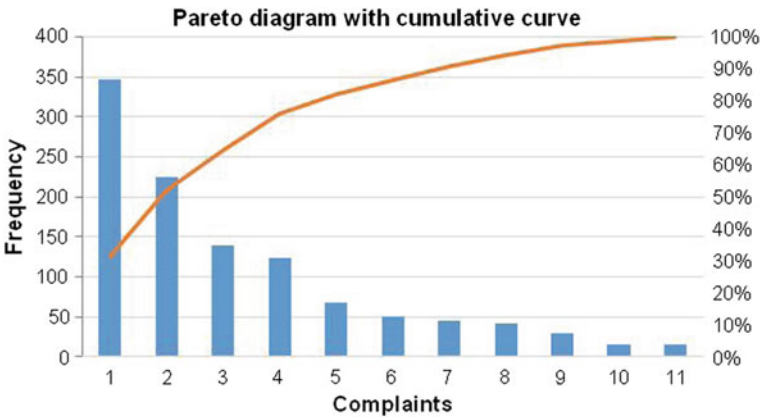


Fig. 1.12 Pareto diagram

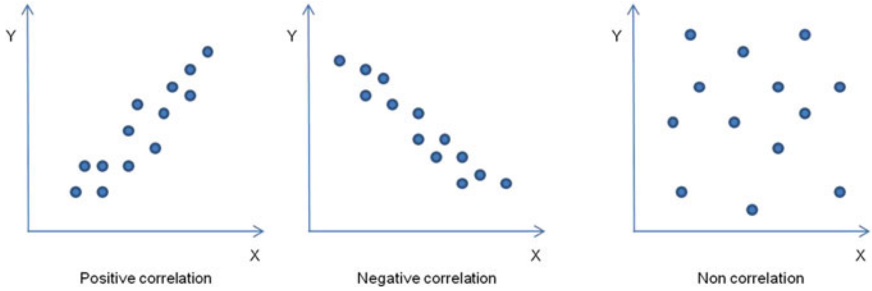


Fig. 1.13 Types of the scatter diagram

Scatter Diagram

It can be determine with scatter chart (correlation diagram) whether there is a relationship between two values, data or features therefore whether one is dependent on the other. There are many types of the scatter charts which are presented in Fig. 1.13.

The basic steps to create and analyze a correlation diagram

- Data collection and systematization: data must be in pair where the relationship is presumable.
- Completion of the scatter diagram: recording independent data on the vertical axis (y), recording dependent data on the horizontal axis (x).
- Representation of data points (dotted line).
- Analysis of the correlation.

A simple method of correlation analysis was presented by Tague (2015) to determine the relationship between the variables. The diagram area is divided into four quadrants so that the number of points above and below the half line and on the left and right is equal (Fig. 1.14). Count the points in each quadrant and make the calculation:

- $A + D = 4 + 4 = 8$; $B + C = 12 + 11 = 23$ $Q = \min\{A + D; B + C\} = 8$
- $N = A + B + C + D = 31$
- Determine the limit value from the trend test table (Table 1.4). The limit is in this case 9.
- Conclusions of the analysis may be:

  If Q < Limit, there is correlation between the two features.
  If Q > or = Limit, there isn't correlation between the two features.
  In this example Q = 8 and the Limit = 9 therefore the two variable are related.

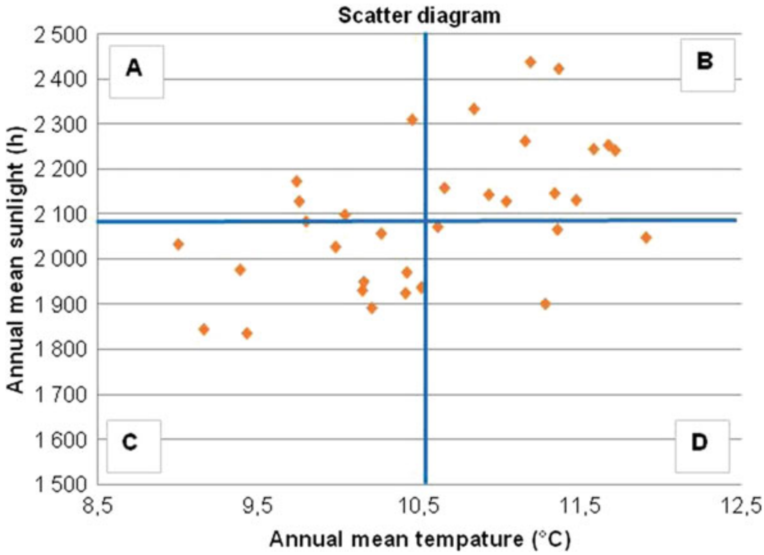


Fig. 1.14 Correlation diagram

Table 1.4 Trend test table

N	Limit
1–8	0
9–11	1
12–14	2
15–16	3
17–19	4
20–22	5
23–24	6
25–27	7
28–29	8
30–32	9
33–34	10

1.3 Results and Discussion

The aim of this chapter is to present risk assessment process, methods and other quality tools. The presentation of the techniques is not exhaustive because the emphasis is on the procedures that may be relevant to the risk analysis. The Table 1.5 involves the ways of using the described methods which harmonize with the IEC 31010:2019 standard.

Table 1.5 Recommended use of described methods during the risk management process

Risk management process	Methods
Risk identification	Failure Mode and Effect Analysis Environmental risk assessment Cause and effect analysis Fault tree, Event tree Consequence/probability matrix
Risk analysis	Failure Mode and Effect Analysis Environmental risk assessment Cause and effect analysis Fault tree, Event tree Decision tree Bow-tie analysis Consequence/probability matrix Data collection Histogram Pareto chart Scatter diagram
Risk evaluation	Failure Mode and Effect Analysis Environmental risk assessment Fault tree Decision tree Bow-tie analysis Consequence/probability matrix Pareto chart

These methods are not new but they have been used effectively in many areas for decades and their usage is increasingly emphasized when appears the risk-based thinking principle. These presented techniques are tools for identifying, analyzing, preventing or reducing problems (risks). The effectiveness of the analyzes is enhanced by a well-organized (so called cross-functional) team which includes representatives of the affected areas. When the goal is to create preventive actions or to analyze a disaster that has occurred these methodologies can help to professionals and experts if they use the right method and can prepare for a future unexpected event more effectively.

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Chapter 2
Model of Effective Civil-Military Collaboration in Natural Disaster Risk Management

Dejan Vasovic, Goran Janackovic and Stevan Musicki

Abstract The concept of effective and proactive natural disaster risk management represents a highly complex phenomenon researched in different scientific disciplines. While the nature of the events that trigger risk scenario and resources that need to be protected are quite clearly defined, there is no such similar compliance level regarding the response. In most countries, civil (emergency response units) and military (modelled forces) structures represent the basis for effective natural disasters risk management. Full-scale collaboration and prompt corrective action during mitigation phase are prerequisites for successful task completion, which poses the necessity of effective civil—military collaboration model development. In this paper, the different approaches aimed to effective disaster collaboration are analysed. Also, the side aim of this chapter is stewarded to in-depth, objective analysis of current state in Republic of Serbia within the field.

Keywords Natural disaster · Management · Civil structures · Military structures · Collaboration model

2.1 Introduction

The analysis of numerous definitions of the concept of safety has shown that it is most accurately defined as the state of a protected value without any potential future or current threat to that value, but which is also a goal that is not fully attainable and which should be strived toward. This paper required the identification of the exact connections between natural hazards, the resulting emergencies, impacts, and states, and the ways society responds to them. The resources in the emergency registry system comprise qualified personnel within the protection and rescue forces and material and technical resources required for emergency response, which are no less important if the system is to function efficiently. An active policy aimed at

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disaster risk reduction, adaptation, preparedness, and effective emergency response can substantially decrease fatalities, as well as material and environmental damage (Nikolic and Zivkovic 2010).

For the purpose of this paper, it is necessary to establish correct linkages i.e. connections among natural hazards, derived emergencies, impacts, state and response activities of the society. According to UNISDR (United Nations International Strategy for Disaster Reduction) the next terminology should be used:

- 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. Hazards may be natural, anthropogenic or socio-natural in origin. Natural hazards are predominantly associated with natural processes and phenomena. Anthropogenic hazards, or human-induced hazards, are induced entirely or predominantly by human activities and choices. This term does not include the occurrence or risk of armed conflicts and other situations of social instability or tension that are subject to international humanitarian law and national legislation. Several hazards are socio-natural, in that they are associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change. Multi-hazard refers to the selection of multiple major hazards that the country faces, and the specific contexts where hazardous events may occur simultaneously, cascading or cumulatively over time, taking into account the potential interrelated effects. Environmental hazards may include chemical, natural and biological hazards. They can be created by environmental degradation or physical or chemical pollution in the air, water and soil. However, many of the processes and phenomena that fall into this category may be termed drivers of hazard and risk rather than hazards in themselves, e.g. soil degradation, deforestation, loss of biodiversity, salinization and sea-level rise. Geological or geophysical hazards originate from internal earth processes. Examples are earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses and debris or mud flows. Hydrometeorological factors are important contributors to some of these processes. Hydrometeorological hazards are of atmospheric, hydrological or oceanographic origin. Examples are tropical cyclones (also known as typhoons and hurricanes); floods, including flash floods; drought; heatwaves and cold spells; and coastal storm surges. Hydrometeorological conditions may also be a factor in other hazards, such as landslides, wildland fires, locust plagues, etc.
- The affected—people who are affected, either directly or indirectly, by a hazardous event. Directly affected persons are those who have suffered injury, illness or other health effects and those who have been evacuated, displaced, relocated or have suffered direct damage to their livelihoods, economic, physical, social, cultural and environmental assets. Indirectly affected persons are those who have suffered consequences, other than or in addition to direct effects, over time, due to disruption or changes in the economy, critical infrastructure, basic services, commerce or work, or due to social, health and psychological consequences.

- Emergency management—the organization, planning and application of measures preparing for, responding to and recovering from disasters. Emergency management is also used with the term disaster management, sometimes interchangeably, particularly in the context of biological and technological hazards and health emergencies. While there is a large degree of overlap, an emergency can also relate to hazardous events that do not cause serious disruption in the functioning of a community or society.
- 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.
- Resilience—the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, for instance through the preservation and restoration of its essential structures and functions by means of risk management.

The disaster risk management system at different levels (national, regional and global) is of great importance for the effective and efficient management of disaster risks (Janackovic 2015; Janackovic et al. 2018). It is necessary to have a clear vision, plans, expertise, guidelines and coordination within and across the involved sectors, as well as to ensure the participation of relevant stakeholders (Vasovic 2016). Strengthening the management of disaster risk management in order to prevent or mitigate consequences requires readiness, reaction, renewal and rehabilitation. In addition, it is also necessary to strengthen cooperation and partnership within all mechanisms and institutions for the implementation of instruments relevant to disaster risk reduction and sustainable development (Musicki 2016).

2.2 Background—Legislative and Subjects

The incidence of natural disasters with catastrophic characteristics indicates that the number of emergencies and other hazardous events increases annually, together with loss of life, material damage, and disruption of ecosystem functions (Vasovic et al. 2016). On a global scale, the current Sendai Disaster Risk Reduction Framework (Sendai framework 2015), which legally succeeded the Hyogo Framework for Action (Hyogo framework 2005), states the primary outcome for the 2015–2030 period: a substantial reduction of disaster risks and losses concerning lives, livelihoods and health, and losses of economic, physical, social, cultural and environmental assets of individuals, businesses, communities, and countries. The Sendai targets closely correspond to sustainable development goals (The Global Platform for Disaster Risk Reduction 2018).

The following global targets will determine the achievement of the primary outcome and goal (they have a dual nature as they are also viewed as sub-goals):

- Substantially reduce global disaster mortality by 2030,
- Substantially reduce the number of affected people globally by 2030,

- Reduce direct disaster-related economic loss in relation to global gross domestic product (GDP) by 2030,
- Substantially reduce disaster damage to critical infrastructure related to healthcare and education and disruption to basic utilities by 2030,
- Increase the number of countries with national and local disaster risk reduction strategies by 2020,
- Enhance international cooperation to provide adequate and sustainable support for developing nations to enable them to implement the disaster prevention framework by 2020,
- Substantially increase people's opportunities to access multi-hazard early warning systems and disaster risk information and assessments by 2030.

Taking into account the experience gained through the implementation of the Hyogo Framework for Action, and with the expected outcome and goal in mind, there is a need for a focused action of countries within and across all sectors at the local, national, regional and global levels in the following four priority areas:

- understanding the risk of disaster,
- strengthening the disaster risk management system for the purpose of managing the risks of disasters,
- investing in disaster risk reduction in order to strengthen resilience, and
- improving readiness for effective response in the event of a disaster and "building a better system from that pre-disaster" during reconstruction, rehabilitation and reconstruction.

The Sendai Disaster Risk Reduction Framework supportive platform offers precise data on the adverse effects of natural hazards (death, damage, affected households, etc.). The supportive platform can be used as a valuable tool for analysing the adverse effects, with a caveat that it heavily depends on up-to-date data.

In the European Union, the INSPIRE Directive provides a relevant innovation pertaining to natural hazards, defining natural risk zones as "vulnerable areas characterised according to natural hazards (all atmospheric, hydrologic, seismic, volcanic and wildfire phenomena that have the potential to seriously affect society because of their location, severity and frequency), e.g. floods, landslides and subsidence, avalanches, forest fires, earthquakes or volcanic eruptions". The INSPIRE directive provides the added benefit of an active online monitoring system.

2.3 Approaches and Models

Disaster risk management is a complex activity involving large number of different actors. In order to manage risks effectively, it is necessary to define basic management principles (Nikolic and Vasovic 2015). The disaster management law is a starting point for defining the context of governance, i.e. basic principles of managing and coordinating activities between different actors. The Serbian Law on Disaster Risk

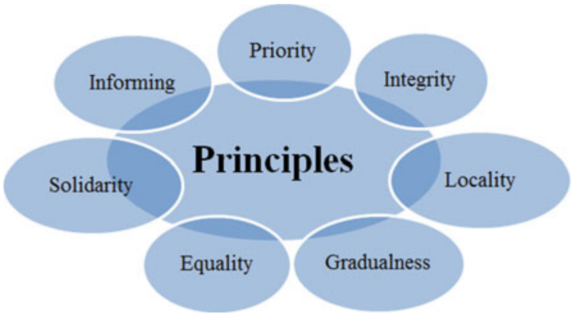

Fig. 2.1 Guiding principles of disaster risk management according to the Serbian Law on Disaster Risk Reduction and Emergency Management (2018)

Reduction and Emergency Management, which is defined in accordance with the Sendai framework and relevant directives of the European Union, identifies seven basic guiding principles of disaster risk management, as shown in Fig. 2.1.

The aforementioned principles of guidance have the following meaning:

- *Priority principle*—the management of disaster risks and the reduction of consequences is of primary national importance, with the protection of human life having the advantage over protection of any other goods or assets;
- *Integrity principle*—all activities of risk assessment and application of risk reduction measures are integrated into plans and programs in all areas of public administration and all units involved in disaster management; all of these actors' activities need to be adequately coordinated, with cooperation and partnership among them being crucial for effective and efficient disaster risk reduction and mitigation;
- *Locality principle*—since disasters are unwanted events of a local character, local government and authorities have to spearhead risk management, relying on national support if required for an adequate response.
- *Gradualness principle*—local resources are used first, and if the local community does not have sufficient coping capacity, additional assets and units, including the police and armed forces, can be used;
- *Equality principle*—all persons have the right to equal treatment in emergency situations, regardless of gender, age, religious affiliation or any other category; risk reduction measures should be applied to persons with disabilities, elderly persons, children, and all other high-risk groups;
- *Solidarity principle*—participative character and solidarity in all disaster risk reduction activities, as well as proposing and undertaking measures during protection and rescue activities, are crucial for efficient response;
- *Informing principle*—the society must be thoroughly and promptly informed of the risks of disasters, as well as of how to protect against the consequences of adverse events.

These general principles for disaster risk management are implemented in the disaster risk management system. Disaster management includes a set of activities whose primary task is to reduce or eliminate the negative consequences of unwanted events. The process is organized in the form of a cycle, and different authors usually define four basic phases or concepts comprising readiness and the ability to respond, recover and mitigate consequences (Khan et al. 2008; Warfield 2008; Otman et al. 2014). However, Lettieri et al. (2009) stated that all disaster management activities can be classified into three phases: pre-crisis (preparedness and mitigation), crisis (response to disaster), and post-crisis (recovery and return to normal functioning). Support for the implementation of this cycle involves human, technical, financial and organizational resources, whose efficient use is the basis of an effective response to the onset of a disaster. Moore (2008) describes disaster and emergency management systems in detail, emphasizing many external factors affecting the system, primarily the natural environment and the state of the society, and also considers the technological factors, the legal factors and local community management style. Disaster management cycle enables effective preparation for responding to adverse events and mitigating the effects these events produce on the functioning of the community. Vatsa (2004) points out that the consideration of vulnerability and risk as key assets is essentially disaster risk management.

Representative disaster management cycles including all four basic phases are presented in Table 2.1. As significant common features, the need for cooperation between stakeholders and timely dissemination of all the information are highlighted. Sanjay and McLean (2003) stress the importance of cycle modelling and simulation based on the detailed analysis of disaster events and entities of interest.

The rapid return of a society to a functional state is the basic task of activities in the disaster risk cycle. Effective coordination of the activities of all stakeholders and the rational use of available resources are the key aspects that influence the effectiveness of the response to adverse events with larger-scale consequences to the local community. Kusumasari et al. (2010) state the importance of available resources for the local government in the process of adequate disaster response.

Table 2.1 Representative disaster management cycles

Model	Main properties
Ahmed (2008)	Traditional model including disaster risk management and mitigation, which identifies pre-disaster and post/disaster activities
Chen et al. (2006)	Integration is the most important, where different stakeholders coordinate their activities and exchange data
Ulrich Boes (2008)	Two additional phases are included and efficient information flow between actors and phases identified as crucial for adequate response
Moe and Pathranarakul (2006)	Importance of integration and identification of key factors of successful activities
Khan et al. (2008)	Cycle diagram defines pre-disaster, disaster strike, disaster response, and post-disaster phase
Ritchie (2004)	Holistic approach to disaster management, based on detailed strategy evaluation, stakeholder collaboration, and resource management

Coping capacity of a community is higher if there are enough available resources to respond to a disaster. The algorithm of typical activities in disaster management cycles is presented in Fig. 2.2.

In the preparation phase, the most important steps are to identify the domain of the problem more precisely, distinguish the key concepts, and define the goals. In order to achieve the desired results, it is necessary to define key performance indicators and establish benchmarking procedures (Janackovic et al. 2013, 2018). Key performance

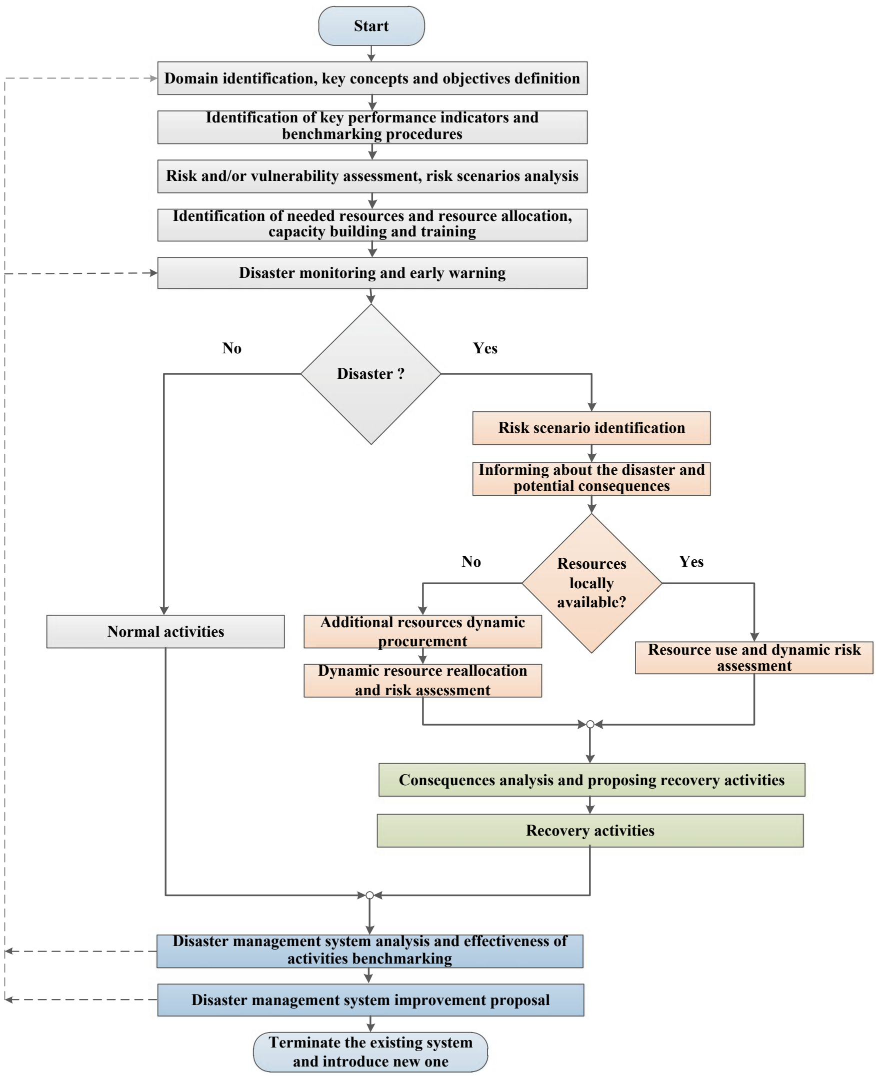

Fig. 2.2 The algorithm of typical activities in disaster management cycles

indicators can be identified by applying different methods of multi-criteria analysis (Janackovic et al. 2013). Precise definition of risk or vulnerability in the community is the next important step, associated with the creation of detailed risk scenarios and possible loss prediction. To eliminate consequences, certain resources are needed, and they need to be obtained and appropriately allocated. Building of human capacities is of particular importance, as is the development of successful monitoring and early warning systems.

When a disaster occurs, a risk scenario is identified, and the public and stakeholders are informed about potential consequences. Based on the available information, the availability of resources that can be further obtained and dynamically allocated is subsequently considered. A dynamic risk assessment is crucial in the decision-making process at this stage, as it affects the response. After the end of the adverse event, the consequences are analysed in detail, and the recovery activities suggested. It is important to constantly improve the existing system based on the evaluation of its performance, as well as to consider the reality of the applied risk scenarios (Vasovic et al. 2018a, b).

2.4 Collaboration During Disaster Management

Numerous actors are involved in the disaster management process. Their adequate cooperation is crucial for the success of the process. Collaborative operations introduce the procedures in which persons who observe different aspects of a problem can constructively discuss the differences and look for solutions that go beyond their limited visions (Malenovic et al. 2016). The essence of this process is to generate new solutions and measures, arising from different viewpoints, based on different knowledge and experience of the actors involved. Basic characteristics of collaboration models are structural representation of collaborative work, identification of key aspects of performance, definition of aspects and ways of interaction among individuals and groups in a system. Effective collaboration requires trust, definition of common goals, mutual understanding, joint use of resources, and efficient interaction. Decision-making and response is based on a mutual understanding of actors and the available data for specific actions that define activities of individuals and teams. An efficient collaboration during emergencies is of major importance for adequate response. Inadequate information exchange and collaboration increase the probability of damage due to adverse events. According to Patel et al. (2012), the following factors are important for the analysis of collaborative activities: domain, support, tasks, interaction, team characteristics, individual characteristics, and additional factors (trust, performance, goals, and experience). Efficient integration of complex disaster management systems is based on organizational, human, technical, and environmental factors, as shown in Fig. 2.3.

The specific properties of disasters (slow-onset or fast-onset) significantly influence the response and the use of available resources. Fast-onset disasters require much faster decision-making and allocation of available resources. Particular emphasis is

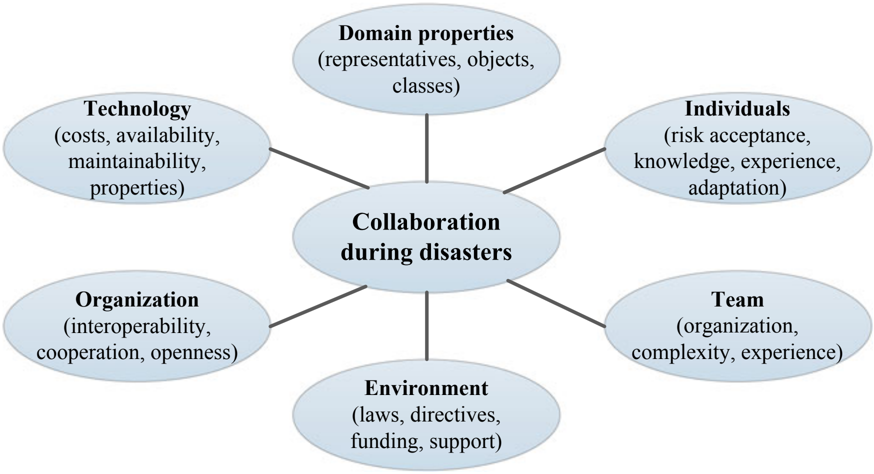

Fig. 2.3 Factors of efficient collaboration during disaster management activities

placed on the characteristics of individuals who can accept the risk and make the right decision in critical situations by adapting to the conditions according to their previous experience and knowledge. Individual reactions may differ in critical situations. An individual is commonly a part of a team, whose complexity and organization, as well as decision-making procedure, affects the outcomes. Therefore, it is important to effectively coordinate activities and to adequately select team members who can respond to all teamwork requirements. Teams are parts of larger organizational units, whose flexibility and openness must enable co-operation and interoperability, which is crucial during and after the onset of adverse events. In these situations, technical equipment is very important. The equipment characteristics, availability, adequate maintenance and usage costs often represent a significant limiting factor during disaster management.

2.5 Serbian Experience

In Serbia, various modalities of emergency response are specified in the overall strategy, the laws and the by-laws, from the standpoint of either environmental protection or human wellbeing. The newly-emerging environmental conditions impose a need for a new way of organizing social security activities. This, in turn, imposes the need for changing the manner of the previous operation, organization and implementation of measures and procedures related to organizing the safety of the society. Comprehensive analysis and monitoring of the situation in the society and the environment should precede the preparation and implementation of support operations to civilian

Table 2.2 Projection of losses due to natural hazards in Serbia

Sector/natural hazards	Estimated losses by sectors	
	Economic losses (in millions of dinars)	Human life losses
Agriculture/floods	From 3.100 up to 8.500	A few to dozens
Water affairs/floods	Approx. 1.960	–
Agriculture/hail, extreme precipitation, extreme wind conditions	Approx. 7.316	A few to dozens
Agriculture/draughts, frost	Approx. 4.0000	No
Energy production, heat/extreme cold	Approx. 716	A few to dozens
Road maintenance, ice, snow	Approx. 3.500	–
Human losses on the highways, regional and local roads caused by natural hazards	–	From 105 to 131
Commercial air traffic	From 54 up to 72	______
Total	From 16.648 up to 48.572	From a few up to 160

authorities in case of unrestricted threats to the community. The trend in the emergence of natural disasters with the characteristics of a catastrophe shows that the number of emergencies and other hazardous situations increases annually, adding both material damage and human fatalities, as shown in Table 2.2.

Identification of integration needs in terms of:

- taking preventive action for risks and mitigating the consequences of disasters;
- building, maintaining and improving the ability to respond;
- protecting people, property, and environmental resources;
- resource protection, rescue and recovery in emergencies;

has led to the establishment of the Sector for Emergency Management (formerly Sector for Protection and Rescue).

The Sector for Emergency Management of the Serbian Ministry of Interior is the authorized body to handle activities pertaining to protection of citizens' life, health, and property, and the environment. Furthermore, it handles the preservation of the conditions necessary for life and the preparation to resolve the crises resulting from natural disasters and other major accidents, technical and technological accidents, and other hazardous circumstances caused by natural, techno genic, or man-made disasters. The Sector for Emergency Management was created by the reorganization of several parts of different state administration bodies, specifically through:

- Integration of functions, employees, and property of the Protection and Rescue Department of the Ministry of Interior, the Emergency Situations Department of the Ministry of Defence, and parts of organizational units of the Ministry of

Environment, Mining and Spatial Planning that deal with risk management and chemical response;
- Establishment of a separate Emergency Response Service.

The Emergency Management Sector seeks to build, maintain and improve the ability of the entire nation to prevent risk-taking, respond to challenges and mitigate the consequences of various disasters that can affect a given region. The Emergency Management Sector unites all existing resources for emergency protection, rescue and response.

The Emergency Management Sector performs the following tasks:

- normative, administrative, organizational-technical, preventive, preventive-technical, educational, and informative-educational tasks; other tasks related to organization, planning, implementation, and control of protective measures for the environment, health and property of citizens; preservation of conditions necessary for life; preparation for dealing with fires, natural disasters from technical and technological accidents, the effects of dangerous substances and other conditions, disasters of larger proportions that could endanger the health and lives of people and the environment, specifically by drafting and proposing laws, norms and recommendations that meet the requirements of the European Union in the field of emergency protection and rescue, with the aim of complete legal regulation for job tasks and performance;
- establishes institutional, organizational and personal conditions for the implementation of emergency protection and rescue;
- takes preventive measures to prevent the outbreak of fire and mitigate the consequences of natural disasters, technical and technological accidents, etc. and prevents health threats to citizens due to the effects of hazardous substances and other hazards;
- provides professional training of members of organizational units within the Sector's area of operation.

In order to acquire the necessary knowledge in the field of personal and collective protection, citizens who are not employed in any civil protection organization are trained in the National Training Center for Emergency Situations.

On the other hand, the National Security Strategy of the Republic of Serbia, National Emergency Management and Rescue Strategy and the National Defence Strategy of the Republic of Serbia define the possible challenges, risks and threats, both in war and peace, to be handled by the Ministry of Defence. The effects of non-armed threats to security, from the military point of view, have not been sufficiently studied despite the fact that non-armed security threats act in peace, and that taking measures against threats to security is an integral part of the strategy of Serbia.

According to the Military doctrine of the Serbian armed forces, the planning, preparation, and implementation of preventive measures are the basis for preventing the emergence of unrestrained threats to the safety of society. Non-malicious threats include natural disasters, industrial and other disasters. Natural disasters affect many human lives and destroy and degrade the environment, causing major material losses and damage. Preventing, mitigating and eliminating the consequences of natural disasters is the responsibility of state bodies and other designated bodies, with proper regulations and engagement of services, with adequately trained personnel, and with procurement, use, and maintenance of equipment and resources. Depending on the volume and types of hazardous substances, civilian structures are forced to seek military assistance in the event of accidents in order to eliminate the resulting consequences. Based on the discussion above, in view of the possibility of consequences, reduction or elimination of the resulting consequences and depending on the scope and complexity, the engagement of forces has the character of an operation.

Pursuant to Article 51 of the Charter of the United Nations, the National Assembly of the Republic of Serbia, in accordance with the Constitution of the Republic of Serbia, defined the missions of the Serbian Armed Forces. One of the missions of the Serbian Armed Forces is the third mission, the mission of—supporting civil authorities in countering threats to security in case of natural, technical, technological and other disasters. The Serbian Army can be used in peacetime and in emergencies in accordance with the available resources and spatial and weather conditions.

Confronting non-armed security threats is a complex non-combat operation, a planned and prepared process in which limited military resources in a given space and for a certain period of time are deployed for non-combat activities to support the accomplishment of the mission. Non-combat operations include: information operation, civil-military operation and civilian government support operations in combating non-armed security threats.

Operations of support to civil authorities in countering non-armed security threats are the highest and most complex form of non-combat activities of civilian structures and defence forces, in which their content is streamlined and directed to achieve the set goal, by means of unified leadership and command, according to a unique project, in a certain space and at a certain time.

Support operations to civilian authorities:

- preserve the life of the population;
- support the local self-government bodies in the protection of infrastructure;
- renew basic public services; and
- create an environment for successful activities of international humanitarian organizations.

The Law on Defence, as it relates to the participation of the forces of the Ministry of Defence and the Serbian Army in the implementation of tasks as part of the mission of supporting the civilian authorities in countering security threats, states that in case of natural and other large-scale disasters in which human life and health, animals, and property are endangered, units of the Serbian Armed Forces, at the request of bodies responsible for the protection and rescue of people and property, may be deployed to assist the population, in accordance with a special law.

In order to protect and save people, property and cultural assets from natural disasters, technical and technological accidents and disasters, consequences of terrorism and other major accidents, the Chief of the General Staff of the Serbian Armed Forces, or the head of the competent command of the Serbian Armed Forces, based on the special authority of the President of Serbia, measures for the conduct of preparedness and the use of parts of the Serbian Armed Forces. This also helps eliminate any harmful consequences that may result from unsuspected threats to security. The support operations to civilian authorities in countering non-armed security threats fall within the range of crucial or essential to negligible levels.

A variety of threats affect the preparation and execution of operations, which have a different impact on the preparation and execution of operations. Threats arise from an operational environment that contains physical, temporal, technological, informational, political, social, economic and military dimensions.

The physical dimension of the operational environment includes the mathematical-geographic, physical-geographic and socio-geographic characteristics of the geospatial surrounding.

The physical dimension consists of:

- space expressed through physical and geographical characteristics;
- time as astronomical weather and as a climatic event; and
- human potential.

The influence of the time dimension is growing in importance because it determines the speed of the operation, which refers to the execution of tasks and activities and the achievement of goals in the unit of time.

The technological dimension of the operating environment can be considered in a material or non-material sense.

The information dimension of the operating environment implies the existence of command-information systems, a developed communication system, fast data and real-time information transmission, complete information protection, and processes that are collected, processed, exchanged, used, and protected by information.

The political dimension of the operational environment is determined by the political goals, commitments and constraints that reflect certain interests.

The social dimension of the operational environment is reflected in the public opinion and its attitude towards the operation, respect for international humanitarian law, provision of support for the accomplishment of the operation, and management of civilian and military cooperation.

The economic dimension as a factor of the operating environment is determined by the readily available resources of the zone of operation and the zone of interest and by the approved degree of their exploitation.

The military dimension is a direct expression of the political, economic, technological, and informational dimension and, as such, it is directly dependent on them. Bearing in mind the importance of military activity and the level of technological development, the military dimension of the operational environment has a decisive influence on the preparation and implementation of an operation to support civilian authorities in countering non-armed security threats.

Members of the Serbian Armed Forces, who possess the necessary qualifications and expertise, may serve as members of the Republic Headquarters for Emergency Situations due to natural disasters, and are appointed to/relieved from duty by the Government of the Republic of Serbia.

Support to civilian authorities in eliminating the consequences of natural disasters is classified as a non-combat operation, so the Serbian Armed Forces are not the carriers of the operation, but only act in support of other defence system forces. The Serbian Army does not train additional forces to support civilian authorities in the event of natural disasters, but deploys the existing forces, according to their primary purpose. Personnel are deployed to temporary units with a designated structure and number of troops. The forces are conditionally divided into command, execution, security, and support forces. The command forces in the civilian government support operation are unique command and control systems with the task of permanently collecting, processing and exchanging relevant, accurate and timely information with all the other forces involved in the operation. Situational knowledge is a prerequisite for timely decisions and their effective implementation. A commander's command is exercised in specific circumstances, given their diversity. Civil-military cooperation is particularly prominent in this operation.

Support to civilian authorities can include a temporary unit comprising both types of military, and the prevalence of one over the other depends on the type and degree of vulnerability and specific conditions. Depending on the development of the situation, units of the army can perform:

- engineering activities: identifying and removing obstacles, creating and maintaining communications, creating and determining embankments and channels, arranging scaffolding and crossing points;
- military-military actions to units of the military police and, if necessary, parts of special units, delimiting and securing the vulnerable area, controlling the movement of people and assets, preventing criminal activity, and protecting important facilities;
- airborne operations to helicopter units: air transport and evacuation, aerial reconnaissance, firefighting, traffic situation control; and
- maritime activities, by engaging units and river resources in river transport tasks, water rescue and evacuation, scouting and coastal surveys, and river and traffic control on inland waterways.

Support teams are heavily engaged in logistical support tasks. Logistic support is realized through:

- health care, medical care of the victims, and veterinary care of cattle;
- technical support, technical care of material assets, and supply of spare parts and energy;
- quartermaster support, supply of food products, clothing, footwear, food, water and accommodation;
- transport support, securing means of transport, transportation of people and property; and
- construction support, clearance of terrain and repair of damaged infrastructure.

Preparations of temporary structures and their functioning are particularly complex due to the diversity of forces involved in the operation, the increased needs of the local population, and the inability to predict the evolution of events and their consequences. The provisional units of the Serbian Armed Forces are formed for the implementation of a specific mission and can be tactical and operational, harmonized and sized in accordance with the missions and tasks.

2.6 Conclusions

The management activities of the natural hazard and environmental and social management system are mutually dependent and consistent with the underlying goal of protecting and continually improving the quality of life. The management system for protection against natural disasters represents a continuous cycle of planning, implementation, review and continuous improvement of the impact of protection at the level of the organization that implements the management system (ISO 2009, 2018). The natural hazards risk management system should be seen as a helping tool in the development and implementation of management principles in all areas, from the primary to the tertiary sector of the economy, i.e. within all interactions between society and the environment.

Thus far, 17 goals of sustainable development have been defined, and they should be achieved by 2030. All of these goals work in conjunction with the following thematic areas of the UNDP Strategic Plan: sustainable development, democratic governance, peace building, climate change, and resilience to shocks and crises, and they are all indirectly connected to the preservation of the natural environment and the existing resources, i.e. the current quality of life. They are implemented on a voluntary basis and according to different national realities, capacities, and levels of development of UN members, but always in compliance with national policies and priorities. To monitor progress, measurable indicators suitable for all aspects of sustainable development have been introduced. It is crucial to note that sustainable development goals can only be achieved with responsible, reliable, and effective management of natural hazards. On the other hand, analysis of Sendai targets clearly reveals the strong interconnection of both social wellbeing and environmental quality concerns.

Further research should be aimed at determinants that are equally important for the development of society, preservation of the environment, and strengthening of resilience to natural and other hazards.

2.7 Recommendations

Understanding the importance of risk from natural disasters is the first component in promoting and strengthening the concept of security culture at the level of individuals, organizations and countries. Safety culture is the first component in the development of an effective system of protection for all levels, but it is based on realistic consideration of the risks associated with natural hazards. Traditional social-environmental development indicators have a restricted scope since they evaluate changes in only one part of the subsystem, as if it were completely separated from other parts or the entire eco-social system. Thus, these indicators do not reflect the reality of close interconnectedness within the natural processes, especially those that can potentially lead to considerable hazardous effects. Therefore, it is necessary to create joint sustainable development goals and Sendai targets indicators. Regarding monitoring programmes, several composite indicators are currently in use, created in order to better understand the global interdependence of different sustainable development aspects. Of the current indicators, the Human Development Index is followed in Serbia and included in the List of Sustainable Development Indicators. However, there is a lack of disaster-resilience indicators, which is something to be considered in the near future. The resources of the Serbian Armed Forces should be seen as an important subject of protection and rescue of people and goods from the consequences of natural disasters within the Serbian disaster management system, although they are not the carrier of the operation, but only provide support to other forces of the disaster management system. Even if the Serbian Army does not have a permanent force for those purposes, or their mission of supporting civil authorities is not their primary activity, they have become an indispensable element in deployment due to their efficiency and speed of response.

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Chapter 3
Natural Disasters Risk Management in Bosnia and Herzegovina

Emina Hadžić, Naida Ademović, Hata Milišić and Suvada Jusić

Abstract Bosnia and Herzegovina (B&H) is exposed to many natural hazards. Changes in hydromechanical regime, long-lasting droughts, extreme rainfalls of high intensity and short duration, as well as endogenous processes caused more and more destructive floods, torrents, earthquakes and landslides. However, in analyzing the causes that lead to the negative consequences of natural occurrences, anthropogenic activity plays a major role. In this connection, this chapter will analyze primarily the causes that lead to the negative effects of natural phenomena. When speaking about anthropogenic activity and role of the man in the increasing of the consequences of natural disasters, will be analyzed activities that are not conducted in a sector of strategic documents and spatial plans, as well as specific gaps in individual sectors of the economy. The development of a disaster risk reduction strategy, consisting of assessing the vulnerability and mapping risks from certain natural disasters, is considered important in the prevention of disasters, and will be processed in particular. Their integration into spatial plans, with the use of modern technologies (such as GIS), could greatly contribute to reducing the consequences of natural disasters.

Keywords Natural disasters · Spatial planning · Risk management · Risk maps and hazards

3.1 Introduction

Natural disasters have a significant impact on the social and economic development of each country, as well as Bosnia and Herzegovina. Although it is clear that weather and climate extremes can not be avoided, it is also clear that, with their timely and accurate announcement, along with strengthening the ability of society to prepare and adapt to the changes that have occurred, they can significantly mitigate or avoid their negative consequences (Hadžić et al. 2018).

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It is important to emphasis that relief and geographic characteristics of Bosnia and Herzegovina is very different, both in shape and age and way of origin, as well as ability to endogenous processes which is quite a big. Most of the reliefs of the country consist of the mountains of different heights. The other part is flatland, and consists of parts of the Pannonian plain, large basins and river valleys, as well as the narrow belt of the Adriatic coast. More than 4/5 area of the Bosnia and Hercegovina are mountains and almost 80% of territory of B&H spreads between 200 and 1500 m above the sea level (see Fig. 3.1). Out of the total land area, 5% are lowlands, 24% hills, 42% mountains and 29% karst.

The climate of Bosnia and Herzegovina is determined by a complex of physical and geographical factors. The largest part of the territory of Bosnia and Herzegovina belongs to the extreme southern branches of the northern moderate belt and the extreme northern parts of the subtropical belt. The territory of Bosnia and Herzegovina is sectorally belonging to the influence of the winter western cyclone and summer azores anti-cyclone with increased tropical influences. The climate of Bosnia and Herzegovina is significantly influenced by the penetration of supertropic

Fig. 3.1 Topographic map of Bosnia and Herzegovina (Hodžić and Abdurahmanović 2017)

air masses, known as warm and dry African air. Circulating over the Mediterranean, these air masses moisten and cool down in their upward ascend towards the Dinaric Alps, discharging copious precipitation. If this warm air penetrates deep to the north, it brings about a long and very warm period in the land.

Observation of collected data from meteorological stations showed that there was a decrease in precipitation during spring and summer, but that there was a rise in rainfall during the winter period of the year. A particular problem is the trend of reducing snow cover in the winter period, which reduces the accumulation of water in the mountainous areas. Also noticeable is the increasing changeability of time in all seasons and it includes quick shifts of shorter periods (five to ten days) of extremely cold and warm weather conditions, so-called warm and cold waves, and periods with extremely high rainfall, as well as droughts. These changes are often accompanied by strong winds, although it must be noted that the values of the wind speed are still lower than in other parts of the world, as well as the damage they are causing.

Such increased oscillations of temperature and rainfall lead to an increase in the intensity and frequency of weather such as heavy rains, often followed by hails. A remarkable change in time was observed in short time intervals and in a small area, and deterioration in biometeorological conditions, as well as evident consequences for agriculture, water management, electricity and human health.

Due to the above factors, the duration of dry periods increases, and the frequency of floods, the intensity of soil erosion, landslides and other natural disasters.

However, in analyzing the causes that lead to the negative consequences of natural occurrences, anthropogenic activity plays significant role also. The negative impact of man's activity is more pronounced in urban areas. Most important artificial causes of floods are changes in basins or urban area, made by anthropogenic influences, notably through deforestation, bad agricultural practice, urbanization—more impervious surfaces and especially "unplanned building", **inadequate water management**, etc. Due to climate changes and anthropogenic impact, stormwater runoff volumes increased and pollution also are getting more and more significant. Stormwater runoff becomes significant loads by sediments, heavy metals, nutrients, oils, grease, bacteria and salt pollutants. All these means increased hazard consequences for environment, especially for water resources and public health in urban area.

In B&H **actual stormwater management** involves the direct removal of surface water through pipes or open channels to the nearest watercourse, by the shortest possible way, to prevent flooding. That means conventional drainage system (separate or combined sewage system) is comon. There are problems with low coverage of B&H population by this system (less than 40%), but coverage by sewage system is higher in urban areas and the percentage of population that are connected to the sewage system is estimated to be 46% at the state level (Water Policy in B&H 2011).

Very often, existing conventional drainage system don't have enough design capacity for reception all increased stormwater volumes caused by (after) extensive urbanization and climate change impacts. In that situation more water is leaving the conventional system causing more frequent and severe flooding and landslides in urban area (Jusic et al. 2019). Unappropriate maintenance of system will increase problem.

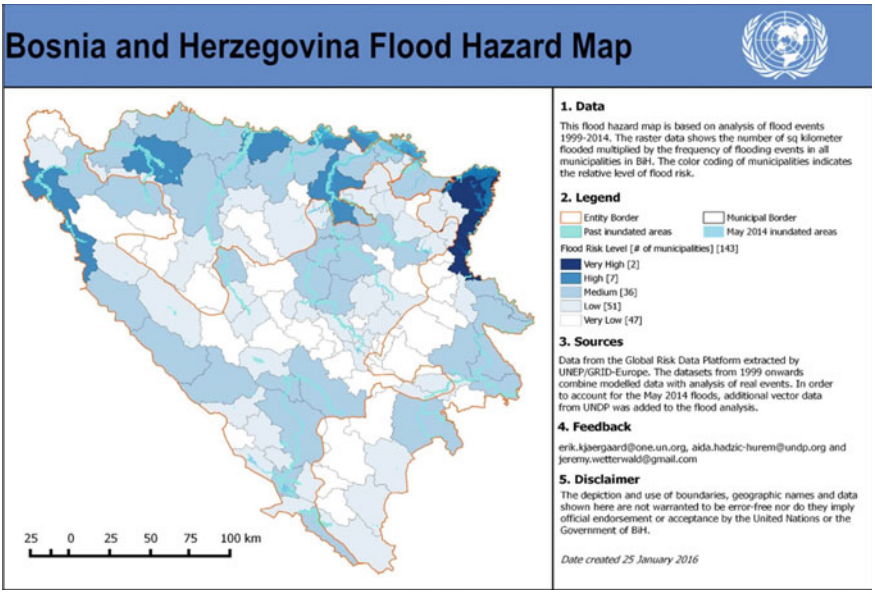

Fig. 3.2 Flood hazard map B&H. *Source* https://reliefweb.int/organization/unct-bosnia-herzegovina

Figure 3.2 shows flood hazard map for all country based on analysis of flood events from 1999 till 2014, as well as multi-hazard map depicts fires, earthquakes, floods and landslides on the Fig. 3.3.

Regarding earthquakes it is important to notice that Bosnia and Herzegovina is situated in the Western Balkans between latitudes 42° and 46° N, and longitudes 15° and 20° E. Due to fact that lies in the path of the second biggest belt (Alpine Belt), going from the Himalayas over Iran, Turkey and Greece, confirming the tectonic activity of this region, which is believed to be one of the most complex tectonics in Europe (Ademović 2011). The whole Mediterranean region has been affected by numerous earthquakes. It is difficult to localize the effects of earthquakes to one country due to their larger effect and impact (Ademović 2012). Bosnia and Herzegovina is a part of the Europe and the Mediterranean region of medium and in some areas high seismicity (Fig. 3.4). Figure 3.5 shows epicenters of all earthquakes in Bosnia and Herzegovina from 306 to 2016 year of magnitude by Richter's scale larger than 3.9.

3.2 Natural Disasters in the Past

Regarding natural characteristics, climate and relief it could be said the territory of Bosnia and Herzegovina is threatened by natural disasters on which human factor

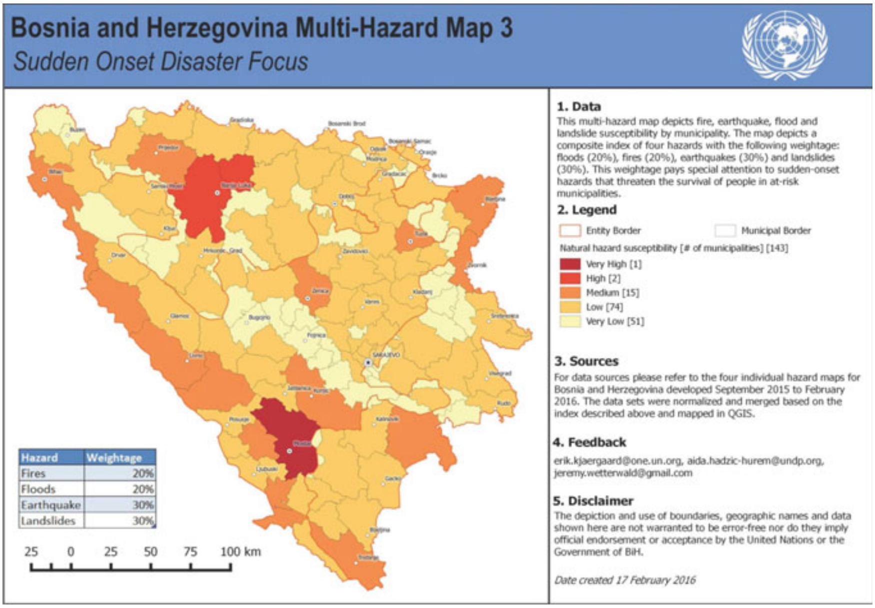

Fig. 3.3 Multi-hazard map in B&H. *Source* https://reliefweb.int/organization/unct-bosnia-herzegovina

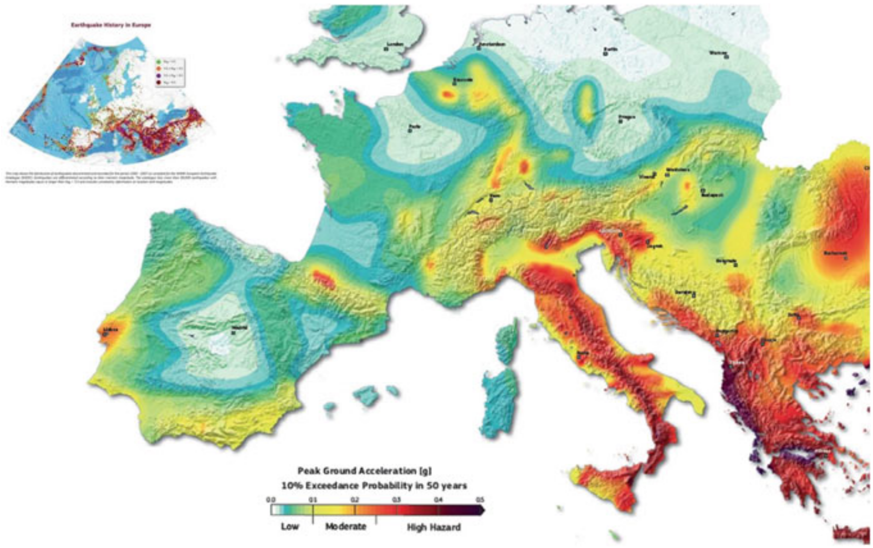

Fig. 3.4 European seismic hazard map (Giardinini et al. 2013)

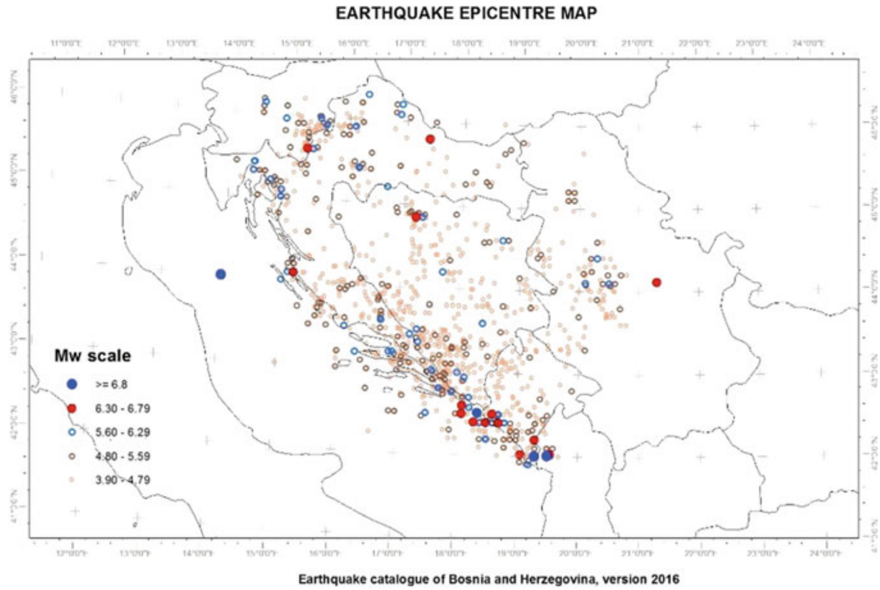

Fig. 3.5 Map of earthquake epicentres (BAS EN 1998-1/NA:2018 2018)

cannot influence but could increase the risk and negative consequences. These natural threats can be separated into flooding, torrents, draughts and other natural causes belonging to the category of extreme weather conditions and artificial earthquakes also occur in the region as a result of constructing water accumulations (dams), but as well as earthquakes which appear as a consequence of endogenous processes. Over the last ten years extreme events have become more frequent, as exemplified, amongst others, by the floods of 2004, 2010 and 2014; the droughts of 2000, 2003 and 2007; 2009, 2011, 2016, 2018, the intense daily rainfall during 2009, 2010, 2014 and 2019 and the appearance of strong and stormy wind and hail in 2005, 2006 and 2009.

According to the previous research, the oldest traces of completed projects on flood control in B&H have been found dating from the Roman period. It is believed that during this period were carried out flood protection of the Sava River downstream from Bosanska Gradiska (Gradiska), between Bosanski Brod (Brod) and willage Klakar and between Bosanski Samac (Samac) to Orasje. Construction of embankments for flood protection on the stretch of river Ukrina to place Klakar begins in 1890.godini. Three years earlier, in 1887, was designed to regulate the river Trebišnjica. During this period, shall be designed and partly executed regulation works for flood control of some cities and industries including: River Željeznica (Ilidža-Sarajevo), Miljacka River in Sarajevo, Bosna River in Zenica and Doboj, and the river Stavnja in Vares (Suljić et al. 2015).

A catastrophic flood on the Drina, Lim and Rzav rivers occurred at the end of October and continued through November 1896. Chroniclers registered that the Drina water level was risen for 17 m in Višegrad, while near Zvornik it was 8.4 m above average. Recorded water level of the Drina was 1 m over fence on the famous bridge of Mehmed Paša Sokolović in Višegrad. The discharge was estimated at 9540 m^3/s. The entire Podrinje was affected by this flood, with catastrophic consequences even along entire Sava River course in Semberija and Serbia (48,000 ha was flooded in the Mačva region). This flood had severely affected several settlements, such as Rudo, Višegrad, Skelani, Ljubovija, Novo Selo, Bijeljina, Bosanska Rača and Sremska Rača. Ljubovija and Sremska Rača were displaced to present location, while Bosanska Rača has never been restored. By constructing reservoirs of HPP Mratinje, HPP Višegrad, HPP Bajina Bašta and HPP Zvornik, probability of occurrence of such catastrophic flood was significantly decreased (Sava River Commission 2014).

In the 20th century, significant work on the regulation of the river was starting, although in 1931 and 1932 occurred the catastrophic flooding of the river Sava which had resulted in enormous damage. On 19 December 1968 large flood recorded in the Sarajevsko Polje, when Bosna River overflowed the bridge at the gauging station in Reljevo by 30–40 cm, and washed away part of the local road on right bank in length of about 80 m.

In 1976, three floods affected a big area of the country. In April 2004, flooding affected over 300,000 people in 48 Municipalities, destroyed 20,000 ha of farmland, washed away several bridges, and contaminated drinking water. In December 2010, Bosnia and Herzegovina experienced the largest amount of precipitation recorded in the last 100 years, which resulted in massive floods on the entire territory. The hardest hit areas were on Drina River, in Central and Eastern Herzegovina. In these areas alone, more than 4000 people were evacuated. The flooding in Bosnia and Herzegovina and neighboring countries, Serbian and Croatian, which occurred in the middle of May 2014 had devastating effects. Following several days of rainfall, which is estimated to be about the heaviest rainfall since records began 120 years ago, there was an extreme increase in water level there has been a rapid increase in the level of the river Bosna, Sava and Drina rivers and their tributaries. Floods and landslides in Bosnia and Herzegovina from May 2014 have caused the loss of human life, and money is the material damage estimated at nearly 4 billion.

The earthquakes that had the major impact on B&H were 1963 Skopje (Macedonia) earthquake, 1979 Petrovac (Montenegro) earthquake and 1969 Banja Luka (B&H) earthquake. The Skopje earthquake was the trigger for drafting new rules for seismic design of structures in the ex-Yugoslavia. The Montenegro earthquake was so strong (magnitude of 6.9 by Richter scale) that an intensity of V by Mercalli-Sieberg Cancani scale (MSC) was registered in B&H. The most catastrophic earthquake for the location of B&H was the 1969 Banja Luka earthquake of 6.6 magnitude by Richter's scale and an intensity which was recorded in the range from VII to IX as per MCS depending on the soil characteristics (Stojanković 1999). A large number of category I objects were damaged and completely destroyed during this earthquake, from schools, hospitals to cultural and heritage structures. Figure 3.6 shows different degree damages of the residential houses due to 1969 Banja Luka earthquake.

Fig. 3.6 Damages of residential houses caused by Banja Luka 1969 earthquake (Stojković 2009)

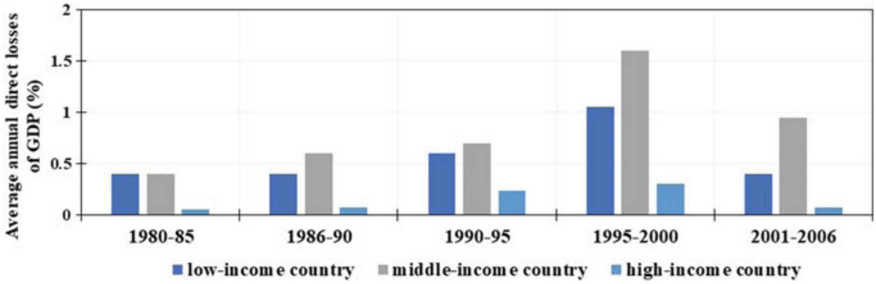

Fig. 3.7 Average annual direct losses from natural disasters compared to GDP (Cummis and Mahul 2009)

There is a medium earthquake risk in Bosnia and Herzegovina, however the level of disaster could be high due to the low level of construction quality and inadequate seismic design of existing structures. Another issues that should be looked at is the gross domestic product (GDP). The analysis indicated that middle income countries are at a higher risk caused by natural disasters in respect to the countries having a high or low GDP (Fig. 3.7), and Bosnia and Herzegovina according to the economic criteria is classified as a country of lower-middle income (Cummis and Mahul 2009).

3.3 Legislation

The Framework Law for protection and rescuing people and material goods from natural and other accidents was adopted in 2008 (Official Gazette of B&H No 50/08). Based on this Law, preparation of the Assessment of Bosnia and Herzegovina from natural and other disasters is completed in March 2011.

Flood protection in the Federation of Bosnia and Herzegovina (FB&H) is regulated by the Water Law—(Official Gazette of FB&H No. 70/06). This subject is completely harmonized with the Republic of Srpska Water Law and EU Water Framework Directive—WFD (2000/60/EC), and by appropriate bylaws. In the field of water management, the most important document is "Water Management Strategy", finally adopted for all part of country. Important document is also the Spatial Plan of the Federation of B&H and RS.

According to the Law on Water of FB&H, the prevention of flooding is the responsibility of the Agency for the Sava River Basin District and Adriatic Sea River Basin District for surface waters of I category and the Cantons for surface waters of II category.

By this Law it is also proposed adopting a new Regulation for protection from the damaging effects of water. Based on the above, the FB&H Government adopted the Regulation for the type and content of plans for protection from the harmful effects of water (Official Gazette of FB&H No. 26/09), in April 2009. This Regulation were transposed the EU Directives on floods (2007/60/EC), but implementation of timelines is harmonized with national legislation. Preventive measures, as the first preparatory phase of flood protection must take precedence over all forms of planned care. These measures are conducted continuously throughout the year and/or for prolonged periods of time in order to create the basis for flood protection.

By the Regulation on Flood Defense Plans (Regulation for the type and content of plans for protection from the harmful effects of water (Official Gazette of FB&H No. 26/09), the types, content and methodology of production, procedure of harmonization of plans for protection against harmful effects of water in FB&H have been defined. In order to protect areas against flooding, the areas are classified into categories under regulation issued by the Federal Minister. The government of FB&H ultimately makes the decision on endangered areas by flooding. The FB&H Government determines the adoption of two plans for protection from the harmful effects of water. One of these plans is the plan of flood risk management that has the focus of flood prevention, considering the characteristics of the river basin and sub-basin. Another plan refers to the active defense from flood and ice.

Regarding earthquakes must be noted that Skopje earthquake is triggered the created and publication of the first temporary codes for Construction in Seismic Regions (1964) in the ex-Yugoslavia. Even thought it was known that this region could be hit by strong earthquakes, during the design process earthquake actions were not considered. After the 1979 Montenegro earthquake and high devastation of the country existing design rules were revised and upgraded, its publication and application was enforced in 1981 (Pravilnik 1981). Ten years after the adoption of the Technical Regulations for Design and Construction of Buildings in Seismic Regions (Pravilnik 1981) a Rulebook for Technical Standards for Masonry Walls were made (Pravilnik 1991), however never enforced.

According to the available data for buildings in Census (CBS 2013) buildings constructed in the period from 1946 to 1960 were mainly unreinforced masonry structures with rigid diaphragms, which were from 1964 replaced by confined masonry structures, after the Skopje earthquake. All the structures constructed before 1963 did not take into account any seismic actions. Construction of reinforced concrete frames started from 1982. Classification of buildings according to the construction age which can be connected to certain building codes used for design of structures, meaning that performance of buildings can be indirect determined according to its stiffness and their capacity to resist seismic actions is presented in Table 3.1.

Table 3.1 Classification of buildings by construction age

Period	Before 1945	1946–1970	1971–1980	1981–1990	1991–2005	After 2006
Construction type	Stone masonry buildings with wooden slabs	Brick masonry with RC slabs	Masonry with rigid slabs	RC buildings, confined masonry buildings		
Seismic regulations (design standards)	–	–	1st earthquake design regulations	Regulations 1981	Prestandards (ENV)	Eurocode 8

Figure 3.8 illustrates different building types in relation to the construction time which is connected to the existence of certain construction regulation. Structures constructed before 1945 were mainly stone masonry buildings with wooden slabs and they represent only 4% of the total building stock in B&H. Brick masonry with reinforced concrete (RC) slabs were the most common type of construction in the period from 1946 to 1970, making a total of only 6% of the total building stock.

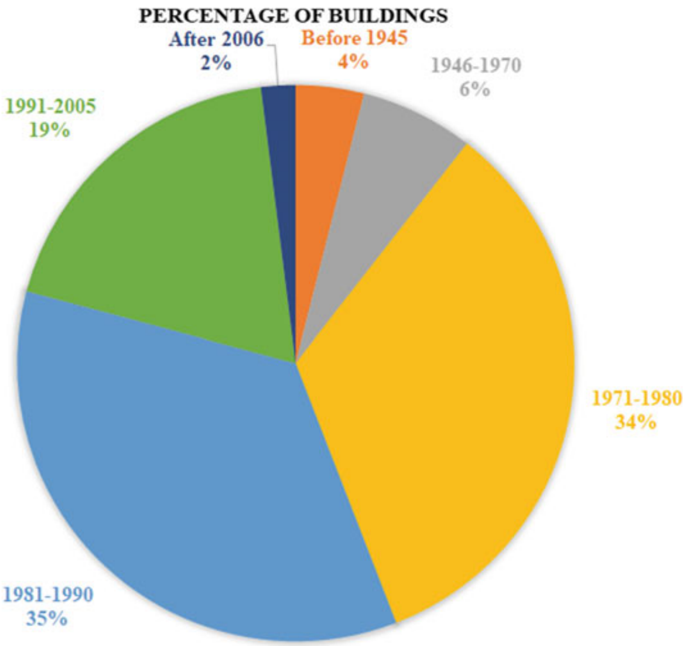

Fig. 3.8 Percentage of buildings in certain construction periods related to the different construction regulations

Two period from 1971 to 1980 and from 1981 to 1990 make both up to 35% of the all the buildings, however their construction type differs, from masonry with rigid slabs to RC buildings and confined masonry buildings respectably. There is a drop of construction period from 1991 to 2005 amounting to only 19% and finally after 2006 only 2% of new structures were built according to the Eurocode 8. Design of these structures did not take into account currently existing seismic hazard maps as they did not exist, but seismic maps from 1981 which were not based on PGA, but on intensity scale by MCS.

Currently B&H is using Eurocodes and Eurocode 8—Design of structures for earthquake resistance together with the seismic hazard map of Bosnia and Herzegovina which is a part of the National Annex of Eurocode 8 (BAS EN 1998-1/NA:2018 2018). For its creation the existing earthquake catalogue was used, consisting of 1944 earthquake records of Mw magnitude from 3.5 to 7.4 covered the span from 306 to 2015 and the territory of B&H and surroundings up to about 100 km.

On the basis of the this new seismic hazard map which is a part of the National Annex of Eurocode 8 (BAS EN 1998-1/NA:2018 2018) earthquakes having a PGA higher than 0.30 g are primarily located in the southern Herzegovina, covering an area of 2724.83 km^2 (Čitluk, Čapljina, Ljubuški, Neum, Ravno, Stolac, Ljubinje and Trebinje). It is interesting that a rather small number of residents occupy this territory, precisely only 5.1%. The percentage of territory of B&H that may experience an earthquake of 0.2–0.29 g is 22.0% on one side and an almost the same percentage of

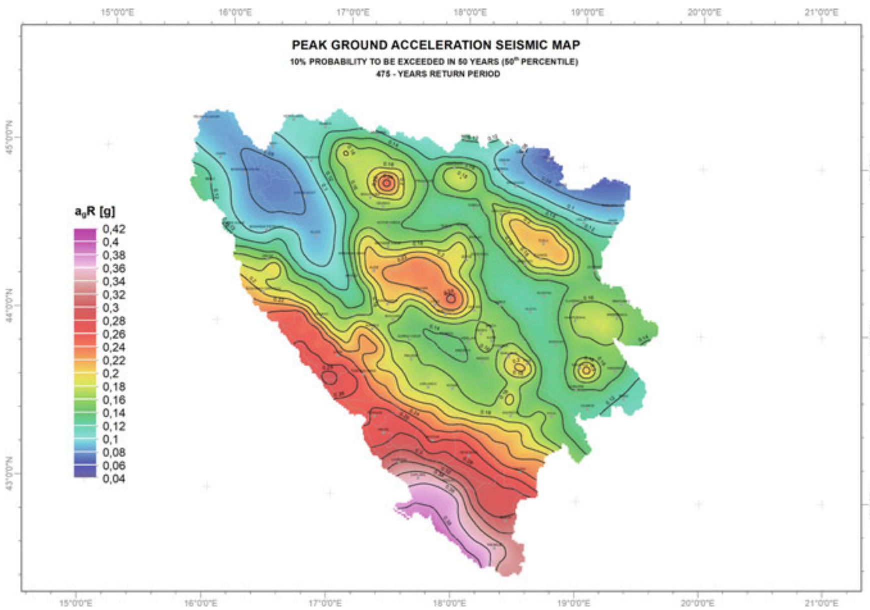

Fig. 3.9 Seismic hazard map of Bosnia and Herzegovina (BAS EN 1998-1/NA:2018 2018)

citizens occupy this region, to be exact 22.9%. The largest percentage of population 58.8% lives in the territory that may be hit by an earthquake of 0.1–0.19 g, which is 63.9%. The remaining 8.7% area of B&H may be exposed to an earthquake having a PGA less than 0.1 g, which is inhabited by 466,410.00 residents (Fig. 3.9).

3.4 Assessment of Natural Disaster Risk, Hazard and Exposure of Structures

Natural processes by itself, without a man could never have been a disaster. This points out to the very important fact that human activities should be spatially planned and adapted to the specificities of each area, in order to minimize the consequences of such natural events. The increase in the population, accompanied by the process of urbanization and increased pressures on natural resources, and land conversion combined with natural hazards, lead to increased vulnerability, both people and material goods. It seems that this sequence of events is not positive and is not in the desired direction for man and his activities. In order to avoid catastrophes in the future, it is necessary to reduce the risk exposure. How complicated is this question and how complex is its solution, can serve us examples of developed, rich countries, which, despite very high security and development of mitigation capacities, did not completely avoid the negative consequences of natural disasters.

Assessment of natural disaster risk for B&H was done in 2012 and it represents the fundamental document which is used for development of the Protection plan and rescue of people and property in the event of natural or other disasters in Bosnia and Herzegovina and Programs for development of protection systems and rescue of institutions and authorities of B&H. This document is not final, and it, as any other document, represents a material that needs to be updated dynamically. It is subject to changes, amendments, additions, upgrading (Council of Ministers 2012).

The plan of protection and rescue of people and property in the event of natural or other disasters of the institutes and bodies of B&H represents a framework for action regarding preparation, organization and implementation of protection and rescuing of people and property of institutes and bodies of B&H in the case of natural or other disasters. In the plan for protection and rescue, organization, measures and means of conducting these protection and rescue measures are determined together with the tasks of institutes and bodies of B&H to be involved in the protection and rescue as well as financial means required for fulfilling these tasks defined in the Framework Law ("Official Gazette" 50/08), Law on ministries and other administrative bodies of B&H ("Official Gazette" 32/02, 5/03, 42/03, 26/04, 42/04, 45/06, 88/07, 35/09, 59/09 and 103/09), and other regulations that are dealing with the role and tasks of the institutes and bodies in the field of protection and rescue, as well as professional materials, international documents and practice. This plan gives guidelines for formation of protection plans and rescue at the entity level and Brčko District. The plan also aims to improve preparedness to natural or other disasters and to clarify the division of authority and responsibility in order to effectively protect people and property with the optimal use of resources. This plan is actually a practical information data and tool for coordination of risk mitigation from natural or other disasters.

The EU Flood Recovery Programme for Bosnia and Herzegovina, worth 43.52 million EUR, in order to support recovery efforts after the floods of May 2014. The Programme recognises the importance of investing in future risk informed decision making and thus initiated the development of a Flood and Landslide Risk Assessment for the urban area (Housing Sector) in B&H (the Assessment). The overall objective of the Assessment is to contribute to strengthening disaster risk assessment and disaster risk management capacities in B&H. The Assessment therefore assesses the flood and landslide risk for the urban area of Bosnia and Herzegovina, prioritises locations based on risk ranking and makes recommendations for *risk reduction*.

The recommendations and measures for flood risk reduction take into account all ongoing or planned initiatives in this area and rely on Action Plan for Flood Protection and River Management in B&H 2014–2017 (Action Plan) as a prerequisite for the start of implementation that was adopted by the Council of Ministers of B&H. This Action Plan covers the main problems and deficiencies (structural and non-structural measures) related to flood risk management in B&H and sets the strategic framework for coordinated work in this area. Furthermore, it is argued that these measures are not sufficient to amend all the shortcomings of the Floods Protection System, hence the need to continually work on the improvement of the System itself and Stormwater Management also. Some of the proposed measures for flood risk reduction in B&H are briefly explained by next sentences.

Unfortunately, until today no major interest has been given to the assessment of seismic risk of the territory of Bosnia and Herzegovina. In the last 15 years some research took place on the European level and in some of these projects Bosnia and Herzegovina was involved directly or indirectly. One of the results of a Global Seismic Hazard Assessment Program (GSHAP), which lasted from 1992 to 1999, was the development of the global map of seismic hazard in relation to the peak ground acceleration (PGA) (Giardini 1999). The result of the second project "Seismotectonics and Seismic Hazard Assessment of the Mediterranean Basin" (IGCP-382 SESAME) which lasted from 1996 to 2000, was the creation of the first unified seismic source model. A special group within this project worked from 1996 to 2002 on the creation of the unified seismic hazard modelling for Europe and the Mediterranean. This all-inclusive model enabled the creation of hazard maps, expressions for ground motions by the utilization of different parameters in the function of different soil characteristics and probability levels for this whole region (Jimenez et al. 2003). Seven years later a new project was launched "Seismic Hazard Harmonization in Europe" (SHARE) (Giardinini et al. 2013). Additionally, in the same time sequence projects on the regional and global level where running, specifically the global earthquake model (GEM) and the earthquake model for the Middle East (EMME). The main goal was to create a new database of all earthquakes, make a new homogenized European seismic source zone model (SSZM) and the first pan-European database of active faults and seismogenic sources. This all would be used as the basis for the revision of the European building code Eurocode 8.

In September 2007, a new project the BSHAP (Harmonization of Seismic Hazard Maps in Western Balkan Countries) was launched aiming to create new seismic hazard maps by utilizing modern scientific methodologies which will enable harmonization within the region. On the basis of available data new seismic hazard maps for peak ground acceleration (PGA) were created and a compilation of an updated and unified earthquake catalogue was made (Gülerce et al. 2017).

Assessment of seismic risk was not one of the priorities of Bosnia and Herzegovina while the researchers and experts dealt with them individually (Ademović 2017; Ademović et al. 2019a, b). There are several laws and regulations on various levels of B&H (state, entity and canton level and Brčko District) which are the basis for implementing the protection and rescue of people and property. Law on protection and rescue of people and property in the event of natural or other disasters, Framework law on the protection and rescue of people and property in the event of natural or other disasters in Bosnia and Herzegovina, the methodology for the development of risk assessment of Bosnia and Herzegovina in the event of natural or other disasters, further for example for the Canton level, the law on jurisdiction of the authorities of the Sarajevo Canton in the field of protection and rescue of people and property in the event of natural or other disasters, the Law on Amendments to the law on jurisdiction of the authorities of the Sarajevo Canton in the field of protection and rescue of people and property in the event of natural or other disasters, Law amending the law on jurisdiction of the authorities of the Sarajevo Canton in the field of protection and rescue of people and property in the event of natural or other disasters etc.

According to the report (Council of Ministers 2012), zones with maximum earthquake intensities have been identified (see Fig. 3.10) and as it can be seen most of the territory is located in the zone 7°, 8° and 9° of seismic intensity of the MCS scale corresponding to 0.1, 0.2 and 0.4 g.

Earthquakes which have been identified as risk representatives in Bosnia and Herzegovina with effects across the border are Banja Luka and Tihanjina earthquake of magnitude higher than 6.5 by Richter's scale. While Treskavica, Grahovo and Ljubinje have been identified as representative earthquake risk of magnitude higher than 6.0 by Richter's scale for the territory of B&H and across the border effects. The criteria which were used for the creation of this representative earthquake selection were: the selected earthquakes were the ones which occurred on the territory of Bosnia and Herzegovina and had the largest magnitudes; earthquakes from the list had the greatest consequences for people, property, infrastructure and the environment, and these earthquakes are characteristic for the region i.e. they are characteristic representatives of a certain seismic zones of B&H (Hrvatović 2010).

On the basis of the analysis a risk matrix was conducted as presented in Table 3.2, followed by the level of preparedness illustrated in Table 3.3.

In order to conduct the seismic risk according to the EC guidelines it is necessary to analyze the risk on the basis of four factors, those being seismic hazard, exposure of structures, vulnerability, and specific cost. After the creation of the seismic hazard map for B&H it could be stated that this is the only parameter which is well defines in

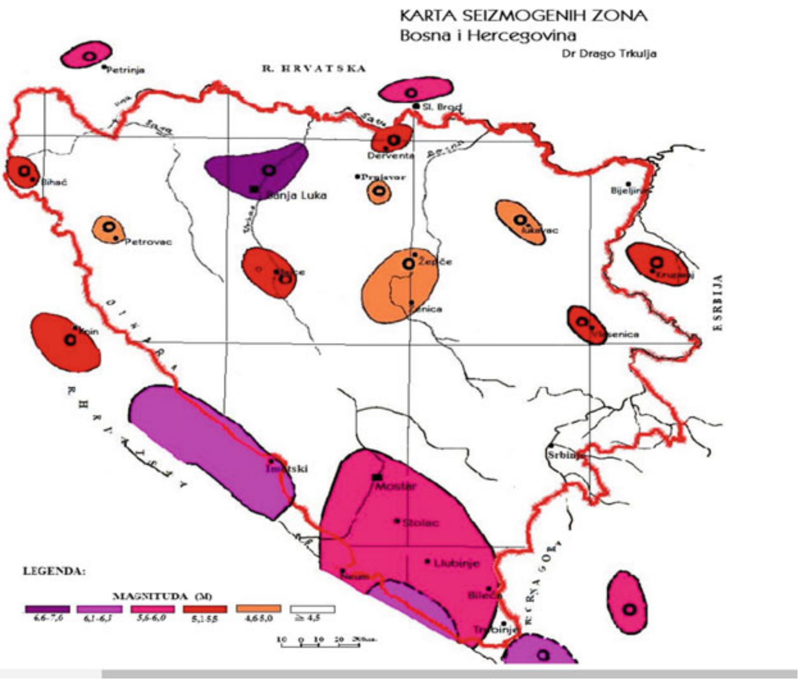

Fig. 3.10 Map of seismogenic ZONES (Trkulja 2010)

Table 3.2 Risk matrix

Probability of occurrence	Very high probability (5)					
	High probability (4)					
	Average probability (3)		5.Treskavica	2.Grahovo 4.Tihanjina	3.Ljubinje	1.Banja Luka
	Low probability (2)					
	Very low probability (1)					
		Limited (1)	Average (2)	Serious (3)	Strong (4)	Critical (5)

Table 3.3 Level of preparedness

🟢	Nothing should be changes	**Assessment of vulnerability level**		
🟡	Adjustment needed	***Before the incident*** Preparation (plans, preventive measures, etc.)	***During the incident*** Capacities for response and mitigation	***After the incident*** Recovery capacity
🔴	Insufficient-Large changes required			
	1. Banja Luka	🔴	🔴	
	2. Grahovo	🟡	🟡	
	3. Ljubinje	🔴	🔴	
	4. Tihaljina	🟡	🟡	
	5. Treskavica	🟡	🟡	

B&H, while all other factors are in direct correlation with the data bases on structure types, construction materials, construction age, height information etc., which are lacking or are not well organized and defined, which is crucial for systematic and quality assessment of seismic risk.

As stated previously the seismic hazard maps have been produced and are a part of the Eurocode 8, National Annex. Secondly, the exposure of structures to earthquake is not defined at all. An attempt has been done by researchers Ademović et al. (2019a, b) in their research paper they applied a fast earthquake scenario based on the Risk Assessment Tools for the Diagnosis of Urban Seismic Risk (RADIUS) Project. This scenario was successfully used for comprehensive estimation of the potential damage from an earthquake in different countries (Mirjalilov et al. 2000; Kaplan et al. 2008; Hadzima-Nyarko et al. 2018).

The RAPID methodology concept developed and validated by data after the L'Aquila earthquake in the case of Croatia (Kalman Šipoš et al. 2017) was extended and applied for Bosnia and Herzegovina (Ademović et al. 2019a, b). This is far from the generally applicable system developed within the GEM (GEM Basic Building Taxonomy) (Brzev et al. 2013).

3.5 Introduction the Role of Spatial Planning on Disaster Risk Reduction

Disaster risk reduction is implemented through a systematic effort of the entire society through reducing risk exposure to danger, reducing vulnerability of people and property, better land management practices and improving preparedness for potential disasters. In addition, according to Mitchell (2003), it is essential to include efforts to reduce the risk of catastrophes in development programs and spatial planning at all levels of government, but at the same time.

Disaster Risk Reduction focuses on three major components of disaster risk, hazard, vulnerability and exposure. Since, most of the danger comes independently of man, and of the forces of nature, it is the human ability to reduce their potential impressions, rather weak. But the vulnerability and exposure of society can be significantly improved through planned human activities. On the other hand, human activities need to be adapted to potential hazards. Reduction of vulnerability requires understanding of the basic factors that create the danger and understanding of their actions. In this regard, spatial planning, and the application of modern technologies, such as, GIS have an important role in reducing the risk of disaster (Hadžić et al. 2017).

Inclusion of spatial planning issues in preventing consequences and reducing the risk of disasters is of paramount importance. Spatial plans should include risk maps in order to understand the possible consequences of a disaster and to develop the development on a sustainable basis. In that sense, the human activities planned and implemented in accordance with the determined risk. It should be noted that the risk can not be completely avoided, or that there is so-called acceptable risk or exceptions that can be applied, depending on the type and purpose of land use. The center of attention should be the local community, which will first feel the consequences and deal with the consequences of disasters. Accordingly, it should have certain powers in spatial planning, but emphasizing the need for a comprehensive planning of space, not only at the level of the municipality, but also at higher levels, to the state and even beyond.

The harmful effects of natural disasters, which are a sudden occurrence and cause environmental, financial and human loss, can be prevented or minimized if society is sufficiently prepared. Natural disaster management involves monitoring specific events, predicting their possible occurrence and warning immediately after a natural disaster. It also includes works on the prevention of natural disasters. If a natural disaster occurs, readiness should be shown in managing appropriate procedures and providing assistance. The management of natural disasters also includes the implementation of disaster recovery plans.

Geographic Information Systems (GIS) can be used to manage the planning, emergencies during and after natural disasters. GIS is a tool for integrating, storing, editing, analyzing, and visualizing spatial data. GIS is a tool that can provide concise and up-to-date information needed by responsible persons in assessing a natural disaster at any stage. The use of GIS combines data from different sources (e.g. road data, population density, relief, vegetation, hospitals, etc.) and visualize them in a unique way before, during or after a natural disaster. When natural disasters occur, a large number of people and institutions are working together. The use of GIS provides the ability to quickly share data between command centers involved in rescue before, during or after a natural disaster.

3.6 Conclusions and Recommendations

In 2009, B&H adopted a methodology for the assessment of the vulnerability of Bosnia and Herzegovina to natural and other disasters, through which, among other things, guidelines for the development of the B&H Endangered Threat Assessment, were defined, in order to identify and analyze risks and mitigation measures to increase safety and protection of people and material goods from natural or other disasters. The assessment of vulnerability was done at state level as well as at entity levels. Through these documents are: identified main risks of all kinds that can cause natural or other disasters, both in Bosnia and Herzegovina and those with transboundary effects; the exposure of people, property, critical infrastructure to all major hazards is estimated; risk sizing was performed, risk hazards based on hazard assessment, exposure to hazard and vulnerability, (risks within Bosnia and Herzegovina or cross-border risks), their likelihood, causes and consequences (expressed in human, material and/or financial losses). Plans for protection and rescue of natural or other disasters of institutions and bodies in Bosnia and Herzegovina and the Program for the development of the system of protection and rescue of institutions and organs of Bosnia and Herzegovina have been developed, based on the B&H Endangerment Assessment.

Also, as a member of the United Nations, Bosnia and Herzegovina, in line with the conclusions of the UN World Disaster Reduction Conference held in January 2005 in Kobe, was obliged to establish a disaster risk reduction platform, which was done 2013 year. The platform is formed as a forum for the exchange of opinions that encompasses all the factors of the society from different fields of activity that will offer the best solutions in their domain in order to prevent and better protect against disasters. This includes the harmonization of attitudes on disaster risk reduction activities, hazard risk assessment, harmonization of activities, encouragement and achievement of the highest quality response to threats and disaster risks and the development of the population's awareness of the existence of a disaster hazard.

Of course, besides these, a number of other efforts have been made, both at state, and at entity, also cantonal and municipal levels, to bring the Protection and Rescue System to an appropriate level.

Thus, B&H has joined a group of 25 European countries that are working to integrate risk reduction from natural disasters into their development plans, policies and programs. For the time being, this bonding is not being realized, as there are no development strategies and there is no connection with budget planning through public investment programs and other programs. The disadvantages in the development that existed before the accident can be annihilated by reforms that encourage competition and modernization above standards that existed before the accident.

It is clear that most natural disasters can not be avoided, but victims and economic losses resulting from their occurrence can be reduced. Especially if the country is more often exposed to these disasters, it is necessary to do it by risk assessment in order to reduce it. Regarding the risk assessment, it is necessary to collectively collect data, assess the degree of exposure of people, activities and assets, then take these analyzes into account when drawing up plans and incorporate them into the fiscal framework of the country. Risk can, as a rule, be reduced by taking measures to reduce vulnerability, setting up accident procedures and building institutions to deal with these issues.

It should strive to the concept of disaster risk reduction (DRR) has come a long way from emergency response to disaster risk management with emergency response now being only one of the components of a broader approach that deals with risk of disaster in terms of prevention, preparedness and response.

The major gap is the nonexistence of quality database which would enable the usage of the modern approaches which are used on the global level where researchers in the last several years are developing methodologies for assessment of seismic risk. One should mention here the initiative Global Earthquake Model (GEM) with one of the goals of production of the most sophisticated data base of wide application possibilities, models and program software for the assessment of seismic risk on the global level (Pinho 2012).

Unfortunately, until today no detail assessment of the structures exposed to earthquake action for the territory of B&H was done. Additionally, the application of the modern assessment methods for B&H is not possible to be applied due to the difficulties (challenges) during the application of such a procedure. The major problem is the lack of good data base with information regarding construction material, age, number of storeys, etc. Additionally, numerous reconstructions and construction of new additional storeys on the existing structures are not documented in a well manned which has a major influence on the structure behavior exposed to future earthquake on one hand and on the other a vast number of illegal constructions built in the last 30 years.

One of the challenges of the modern times is the connection of several natural hazards, seen in the multi-hazard assessment, specifically connecting earthquakes with landslides and floods (Ademović 2017; Ademović et al. 2017).

In this respect the first and crucial step would be creation of comprehensive data base. Once this is done it would be necessary to conduct rapid assessment methods and in highly earthquake prone areas according to a very detailed data base a Detailed Seismic Assessment should be done.

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Chapter 4
International Trends in Managing Natural Hazards and the Role of Leadership

Maria Bakatsaki and Leonidas Zampetakis

Abstract The frequency and intensity of natural disasters and the deriving economic losses throughout the world increase, making more imperative the implementation of the 'Sendai Framework for Disaster Risk Reduction 2015–2030' that was adopted from United Nations Member States in 2015. The results from the study on the first 3 years implementation of the Sendai framework have shown that the States should adopt an holistic approach were the responsibility should be shared among all the stakeholders. Crises often intensify the extent and complexity of demands placed on leaders, in order to guide and support relief staff and civilians through a high stressful emergency situation. The key leadership style, as it is suggested from experienced disaster leaders of being more effective in such emergency situations in all phases of emergency, should be persuasive rather than directive. Some of the questions that are trying to be answered in this paper through an extensive literature review are: 'What leadership style should be more appropriate to handle the deriving occupational hazard?' and "How a leader can engage members of their organizations, as well as external parties to get everyone collectively to act as one in the case of crisis?" Many leadership models, theories or philosophies are analyzed and are examined about their usefulness for managing successfully crisis deriving from natural disasters. Finally, it is highlighted the importance of higher education creating leaders skilled for disaster relief.

Keywords Natural hazards · Crisis leadership · Compassionate leadership · Leadership skills for disaster relief · Sendai framework

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4.1 Introduction

The climate change has led the last decade to doubling of the average number of events per annum, while most of these phenomena are characterized by weather extremes (Wallemacq and Below 2018). For instance, during 2018, in Japan heavy rains triggered the deadliest floods since 1982, killing 230 people, and in India's Kerala state the August flash flooding was the worst the region had experienced since 1920, killing 504 people, over 23 million people were affected and costed US$2.85 billion. The Attica Fires in Greece, killed over 100 people, making the deadliest wildfire recorded in Europe within EM-DAT records since 1900 and in USA the California wildfire season was the deadliest and costliest on record (CRED & UNISDR 2019). It is very important to understand that humanity is in severe danger due to these weather extremes. The emergency of the situation makes more imperative the implementation of the 'Sendai Framework for Disaster Risk Reduction 2015–2030' that was adopted from UN Member States in 2015 (Wallemacq and Below 2018).

As the intensity of natural disasters and the deriving economic losses throughout the world increase, so do the demands for humanitarian relief and the importance of the experienced and well educated emergency leaders (Buschlen and Goffnett 2013). Natural disasters usually are unexpected, and cause complex emergencies, such as loss of life, of health, of home and property, of important documents, of access to food and water and could be of so many other losses. They are stressful situations, which create political challenges and realities of public leadership in times of crisis. Citizens look at their leaders—presidents and mayors, elected politicians and administrators, public managers and top civil servants—and they rely on them (leaders and policy makers) to avert the threat or at least minimize the upcoming damages (Boin et al. 2005). Leaders should have certain skills and abilities in order to be able to cope through these difficult situations.

The main purpose of the present chapter is to examine the appropriate leadership skills and style that are necessary for a leader to manage the unexpected, assess and adapt to the circumstances, take the appropriate decisions and promote the coordination between all the stakeholders (public, private and Non-profit organizations, and volunteers). More over it places an emphasis on whether these leadership abilities and competences can be cultivated and taught. Students will become the future leaders, governors and public administrators or head of civil protection programmes. As such, the chapter also examines the emerging role of higher education role in the development of leaders for future disaster situations (Buschlen and Goffnett 2013).

4.1.1 Terminology

Natural disaster is defined by the Centre for Research on the Epidemiology of Disaster (CRED) as "*a situation or event which overwhelms local capacity, necessitating* *a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering*" (Below et al. 2009).

The Integrated Research on Disaster Risk (IRDR) has classified the natural disasters into six categories groups, each having different set of generic hazards: Geophysical (Earthquake, Volcanic Activity, Mass Movement), Hydrological (Flood, Landslide, Wave Action), Meteorological (Convective Storm, Extratropical Storm, Extreme temperature, Fog, Tropical Cyclone), Climatological (Drought, Glacial Lake Outburst, Wild fire), Biological (Animal Incident, Disease, Insect infestation), and Extra-Terrestrial (Impact, Space Weather). Each event can be reported more analytical at the peril level. A peril is the specific cause of the loss, such as lighting or tornado and it may be associated with one or more generic hazards. For example, lighting could be associated with convective storms or with tropical cyclones (Integrated Research on Disaster Risk 2014).

A crisis refers to an unpredictable situation, which is accompanying by a high degree of uncertainty. This situation is classified, according to the predictability level and the seriousness of its impact to human life, as an emergency, disaster, catastrophe, threat/hazard or risk (Demiroz and Kapucu 2012; Johnson 2000). These terms are defined as (Johnson 2000):

- *Emergency*: is a deviation from planned or expected behaviour or a course of events that endangers or adversely affects people, property, or the environment.
- *Disaster*: It is characterized by the scope of an emergency. An emergency becomes a disaster when it exceeds the capability of the local resources to manage it. Disasters often result in great damage, loss, or destruction.
- *Catastrophe*: is a more severe disaster.
- *Risk*: is the potential or likelihood of an emergency to occur. For example, the risk of damage to a structure from an earthquake is high if it is built on or adjacent to an active earthquake fault. The risk of damage to a structure where no earthquake fault exists is low.
- *Hazard*: Hazard refers generally to physical characteristics that may cause an emergency. For example, earthquake faults, active volcanoes, flood zones, and highly flammable brush fields are all hazards.

Disasters could be classified into two categories: *manmade* and *natural* disasters (Demiroz and Kapucu 2012).

A *natural hazard* is natural phenomenon than might have a negative effect on humans or the environment.

4.2 How Crucial Are the Consequences of the Climate Change?

The joint statistical review of CRED and United Nations Office for Disaster Risk Reduction for the years 1998–2017 (Wallemacq and Below 2018) reports that climate-related disasters over the past 20 years, in terms of occurrences, are accounting for 91% of all 7255 recorded events between 1998 and 2017. Within this total, floods were the most frequent type of disaster, 43% of all recorded events. It must be noticed that the average number of disasters per year for the last decade (1998–2017) of 329 events are double than the average of 165 events per annum in 1978–1997 (Wallemacq and Below 2018).

In 1998–2017, by far the deadliest type of disaster was earthquakes, including tsunami, with 56% of total events. Storms, including tropical cyclones and hurricanes, were posed in term of fatalities at the second place (17%), Extreme temperature at third place (13%) and Floods at the fourth place (11%). Concerning the affected number of people, floods affected the most people (more than 2 billion), followed by drought which affected 1.5 billion people in 1998–2017. During the last 20 years, the biggest damage was caused in 2017 to USA (US$245 billion) by a remarkably Hurricane season having 5 tropical cyclones of Category 5. The second event with large economic costs was caused in 2011 by the Great East Japan Earthquake and Tsunami with subsequent shut down of the Fukushima nuclear energy plant, and losses totalling US$228 billion (Wallemacq and Below 2018).

In the 21st centuries, earthquakes and tsunami have been the deadliest disaster and this trend continued in 2018. In the 'Annual Disaster Statistical Review 2018' of CRED (CRED & UNISDR 2019) is mentioning that remain the same pattern with floods as the main type of disaster that affected most people (50%) and earthquakes as the deadliest type of disaster (45%). According to the "Annual Disaster Statistical Review 2017" of CRED (Wallemacq and Below 2018) although on 2017 there were fewer natural disasters, deaths and total people affected than the previous decade (2007–2016), in terms of economic losses there was an increase of 49% than the previous annual average of $141 billion.

The direct impact of climate change on human populations will increasingly be felt through catastrophic phenomena, such as (a) droughts and extreme temperatures, and (b) floods due to heavy rains, which happen in countries (like Japan, Somalia and Europe) that doesn't face often floods by the monsoons as it is happening in Southern and Southeastern Asia. Particularly the floods, have affected more people than any other type of natural hazard (50%) (CRED & UNISDR 2019). These disasters influence agriculture beyond the short-terms, provoking reduced production, loss of harvest and livestock, outbreaks of disease, and destruction of rural infrastructure and irrigation systems. The farmers are the main victims who are lead directly to subsequent economic loss.

Specifically, droughts have typically long duration and high spatial coverage and in countries dependent on agriculture have a high impact on agricultural production, food supplies, human welfare and rural livelihoods. They are by far the most harmful disaster for livestock (Wallemacq and Below 2018). While droughts represent low (16%) percentage of total economic losses, research by CRED in 2011 into 2481 disasters found out that in national level, droughts often inflict significantly greater losses than other types of disasters, with almost 40% of droughts provoking damage equal to or greater than 0.5% of the GDP of the country where they occurred (Guha-Sapir et al. 2013). This percentage of 0.5% of GDP losses is The International Monetary Fund's threshold for a major economic disaster.

The UN's Food and Agriculture Organization (FAO) pointed out that "*the rising incidence of weather extremes will have increasingly negative impacts on agriculture because critical thresholds are already being exceeded*" (Food and Agriculture Organization of the United Nations (FAO) 2018). Consequently, reducing disaster losses is the key to eradicating poverty.

While early warning systems and timely evacuations have led to reduced loss of life, economic losses continue to increase with high rates and the numbers of people who are affected remains high. All the earlier mentioned facts make more imperative the implementation of the 'Sendai Framework for Disaster Risk Reduction 2015–2030' that was adopted from UN Member States in 2015 (Wallemacq and Below 2018).

4.3 The Sendai Framework for Disaster Risk Reduction 2015–2030

The United Nations Member States adopted the Sendai Framework for Disaster Risk Reduction 2015–2030 on 18 March 2015 at the Third UN World Conference on Disaster Risk Reduction in Sendai City, Miyagi Prefecture, Japan. It is a 15-year, voluntary, non-binding agreement, people-centred preventive approach to disaster risk. It recognizes that the State has the primary role to reduce disaster risk with the support of other stakeholders including local government, communities businesses and aims for the following outcomes (UNISDR-UN Office for Disaster Risk Reduction 2015b):

> The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.

The Sendai Framework for Disaster Risk Reduction 2015–2030 outlines seven clear targets, 38 indicators for measuring progress on reducing disaster losses and four priorities for action to prevent new and reduce existing disaster risks. These indicators align implementation of the Sendai Framework with the UN's global Sustainable Development Goals (SDGs) and the Paris Agreement on climate change.

The four priorities are (UNISDR-UN Office for Disaster Risk Reduction 2015b):

(i) Understanding disaster risk;
(ii) Strengthening disaster risk governance to manage disaster risk;
(iii) Investing in disaster reduction for resilience and;
(iv) Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

The seven global targets are:

(a) Substantially reduce global disaster mortality by 2030, aiming to lower the average per 100,000 global mortality rates in the decade 2020–2030 compared to the period 2005–2015;
(b) Substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015;
(c) Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030;
(d) Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030;
(e) Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020;
(f) Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of the present Framework by 2030;
(g) Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030.

Managing the risk of disasters is aimed at protecting persons and their property, health, livelihoods and productive assets, as well as cultural and environmental assets, while promoting and protecting all human rights, including the right to development (UNISDR-UN Office for Disaster Risk Reduction 2015b).

It is important to be notified that Sendai Framework should be linked and developed through the context of the “Transforming Our World: The 2030 Agenda for Sustainable Development”, as it is recognized from United Nations the role of disaster risk reduction as a core development strategy. There are 25 targets related to disaster risk reduction and resilience in 10 of the 17 Sustainable Development Goals (SDG) (UNISDR-UN Office for Disaster Risk Reduction 2015a).

4.3.1 GAR 2019-Results from the Implementation of the Sendai Framework

The United Nations’ Office for Disaster Risk Reduction presented recently the results of the 3-year implementation of the Sendai Framework the so-called “2019 United Nations Global Assessment Report on Disaster Risk Reduction (GAR)”. The emergency of the global situation could be expressed in a sentence as follows:

> We are fast approaching the point where we may not be able to mitigate or repair impacts from realized cascading and systemic risk, particularly those due to climate change. The urgency is evident (UNDRR 2019).

According to the results from the GAR 2019 the following challenges require direct attention and action:

- *Awareness*: Further educational and awareness raising campaigns are needed to help stakeholders recognize vulnerability to hazards.
- *Risk governance*: Risk governance should be approached in a holistic way. Also, private sector and government need to have the incentives and modes that facilitate sharing the responsibility and cost of risk. IRGC proposes an innovative risk governance framework and guidelines on how to address emerging risks.
- *Legal infrastructure*: As experience shows that risk reduction works best if required by law, specific legislation for risk reduction should be enacted and enforced. This needs to be accompanied by guidance on how to achieve the goals set out in the legal framework to help industry be compliant and to support authorities in assessing if undertaking has met the associated safety objectives. A liability and compensation framework is also required.
- *Risk communication*: Communication at all levels should be improved to ensure that information on risks flows freely and effectively across all of society. Better exchange of and access to risk management resources should also be guaranteed.
- *Risk assessment*: Research should focus on the development of methodologies and tools for risk assessment and mapping. For this purpose, better loss and damage functions are needed for all hazards. Human, environmental and economic impacts should also be assessed, with the latter two often being neglected.
- *Data collection:* The easy and free sharing of relevant data on all risks, disaster events and even near misses should be promoted and facilitated to support learning from past events for prevention and mitigation. Data exchange should ideally also happen among sectors and countries.
- *Cooperation and partnerships*: Cooperation among all stakeholders, particularly at the local level, is essential for reducing risks. Public–private partnerships, regional and international networks should be fostered to facilitate collaboration for effective risk management.

Some other important results deriving from 2019 GAR (UNDRR 2019) are the following:

- In terms of losses, severe inequalities between low- and high-income countries persist, with the lowest-income countries bearing the greatest relative costs of disasters. Human losses and asset losses relative to gross domestic product tend to be higher in the countries with the least capacity to prepare, finance and respond to disasters and climate change, such as in small islands developing States.
- The increasing complexity and interaction of human, economic and political systems within ecological systems has emerged the fact that risk has become increasingly systemic. Consequently, it is essential a fundamental re-examination and redesign of how to deal with risk.

- Climate emergency is evident. Vulnerability reduction measures—captured in national adaptation plans for action and Disaster Risk Reduction (DDR) plans—must be closely linked to the simultaneous systemic changes that must be engineered in energy, industrial, land, ecological and urban systems if we are to remain below 1.5 °C threshold of the planet's temperature.
- Risk reduction processes have multiple connections with climate change mitigation, adaptation and vulnerability reduction, and yet few DRR plans take these connections into account. Given the very threat to humanity posed by the effects of climate change, a more integrated approach is required to adapt to and reduce risk from climate change, as well as from shorter-term risks from natural and man-made hazards, and related biological, technological and environmental hazards and risks, when seeking to prevent the creation of new risk through development. Failure to include climate change scenarios in assessment and risk reduction planning will build inherent redundancy in all we do.
- While the onus rests with States, the responsibility to prevent and reduce risk is a shared with all stakeholders. Risk is ultimately the result of decisions that we all make, either individually or collectively. We must provide decision-friendly scenarios and options at relevant geospatial and temporal scales, providing data and information to support people to better understand the nature of their own risk and how to deal with it.
- Partnerships with other stakeholders and expert organizations—including from the private sector—must be built on a foundation of global public benefit to enable strong data-sharing networks and comprehensive reporting, including those addressing the data challenges of the 2030 Agenda.
- Many countries are unable to report adequately on progress in implementing the Sendai Framework and risk-related SDGs. Others lack the capacity to analyse and use data, even if they have the means to collect it. Development actors, the private sector, and the academic and research community may have the capacity, but the true dividends of interoperable, convergent data and analytics often remain elusive. This will not change without a sense of urgency translated into political leadership, sustained funding and commitment for risk-informed policies supported by accurate, timely, relevant, interoperable, accessible and context specific data.
- Above all, we cannot let inertia and short-sightedness impede action. We must act with urgency and with greater ambition, proportional to the scale of threat.
- Challenges to change outlines some issues, such as changing our mind-sets, political factors, and technological and resource challenges. To succeed it, the technical enablers of improved data science, risk assessment and risk modelling rely on the willingness of people to work with other disciplines, across cultural, language and political boundaries, and to create the right regulatory environment for new and urgent work to proceed.
- Capacity development is a long-term process that should be included in the implementation plans of DRR strategies, to effectively support the implementation of the strategy and realize the Sendai Framework.

The capacity development and changing the mind-set of all stakeholders is very challenging and most of the effort should be addressed not only to national level (adoption of SDG and Sendai frameworks in each country) but also to each one of the involving stakeholders.

The success of humanitarian relief, additionally is often determined by leadership exercising interpersonal skills (e.g., listening, awareness, problem solving, persuasion, participation), rather than strictly applying technical skills (e.g., delivery, installation, maintenance, programming) (Waugh and Streib 2006). These soft skills, as well as the appropriate leadership style for disaster relief should be examined thoroughly through literature review in the next section.

4.4 Crisis Management

Crisis management is defined as the sum of activities aimed at minimizing the impact of a crisis (Boin et al. 2013). The emergency management phases, according to the Environmental Systems Research Institute (ESRI) White Paper, can be grouped into five phases that are related by time and function to all types of emergencies and disasters (Johnson 2000). These phases also related to each other and each involves different types of skills:

1. *Planning/Prevention (Before).* Activities necessary to analyze and document the possibility of an emergency or disaster and the potential consequences or impacts on life, property, and the environment. This includes assessing the hazards, risks, mitigation, preparedness, response, and recovery needs.
2. *Mitigation (Before).* Activities that actually eliminate or reduce the probability of a disaster. It also includes long-term activities designed to reduce the effects of unavoidable disaster (for example by public education, improved infrastructure). Typical mitigation measures include establishing building codes, installing shutters, constructing barriers such as levees (City of St. Louis, n.d.). Mitigation measures include engineering techniques and hazard-resistant construction, as well as improved environmental and social policies and public awareness (UNDRR 2017).
3. *Preparedness (Before).* Activities necessary to the extent that mitigation measures have not, or cannot, prevent disasters. In the preparedness phase, governments, organizations, and individuals develop plans to save lives and minimize disaster damage (for example emergency response plans, evacuation routes, training and exercises, sirens)
4. *Response (During).* Activities following an emergency or disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected (UNDRR 2017) (for example evacuation and shelters, mass care, life safety, incident stabilization, property preservation).
5. *Recovery (After).* Decisions and actions taken to return a community to minimum operation levels and continuing to provide support until the community

returns to normal or better conditions Short-term recovery activities restores vital services and systems (temporary food, water and shelter to citizens), while long-term recovery restores all services back to normal (replacement of homes, water systems, streets, hospital, bridges, schools, economic recovery) (Johnson 2000; Petak 1985).

4.5 Natural Crisis Management and Leadership

The management of a crisis is one of the greatest challenges of the 21st century, as the frequency and intensity of events have been increased, producing thus even more human, economic and environmental losses (Wallemacq and Below 2018). A multi-disciplinary understanding and disaster risk management framework is required for improving resilience and mitigating the impact of natural disasters (Horita et al. 2013). Thus, the United Nation Member States adopted in 2015 the Sendai Framework for Disaster Risk Reduction 2015–2030. The progress of the Nations in the implementation of the Sendai Framework is considered by the United Nations as a key part for the success of the 2030 Agenda for Sustainable Development, as disaster risk reduction cuts across different aspects and sectors of development and it is critical for the poverty reduction (UNISDR-UN Office for Disaster Risk Reduction 2015a). At the macro-economic level, losses incurred from disasters—beyond the incurred destruction or loss of assets, capital and infrastructure—can have a negative toll on employment, economic activity and growth for many years after a disaster event (Overseas Development Institute et al. 2015). The Sendai framework clearly conveys the message that while States have the primary responsibility to prevent and reduce disaster risk, the responsibility is shared with all relevant stakeholders (local, regional and national authorities, science and technology institutions, civil volunteers, private sector and others) (UNISDR-UN Office for Disaster Risk Reduction 2015b).

4.5.1 Disaster Leadership Needs, Activities and Challenges

The importance of leadership in emergency management is widely acknowledged (Demiroz and Kapucu 2012; Kapucu and Van Wart 2008; Waugh and Streib 2006). Natural disasters usually are unexpected, and cause complex emergencies, such as loss of life, of health, of home and property, of important documents, of access to food and water and could be of so many other losses. Crises are transitional phases, during which the normal ways of operating no longer work and the perception of threat is accompanied by a high degree of uncertainty (Boin et al. 2005). They are stressful situations, which create political challenges and realities of public leadership in times of crisis. Citizens look at their leaders: presidents and mayors, elected politicians and administrators, public managers and top civil servants and they rely on them (leaders and policy makers) to avert the threat or at least minimize the upcoming damages (Boin et al. 2005). Leadership in managing disasters and emergencies can minimize the impact and may make the difference between life and death, whilst lack of successful leadership can increase the losses (Demiroz and Kapucu 2012). Furthermore, the aftermath search of explanations—how could this have happened?—often start a disclaimer and blame game.

The success of humanitarian relief, however, is often determined by leadership exercising interpersonal skills (e.g., listening, awareness, problem solving, persuasion, participation), rather than strictly applying technical skills (e.g., delivery, installation, maintenance, programming) (Waugh and Streib 2006). According to Boin et al. (2005), we need to build on the neglected dimensions of leadership such as communication and networking abilities, decision making, flexibility, urgency, teambuilding, and planning among others. Time compression is especially relevant for understanding leadership at the operational level, where decision on matters of life and death must sometimes be made within a few hours, minutes or even a split second (Boin et al. 2005). Another critical factor could be, especially in long lasting and high intensity events with a lot of injuries and deaths, the occupational hazard deriving from personal characteristics (experience and training history in emergencies, stress management, personal unresolved trauma or grief reactions from current or past losses). If this risk cannot be managed, can result in complete emotional and physical collapse of the humanitarian relief persons, limiting their ability to be effective and putting in danger their life, as well as others lives, and the successful mitigation of the natural disaster (United Nations, n.d.).

Leadership needs to be understood across all phases of emergency management (i.e. prevention, mitigation, preparedness, response, recovery) and it is vitally important to realise how leadership in such severe, complex and stressful situation really works and what variables affect leadership efficacy (Trainor and Velotti 2013). In the literature review, there are many theories concerning the leadership styles, but in the next subsections it will referred only these that seems useful to cope with emergencies.

4.5.2 Lewin's Leadership Styles

There many theories concerning the Leadership Styles. Lewin et al. (1939) has identified three leadership styles:

- *Authoritarian Leadership* also known as Autocratic leadership. Leaders provide clear directions and expectations about the desired outcome and the control over staff is obtained by commands and punishments. The communication is one-way and can create a non-productive and distressing climate.
- *Participative Leadership* also known as *Democratic Leadership*, is the most effective leadership style producing better quality results. The leaders offer guidance to

group members allowing them to decide in cooperation with other group members. This style helps them in the generation of better ideas and creative solutions from staff members.

- *Laissez-faire Leadership*, also known as *Delegative* leadership. Leaders provide the tools and resources needed and allow group members to make the decisions and solve problems on their own. This style is appropriate for expert, competent, motivated and well-educated staff.

4.5.3 Situational Leadership Model (Hersey and Blanchard)

According to the Situational Leadership Model of Hersey and Blanchard there is no best type of leadership; it depends upon the situation within which the attempt to influence takes place (Hersey et al. 2001). It is based on interplay among the amount of (Schermerhorn 2001):

- direction (task behaviour) a leader gives,
- two-way or multi way communication and supportive behaviour (relationship behaviour), such as socio-emotional support, facilitating behaviours, active listening, provision of feedback,
- 'Readiness' level that a follower (individual or group) exhibit on a specific task or activity It is not a personal characteristic or an evaluation of a person's trait values, ages and so on, but the ability (knowledge, skill, experience) and willingness (confidence, commitment, motivation) to accomplish a specific task (Hersey et al. 2001).

Situational Leadership identifies four leadership styles: S1-Telling, S2-Selling, S3-Participating, S4-Delegating. The follower determines the appropriate leader behaviour (Hersey et al. 2001) (Table 4.1).

Table 4.1 Leadership styles appropriate for various readiness levels (Hersey et al. 2001)

Readiness level	Appropriate style	Descriptors for high probability match
R1. Low readiness (unable and unwilling or insecure)	*S1. Telling* (high task-low relationship)	Telling, guiding, directing, establishing
R2. Low to moderate readiness (unable but willing or confident)	*S2. Selling* (high task-high relationship)	Selling, explaining, clarifying, persuading
R3. Moderate to high readiness (able but unwilling or insecure)	*S3. Participating* (high relationship-low task)	Participating, encouraging, collaborating, committing
R4. High readiness (able and willing or confident)	*S4. Delegating* (low relationship-low task)	Delegating, observing, monitoring, fulfilling

The four leadership styles were relabelled by Blanchard (Blanchard et al. 1993) in the revised model. Style1 became *Directing,* instead of Telling, Style 2 *Coaching* instead of Selling and Style 3 *Supporting* instead of Participating.

Hersey et al. (2001) also refer the Style S1-Directing/Telling as '*crisis leadership*' because it is appropriate in time of crisis. The authors pointed out that the term should be used to respond to crisis, not to create it. Effective leaders should have positive assumptions about person's potential. This is based on one of the most important concepts of the *self-fulfilling prophecy*, a concept in the field of applied behavioral sciences, in which behavior, influenced by expectations, causes those expectations to come true (Darley et al. 2000). The situational leadership approach requires a leader to develop the capability to diagnose the demands of the situations and then to choose and implement the appropriate leadership style (Schermerhorn et al. 1998).

4.5.4 Crucial Competence Framework About Emotional and Social Intelligence in Leadership (Daniel Goleman)

Another approach of leadership, that could be useful for emergency leaders—as emotions play significant role in high stress work environments (United Nations, n.d.), is given by Goleman and is based on Emotional Intelligence (EI). EI distinguishes the best leaders, professionals or scientists. The talented leaders are deriving when the heart and head meet emotions and thoughts (Goleman 2011). In an interview for Forbes (2011) Goleman summed up "*the ability to manage oneself, to be aware and to know how to regulate is the basis for learning how to manage others*". The art of leadership lies on keeping people in their highest performance levels, and this happens "*when people are in an optimal state, called 'Flow', in which the person is astonished by the results obtained*". One way to create this situation is by establishing clear rules and objectives, but to leave flexibility on how to achieve them. Another way is immediate feedback and the third is to test and grow skills and try to match what people can do with the tasks assigned to them (Goleman 2013).

According to 'Crucial Competence Framework about Emotional and Social Intelligence in Leadership' of Goleman and Boyatzis (Goleman 2011), a leader needs 4 domains and 12 competencies:

1. *Self-Awareness*: lets you know your strengths and limits and strengthen your inner ethical radar (1.1 Emotional Self-Awareness),
2. *Self-Management*: lets you lead yourself effectively (2.1 Emotional balance, 2.2 Achievement Orientation, 2.3 Adaptability, 2.4 Positive Outlook),
3. *Social Awareness*: lets you recognize and understand other people's emotions (3.1 Empathy, 3.2 Organizational Awareness) and
4. *Relationship Management:* lets you manage relationships (4.1 Influence, 4.2 Conflict Management, 4.3 Teamwork, 4.5 Inspirational Leadership)

After a thorough study to over 3500 executives, Goleman (2000) concluded that an effective leader should not rely on just one leadership style. He must practice himself to switch among different leadership styles to have the very best climate and business performance, transforming the art of leadership into a science. He outlined six distinct leadership styles, each one deriving from different components of emotional intelligence and provoking distinct effect on a company, division or group:

- *Coercive leaders*—demand immediate compliance. It works best in crisis or with problematic people. Negative climate.
- *Authoritative/Visionary leaders*—mobilize people toward a vision. It works best when a clear direction or change is needed. Most positive climate.
- *Affiliative leaders*—create emotional bonds and harmony. It works best to heal rifts in teams or motivate people with in stressful times. Positive climate.
- *Democratic leaders*—build consensus through participation. It works best to create consensus or get input. Positive climate.
- *Pacesetting leaders*—expect excellence and self-direction. Works best to get quick results from a highly competent team. Negative climate.
- *Coaching leaders* develop people for the future. Works best when helping people and building long-term strength. Positive climate.

4.5.5 Charismatic Leadership

The concept of *charisma* is not very clearly defined in the literature, as it can easily be apparent but difficult to specify how someone can obtain it (Bateman and Snell 2017). Charisma provides vision, inspires followers beyond the usual appreciation, respect, admiration, and sympathy, and creates blind trust. This is how leaders are able to motivate and push their followers to achieve tough targets and goals (Bass 1985; Schermerhorn et al. 1998). If it is used for good purposes and not as negative manipulation tool of a perverted leader that seek blind followers (dark-side charismatic leaders, like Adolph Hitler or David Koresh) (Howell and Avolio 1992), it can create charismatic leaders with exceptional confidence and positive behavior, who promote funs to action and operate as role models of ethical behavior to others (Brown and Trevino 2006). Some of the most prominent characteristics of charismatic leadership are: strong personality, visioning, extraordinary communication skills, sense of humility, compassion, self-monitored, confident in his own skill, to be true and substantial beneath the facade, positive body language, good listener and disposition for continuous development (Schermerhorn et al. 1998).

4.5.6 Authentic Leadership

Authentic according to the Oxford English Dictionary definition means simply 'Genuine' and *Authenticity* means being true to oneself character. The term *Authentic Leadership* was first used by Bill George in his book *Authentic Leadership* (2003). Bill argued that the key to become an authentic leader is to learn how to lead himself and to pay attention to his character development, inner leadership or self-mastery. He originally listed four elements of authentic leadership: (a) being true to oneself, (b) motivated by a larger purpose (not by his ego), and (c) prepared to take right decisions (not politically or ego-driven), and (d) concentrating on achieving long-term sustainable results (Bill et al. 2008). The term became popular and was overlapped with other philosophies, such as servant leadership, which expresses the intention of the leader to adopt an attitude of service towards colleagues and respect their free will. The second element of Bill's list also implies a sense of service.

4.5.7 Compassionate Leadership (Jeff Weiner)

In United Nations' tipsheet No. 5 (United Nations, n.d.) empathy is considering very important dimension of emotional intelligence, as an emergency leader in order to understand and respond effectively to the emotions of his followers must know what they are thinking and feeling. Jeff Weiner, LinkedIn CEO, is applying at LinkedIn his new leadership philosophy, which he calls *compassionate management*. According to this philosophy, compassion is set the company's core value (Fryer 2013). Weiner was influenced by the book of Lama and Cutler (1998) *The Art of Happiness*, which taught him about the distinction between empathy and compassion.

Compassion is defined as the emotional response when perceiving suffering and involves an authentic desire to help (Seppala 2013), that is, "*compassion is empathy plus action*" (Lama and Cutler 1998). Empathy is defined by the researchers as the emotional experience of another person's feelings, like tearing up at a friend's sadness (Seppala 2013), while compassion is the concept of *cura personalis*, that means in Latin the intent to contribute to the happiness and well-being of others (Hougaard et al. 2018b; Valdellon 2018). For example, when you meet an old lady you don't just greet her, but you help her to pass the road. Compassion differentiates also from altruism. Altruism is an action that benefits someone else and may not be accompanied by empathy or compassion (Seppala 2013).

Weiner articulates that compassion can help people better understand what they are trying to accomplish and obtain their goals in cooperation with other people. Lama has characterised also compassion and intimacy two of the strongest emotions a person can achieve (Lama and Cutler 1998). Compassion is more proactive, which means we can cultivate it with training (Weng et al. 2013) and make a habit of it (Hougaard et al. 2018b). Decades of clinical research indicates that compassion promotes altruistic behavior (Seppala 2013) and activates neural systems implicated in understanding the suffering of other people, executive and emotional control and rewarding processing (Weng et al. 2013). It can also improve personal well-being, including stress-related immune response (Pace et al. 2009), positive affect (Fredrickson et al. 2008; Hutcherson et al. 2008) and psychological and physical health (Fredrickson et al. 2008). Leadership practitioners have started to recognise compassion as a foundational aspect of leadership (Hougaard et al. 2018a), which it is not a soft skill but a crucial power skill (Valdellon 2018). Furthermore, a growing number of business conferences are focusing on this topic (Fryer 2013).

Campbell (2018) articulates seven traits of Compassionate Leadership. Leaders should: (1) learn from experience, mentoring and their faults, (2) remove barriers harming productivity of hindering reciprocal communication when closing deals, encouraging each team member to express new patterns of thinking, (3) leave behind selfishness and try to understand and help other team members to have deep and lasting positive impact on all who serve, (4) hold themselves and their ethics to high standards, (5) seek influence, not authority and they don't demand but encourage others to discovery their own unique power, (6) inspire passion in others who may not know how to achieve their goals and 7) bring their team members together to work as a functional unit.

4.5.8 Meta-leadership Framework (NLPI)

The *Meta-Leadership* is a framework and practice method, which derived from extensive field research on events including natural and man-made disasters. It has been developed by faculty of the National Preparedness Leadership Initiative (NPLI), a joint venture of the (a) Harvard T.H. Chan School of Public Health's Division of Policy Translation and Leadership Development and (b) the Harvard Kennedy School's Center for Public Leadership. It is designed to provide tools that will help to act and direct emergency leaders in public, private and non-profit sectors to cooperate and achieve the connectivity between all the stakeholders.

The Meta-Leaders should take a holistic view and should intentionally link and leverage the efforts of the whole community to act as a unity of purpose and effort. In order to achieve this they are equipped with method, processes and practice with main aim of: (1) understanding and integrating the many facets of leadership, (2) catalyzing collaborative activity and (3) reframing their focus on improving community functioning and performance. The dimensions of meta-leadership are tree (NPLI, n.d.):

- *The Person*: Development in high level of their self-awareness, self-regulation and self-knowledge, in order to build the capacity to confront fear and lead themselves and others out of the 'emotional basement' to higher levels of thinking and functioning.

- *The Situation*: Build the capacity to map the situation in order to determine what is happening, who are the stakeholders, what is likely to happen next, and what are the critical choice points and options for action.
- *Connectivity*: the decisions and operationalization of these decisions should communicated to all four directions: (a) *Down* the formal chain of commands to subordinates in order to create a cohesive, proactive team, (b) *Up* to those to whom the leader is responsible building confidence with formal supervisors, political officials, community leaders, and oversight agencies, (c) *Across* to peers and other units within the organization encouraging coordination and collaboration and (d) *Beyond* to outside entities including the general public and the media creating whole community unity of purpose and effort.

It is worth mentioning that in the heart of NPLI' s meta-leadership approach to crisis is *rapid response research*, which means that faculty is trying to reach field as soon as the crisis emerged to better understand the challenges, lessons affirmed and lessons learned. This activity is funded by organisations, which pay from $25,000 to $75,000 with a three-year tax-deductible commitment to NPLI Research Council, for supporting the training of their corporate leaders, having access to Meta-Leadership studies and keeping the resilience of the community partnership.

4.5.9 What Leadership Style Is Effective in Emergencies?

The United Nations (UN) recognizing the role of leadership in emergencies have created a toolkit "Leadership in Emergencies" with main intention to give guidelines to support operational managers and staff in times of extreme stress following disasters, kidnapping, civil conflict and other crises. In Tipsheet 'No. 5-Leadership in Crisis' United Nations suggest that leaders should identify which style works best for the situation and use a more flexible style, obviously influenced by Lewin's Leadership Styles (1939) combined with the Hersey and Blanchard's (Hersey et al. 2001) Situational Leadership Model:

> Emergency leaders should provide an autocratic style when there is little or no time to spare, a laissez-faire style with highly educated, competent and motivated staff, and a democratic style when possible (United Nations, n.d.).

In the aftermath of a crisis, strategic and operational leaders on the basis of different cognitive needs, make different assessments of the situation, thus generating what Boin and Renaud term 'appreciative gap' and they suggest that the two leaders must be aware of each other's cognitive needs and tasks (Trainor and Velotti 2013). Consequently, connectivity between all the stakeholders is very important. This gap could be overlapped more effectively using the third dimension *Connectivity* of the Meta-Leadership framework (information should directed through all directions).

The Meta-Leadership framework of the National Preparedness Leadership Initiative (NPLI), is the most comprehensive and integrated framework from all the mentioned above leadership theories/models concerning emergencies. Besides, it has emerged from practice and extensive field research on many disastrous events (NPLI, n.d.).

Emotional intelligence in humanitarian relief could help emergency leaders in managing their own emotions and the emotions of their staff (Goleman 2011). Recently, Zampetakis and Moustakis (2011) extending the emerging literature on the effects of managers' emotional skills on group outcomes, provided evidence that managers' emotional intelligence has a significant indirect effect on the group job satisfaction of their immediate team members. This regulation may leverage leaders to demonstrate positive emotions and control the negative ones, such as panic, disappointment or uncertainty, which the latter could limit their ability to be effective. This creates a supportive and positive organizational climate and contributes to the successful mitigation of the natural disasters (United Nations, n.d). The first dimension of the Meta-Leadership Framework, which is related to *Person*, is taking into consideration the emotional basement, by developing self-awareness, self-regulation and self-knowledge (NPLI, n.d). The compassionate leadership theory could reinforce more the *Person* dimension of the Metal-Leadership framework by including as well the *compassion*. The use of compassion is a crucial power skill (Valdellon 2018), which is more useful to natural disasters as it promotes the altruistic behaviour (Seppala 2013) and furthermore is '*empathy plus action*' (Lama and Cutler 1998). It can help people to improve their stress-related immune response (Pace et al. 2009) and the positive affect (Fredrickson et al. 2008; Hutcherson et al. 2008), enabling them to accomplish and obtain their goals in cooperation with other people. It could be also the right value for the provision of Authentic Leadership, as the leader leaves behind selfishness and seek influence not authority, keeping his ethics to high standards (Campbell 2018).

The authors of the present chapter propose that during an emergency, which is usually a stressful situation, the leader should alter his behaviour according the readiness level of the personnel or volunteers and regulate relatively his communication type and supportive behaviour (Schermerhorn 2001; Schermerhorn et al. 1998). The two major components of readiness level is the ability (knowledge, experience and skills) and the willingness (confidence, commitment, motivation) to perform a specific task (Blanchard et al. 1993; Hersey et al. 2001), but the demonstrating leadership styles it is suggested to be one of the following:

- *Directing style* for less competent (inexperienced or newbies) unwilling personnel to person a task (probably due to panic, traumatic stress or burnout). The leader mainly adapts an one-way communication, as he is guiding and providing specific instructions, and he closely supervises performance. The issue should be to (a) seek influence but not authority, (b) encourage others to discover their own unique power but not demand, (c) take right decisions but not politically or ego-driven (Bill et al. 2008).
- *Coaching style* for less competent (inexperienced or newbies) and willing personnel. The leader mainly decides, explains his decisions and provide opportunity for clarifications. There is dialogue and thus the communication is two-way. Although

personnel is still unable, they are still trying and the leader must be supportive in order people to develop mutual trust, motivation and commitment.

- *Affiliating and Visioning style* for personnel with abilities but unwilling (e.g. due to a conflict or burnout). The leader mainly is collaborating, encouraging, communicating, and sharing responsibility with the followers (Hersey et al. 2001). The issue should be to create emotional bonds, praise to gain confidence, heal rifts in teams, inspire and motivate people toward a specific target in these stressful times (Goleman 2000).
- *Laissez-faire style* for personnel with abilities and willingness. The leader is active listener, observes but remains accessible for providing support and resources to employees when asking, and he assigns tasks under the full responsibility of the subordinates. The issue should be the leader to (a) monitor without abandoning the group, (b) allow group members to make decisions and solve problems for developing their creative thinking, (c) encourage autonomy and freedom for risk taking, and (d) reinforce results (Lewin et al. 1939; Hersey et al. 2001).

Even though the situation would very crucial and irrelevant of the adopted type of leadership style, leaders should always (a) remain sincere and genuine, that is authentic (Bill 2003), (b) have confidence on their own skills and sense of humility, (c) develop in high level of their self-awareness, self-regulation, self-knowledge (NPLI, n.d.) and generally their emotional and social intelligence (Goleman 2011; Zampetakis and Moustakis 2011), (d) react with compassion to their colleagues, their subordinates, the volunteers and the civilians and (e) show disposition for continuous development (Schermerhorn et al. 1998).

An effective emergency leader should try to enforce ideally all of the leadership traits under normal conditions, so that he can draw them as needed depending on the specific demands of the situation (United Nations, n.d.). Only then, he could successfully engage all stakeholders to act as a unity during a natural disaster crisis.

4.6 Educating Future Leaders for Disaster Relief

Dugan (2006) argued that one of the most vital roles of higher education is to develop responsible citizens and the future emergency leaders, who will be ready to offer positive social change leadership to their communities and to society (Buschlen and Dvorak 2011). It is very important that schools and universities should not remain to simply "leadership development" following traditional learning methods (e.g. classroom lectures, internships) (Buschlen et al. 2015). Developing future leaders for business differs from crisis leaders. Crisis leaders must be effective, collaborative, transformational, ethical-minded (Komives et al. 2005), socially minded, civil-engaged (Jacob 2006), authentic (Bill 2003) and compassionate (Fryer 2013). Additionally, they should be equipped with communication skills, humanitarian logistics knowledge, data collection techniques and GIS knowledge that inform the research (Buschlen et al. 2015).

The educational programs should develop the idea that leadership is broad, complex, multifaceted and multidisciplinary in nature (Buschlen and Guthrie 2014) and occurs in a real-word operating with real people (Mumford and Manley 2003). Students should attain the crisis leadership knowledge through a more Service Learning experience that occurs inside and outside the classroom through curricular and co-curricular activities and become more effective members of society through leadership practice (Astin 1993). As Service Learning is defined formally 'a course-based educational experience in which students (a) participate in an organized service activity that meets identified community needs and (b) reflect on the service activity in such a way as to gain further understanding of course content, a broader appreciation of crisis leadership, and an enhanced sense of personal values and civic responsibility' (Bringle and Hatcher 1995). It is actually a pedagogical method for strengthening relationships between universities and communities (Thomson et al. 2010).

Students could gain more experiences, by participating as volunteers to the devastation of real events of natural disasters. The results from pilot projects, where students were intentionally engaged in emotionally charged contexts and varying degrees of extreme labor, showed that neither team was prepared mentally or emotionally for what they experienced. They were shocked and faced a 'disorienting dilemma', which forced them in action (Buschlen et al. 2015). These personal reflections could ultimately transform into permanent knowledge and skill (Mezirow 2000).

Curriculum should contain among others courses of humanitarian logistics. During a natural or man-made crisis there is need for planning, implementing and controlling the storage of the goods, shelters, medical supplies, services and information between the point of origin and the point of consumption to meet citizens' needs. It becomes more complicated as there are many organizations, sometimes from other countries, such as non-governmental organizations, community agencies and different service providers that support disaster relief and they are open to collaboration (Kovacs and Spens 2011; Perry 2007).

Teaching should focus in the interpersonal skill of leadership (e.g. problem solving, persuasion, communication skills, listening etc.), rather than strictly in the technical skills (e.g. delivery, installation, programming, etc.) (Waugh and Streib 2006). Ultimately, students should expand through curricular and co-curricular activities on the notion that as future leaders should make a difference in their communities (Komives et al. 1998).

4.7 Future Perspectives for Sustainable Development Is Based on Holistic Approach

The recent 2030 Agenda for Sustainable Development has adopted in 2015 a holistic approach, where quality education is at the heart of the Agenda. Education is considered as an accelerator of progress towards the achievement of all of the 17 Sustainable

Development Goals (SDGs), and therefore should be part of the strategies to achieve each of them (UNESCO 2016).

Recognizing the important role of education, the 2030 Agenda for Sustainable Development highlights education as a stand-alone goal (SDG 4) and includes targets on education under several other SDGs, notably those on health; growth and employment; sustainable consumption and production; and climate change. The renewed education agenda encapsulated in Goal 4 is comprehensive, holistic, ambitious, aspirational and universal, and inspired by a vision of education that transforms the lives of individuals, communities and societies, leaving no one behind. It is rights-based and inspired by a humanistic vision of education and development, based on the principles of human rights and dignity, social justice, peace, inclusion and protection, as well as cultural, linguistic and ethnic diversity and shared responsibility and accountability

Higher education specifically forms an important part of other goals related to poverty (SDG1); health and well-being (SDG3); gender equality (SDG5) governance; decent work and economic growth (SDG8); responsible consumption and production (SDG12); climate change (SDG13); and peace, justice and strong institutions (SDG16). The international organizations have realized that all the challenges of our era should be faced by a holistic approach and they have adopted subsequent frameworks based on the 2030 Vision of UNESCO (Sendai Framework for Disaster Risk Reduction 2015–2030, Global Inventory of regional and national qualifications frameworks 2017, Digital Competence Framework (DigComp), The Entrepreneurship Competence Framework (EntreComp)). Learning outcomes based on qualification frameworks can contribute to the promotion of inclusive and equitable education as well as lifelong learning opportunities for all (UNESCO 2017).

In June 2016, European Commission has adopted the *New Skills agenda for Europe* in order to (a) make skills more visible and comparable, (b) improve the understanding of trends and patterns in demands and (c) improve the quality and relevance of training and other ways of acquiring skills (European Commission 2016).

Labor market faced many challenges the last decade (Cedefop 2018):

- Many people are working in workplaces irrelevant of their talents and potentials. The existing mismatches are impressive, hindering the development.
- The internationalization and the radical development of digital technology have led to the demand of new skills and competencies, and mobility is encouraged.
- There is lack of entrepreneurial culture and relevant skills to establish their own company.
- The crucial situation emerged from natural disaster demands from humanitarian staff to obtain high-level knowledge (mainly interpersonal than technical skills).

Educational organizations should focus on *student success*. With the term *student success* is meant the attainments, progression and retention of students to their studies. Teaching quality, student satisfaction and the achievement of graduates should become core to institutional success (Cole 2018). It is not tied to one rigid view of success of all, but rather providing some guiding principles whereby they might construct a more meaningful sense of student success for themselves. Focus should not be given to produce just '*work ready'* alumni with generic competencies (generic and job specific skills and knowledge) relevant to today, but '*workers ready plus*' with capabilities for tomorrow—capabilities like the ability to manage the unexpected, remain calm and tolerate ambiguity.

The acquisition of legitimate skills is a lifelong process and is a product of both formal and informal learning, which should start from pre-school age. During the early childhood, character is formed, and self-confidence and responsibility are built. Early acquisition of these skills is the foundation for developing higher, more complex skills needed to promote creativity and innovation. These skills enable people to evolve into rapidly developing workplaces and society, and to cope with complexity, creative thinking and uncertainty. Besides, they will become the future scientists, experts, leaders, humanitarian relief staff and entrepreneurs.

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Chapter 5
Natural Disasters in Industrial Areas

Jelena Đokić, Nebojša Arsić and Gordana Milentijević

Abstract Simulations of the environmental accidents related to the chemical hazard were performed in order to estimate the contamination triggered or caused by natural disasters occurrence in the area heavily loaded with passive hazardous waste deposits. The mining and metallurgy waste deposits, when being exposed to the extreme weather conditions and droughts are scattered on the wider areas, and washed down by the floods, creating erosion ditches along the river banks, and penetrating into the deeper layers of soil. For this purpose the waste materials characterizations were performed by using modern instrumental techniques, considering the heterogeneous nature of the waste. The screening tools are used to estimate the level of air contamination in different climatic conditions, and the simulation of the movement of water and variable solutes to predict the soil contamination along the depth column related to the river flows. The modeling can't replace the regular monitoring, but can help determine the regularity, frequency and location of the probes for measurements, and raise the red flag with the authorities. Finally, Application of intelligent Multi-Criteria Analysis has been performed for the purpose of ranking the degree of negative impact on the environment of tailing ponds. Analysis is performed for five tailing ponds of MMCC (Mining Metallurgy Chemical Combine) "Trepča", whereby two of the ponds are active and three inactive. In order to achieve the most objective results, the AHP and PROMETHEE methods were applied.

Keywords Tailing waste · Pollution · Extreme weather · Floods

5.1 Introduction

Mining presents a significant element of economic development in every state. It is also known that the biggest environmental pollutant is the mining sector. Mining is followed by a mass production of waste in the form of tailing on tailing ponds. They are often formed in areas which have other potential (agriculture, water supply, urban areas, water flows, etc.). In general, all material left after the extraction of minerals

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or after the process of exploitation is waste, which when dumped on the deposit spot creates the tailing pond (Ristovic et al. 2010).

Vast areas are covered with mining tailings. For example, amounts of waste from mining in EU countries are around 400 Mt, and tailing waste is approximately 29% of total waste produced as reported by the Commission of the European Communities (2003). In the Environment and Security Initiative Project: Mining in South East Europe (Peck 2004), it was concluded that almost the full range of warning signals for environmentally damaging incidents of large scale consequence are present in the region. These include large (historical) milling and metallurgy plants with significant slag deposits, mountainous terrain; abandoned sites with little or no closure or control; lack of ongoing physical and/or biochemical monitoring of operational and/or abandoned sites; lack of ongoing maintenance, both proactive and reactive.

According to the Environmental Protection Agency (Environmental Protection Agency 2005), in the "Report of the State of the Environment in Republic of Serbia," it is estimated that there are around 700 million tons of flotation and separation tailings, between 1.4 and 1.7 billion tons of tailing wastes from opening pits and around 170 million tons of ashes from thermal power plants on deposit spots and landfills in Serbia. Metallurgy in the Republic of Serbia contributes 10% to the total gross domestic product for production of basic metals and metal products.

In mines with metallic mineral ores, concentration of heavy metals in tailing has increased. This is why the problem of environmental protection is severe in systems like Mining Metallurgy Chemical Combine (MMCC) "Trepča". The oldest tailing waste deposit in Trepca is Gornje polje, and being located inside a processing plant and in a close vicinity to the residential are, a lot of attention is put on its environmental impact. Different reports were made on the projects initiated by international organization, about the proposed activities for solving the environmental problems, and in those reports the tailing waste deposit Gornje polje was described to be some 50 ha large surface area with 12,000,000 ton of waste materials (Milentijevic et al. 2016). The published studies on this tailing (Borgna et al. 2009; Nanonni et al. 2011) analyze the environmental impact of the Trepca's tailings, by analyzing the top soil in the surrounding location. The Gornje Polje tailing waste deposit is a resource to manage and a threat to control. By its location on the river bank, and constant risk from flooding and low level of slope stability, it presents an environmental disaster risk. On the other hand, by its heavy metal content, and occurrences of the rare metals, it can be treated as source of valuable components. In order to determine the level of environmental risk, in the changing climatic conditions, some proper materials characterization was conducted, and imported into simulation of the Natech situation where the extreme weather conditions were simulated.

The purpose of this paper is to rank the flotation tailings of MMCC "Trepča" in terms of negative environmental impact. For these purposes, selection of relevant parameters was undertaken and calculations were made through the application of multi-criteria analysis (MCA). This method has recently been used in a variety of studies by numerous researchers deliberating different problems. In the field of mining, such researchers include Bogdanović et al. (2012) and Ataei et al. (2008) and in the area of environmental protection, Kiker et al. (2005) among others.

In this paper, analysis includes five non-remediated flotation tailings. On all five tailings, MMCC "Trepča" disposed their waste. Two flotation tailings are active (waste is still being disposed there) and three are passive, meaning there is no longer any dumping of waste.

5.2 Methods and Materials

5.2.1 Study Area

The study area is situated on the large highland Kosovo, to the north of the Autonomous Region Kosovo and Metohija (Fig. 5.1). Administratively, it belongs to the municipalities of Zvečan and Kosovska Mitrovica. The study area has the typical continental climate with long and hot summers and cold winters (Milentijevic et al. 2016).

In the last century, Mining Metallurgy Chemical Combine "Trepča" has produced around 120,000 ton of raw lead, 100,000 ton refined lead, 100 ton of silver, 80,000 ton electrolyte zinc, 140,000 ton artificial fertilizer, 50,000 ton super phosphate, and 30,000 ton lead acid batteries, while daily production in mines was up to 10,000 ton of mined ores (Milentijevic et al. 2013).

By mining in Kopaonik's metallogenic zone and flotation processing of metallic minerals, MMCC "Trepča" established tailing ponds: Žarkov Potok, Gornje Polje, Žitkovac, Tvrđanski Do and Bostanište. All five tailings are in an administrative unit of the Kosovska Mitrovica area and in the municipalities of Zvečan and Mitrovica. The tailings are polymetallic and their mineral compositions are mostly heavy metals,

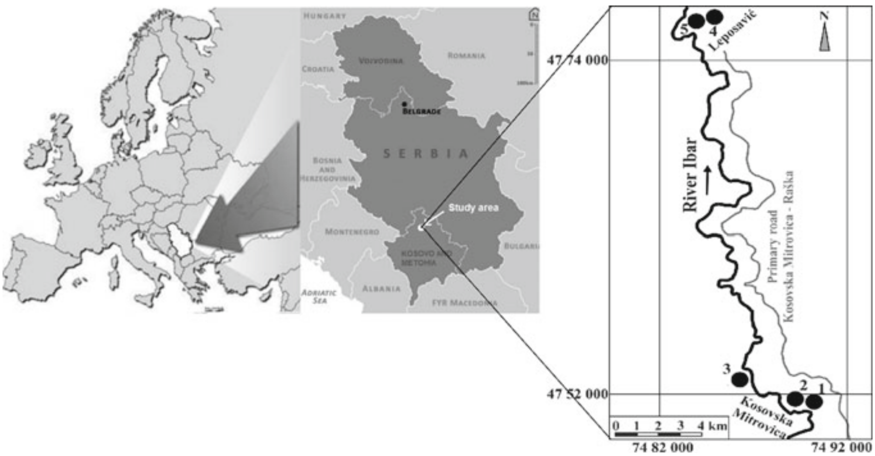


Fig. 5.1 Schematic review of the study area. ●—Tailing ponds: 1—Žarkov Potok; 2—Gornje Polje; 3—Žitkovac; 4—Bostanište; 5—Tvrđanski Do

as they were extracted from ore. In the process of creation and expansion of these five tailing ponds, material was transported hydraulically and deposed physically by hydrocyclone.

The landscape where the tailings are situated is the Ibar River's alluvial plain (Nikic 2003). Since the tailing deposits have not been rehabilitated, the material from the deposits have scattered over the years in the environment through the aeolian process, gravity and water flows. Tailing material from the analyzed deposits shows permanent toxic pollution of water and agricultural land. All atmospheric water and waters from tailing ponds are released into the Ibar River through drainage systems in the tailings. The water bodies from the area as well as those from remote areas are highly endangered by the leaching contamination from the tailings. On the northern part of the landfill, tailings from the lead smelter have been disposed for a long time, so the landfill has taken on the form of a cone. Deep cuts have been created as a result of erosion on both sides of the dam, through which comes discharge of atmospheric waters from the landfill directly into the Ibar. Deposed flotation tailing is in general oxidized and solid (Milentijevic et al. 2016).

5.2.2 Chemical Analysis

The chemical composition of the tailing waste is determined by using x-Ray fluorescence (ARL86480). For the chemical analysis of the samples also the following techniques are used: Ca and Mg concentrations are analyzed by using Volumetry-EDTA, Si is analyzed by Gravimetry, HCL digestion, Al, Na, K, Pb, Zn, Cd, Cu, Sb by AAS, equipment AAnalysist 300, Perkin-Elmer. Volumetry method by oxi-reduction is used for Fe analysis. The river Ibar water analysis is done by application of AAS (Atomic Absorption Spectrometry) instrument. The samples were taken from two sites: Dudin Krs and Rudare, i.e. before and after the tailing waste deposit Gornje polje, Fig. 5.1. In all the samples heavy metals concentrations are determined.

5.2.3 Microscopy and Mineralogy

SEM investigation was carried out on Scanning Electron Microscopy instrument from JEOL (JSM6460), with Energy Dispersive Spectrometer, EDS by Oxford Instruments. XRD (X-Ray Diffractometry) analysis was used for mineralogical investigation. Samples were investigated using diffractometer Philips PW 1710 under following conditions: radiation from copper anticathode with $CuK\alpha = 1.54178$ Å and graphite monochromator, working voltage $U = 40$ kV, current strength $I = 30$ mA. Samples were investigated in the range of 5–70° 2θ (with step of 0.02° and time 0.5 s).

5.2.4 Dusting Experiment

A fan type ABVE-3,5 apparatus was employed for measuring dust loading (mg/m^2) in the laboratory, using a flow of 3600 m^3/h and a vacuum of 200 Pa for airflow simulation, with a gravimetric sampler of the respiratory dust. The sample was set in a shallow metal plate, along with the measuring scale for the residual solid particles on the filter paper and a digital anemometer (DA-4000). The measurements were performed with the material set in the airflow direction from the fan and before the apparatus for polluted air vacuuming. The wind velocity was changed by the distance between the fan and the metal plate for each sample. The measurements were performed in wind velocities of 5, 7 and 10 m/s. The humidity in the laboratory was within the interval of 37–53% and the dust concentration was 0%.

5.2.5 Modeling and Simulation

Simulation was performed by using Gaussian Plume Air Dispersion Model AERMOD. AERMOD was using the calculations for the complex terrain data, taken from the In this case the plume is modeled and impacting and following the terrain. AERMET first use the terrain characteristics as albedo, surface roughness and Bowen ratio, and meteorology data (wind speed, wind direction, temperature, and cloud cover. AERMET calculates the PBL parameters: friction velocity (u*), Monin-Obukhov length (L), convective velocity scale (w*), temperature scale (*), mixing height (z i), and surface heat flux (H). These parameters are used to calculate vertical profiles of wind speed (u), lateral and vertical turbulent fluctuations (v, w), temperature gradient (d/dz), potential temperature ( ), and the horizontal Lagrangian time scale (TLy).

5.2.6 Multi Criteria Analysis

The waste tailings from processing of flotation of metallic mineral ores are by-products of MMCC "Trepča" mining activities. The method for ranking the effect of tailings on the surrounding ecosystem had to fulfil the following criteria: it should be in compliance with the concept of sustainable development; it should be in compliance with different cultural, social and organizational frameworks; it should be applicable to large and small companies and for large and small-scale environmental pollutants. It was thus decided that the ranking of five current tailing ponds should be done by multi-criteria analysis.

Field work and analysis of flotation tailings and surroundings was undertaken as part of the preparation. Data collection and analysis of documentation and published papers addressing the problem were done. The mapping of five tailings with waste from the flotation process is done through terrain research for: Žarkov Potok, Gornje Polje, Žitkovac, Tvrđanski Do and Bostanište. All five tailings are in an environment with agricultural, urban, recreational, cultural and other potential. All are in close proximity to water streams or on the banks of the Ibar. It should be noted that, besides problematic ownership, lack of data about the current conditions of the landfill, characteristics of the deposed material and environmental impact assessment analyses is also a concern

Important environmental aspects (air, water, soil), character of deposed material (chemical, quantities and other), elements with special value in their environments (natural rarities, archaeological and religious sites, etc.), technical and sociological aspects as well as many others are included in the assessment of the tailing ponds' impact on the surrounding ecosystem.

The analysis started with criteria selection for the purpose of the ranking of the tailings for their ability to endanger the environment in the case of extreme weather and flooding (Milentijevic et al. 2016). The criteria selection for assessment is an important and very complex step, determining the final results of the MCA. The set criteria estimation result essentially depends on their weight factors. For coupling the weight factor to the selected criterion, it the mixed approach was applied, using subjective and objective methods in order to achieve final integrated weight factors. The analyzed criteria for all five flotation tailings are shown in Table 5.1.

In order to ascertain the impact ranking of tailing on the local environment, AHP (Analytic Hierarchy Process) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) are used. The consideration and description of these two methods from a mathematical aspect is presented briefly considering that these methods are explained in detail in numerous papers.

In the analysis conducted in this study for the PROMETHEE method, the commercial software Visual PROMETHEE 1.4 Academic Edition was used. The PROMETHEE method does not provide us the opportunity to analyze decision making on simpler parts compared to AHP. In cases of a bigger number of criteria, this method makes it harder to come to a conclusion for the analyzed problem.

Table 5.1 Presentation of criteria of analyzed flotation ponds

Criteria	Analyzed criteria
C1	Proximity of water source
C2	Proximity of the settlement
C3	Proximity of agricultural area
C4	Proximity of permanent water flow
C5	Quantity of material deposed
C6	Existence of the flooding water sources
C7	Activity of the tailings
C8	Geological environment
C9	General slope of the terrain
C10	Tailing maintenance

For a more complete graphic presentation of the results obtained by the PROMETHEE method, the GAIA plan (Geometrical Analysis for Interactive Assistance) was used from the software Visual PROMETHEE 1.4 Academic Edition. The basic purpose of this application is better visual presentation of the multi-criteria analysis. In the frame of the GAIA plan, some information can be lost after the projection. Based on the main components, the presentation is defined by two vectors, responding to the basic flow of one criterion. Although GAIA includes some percentage of total information, it does not provide strong graphic support.

5.3 Results and Discussion

The material characterization has shown that the waste is small grained, toxic mineral mixture. All five tailings were widely investigated by the authors. Zitkovac was widely investigated by its environmental impact (Frese et al. 2004), Zarkov potok was investigated for its drainage waters (Barac et al. 2016) and Bostaniste and Tvrdjanski Do were investigated for the estimation of the pollution range in the different climatic conditions (Djokic et al. 2012a). Gornje Polje tailing is on the river bank, with the large deposit of lead metallurgy slag in the form of cone on the top of it, with the piles of secondary lead production slag and waste (Djokic et al. 2012b). As a perfect example of the complex nature of this waste, in this chapter there will be only presented the results of the chemical, granulometric, mineralogical and morphological testing of the tailing waste material from the location Gornje Polje.

5.3.1 Chemical Composition and Granulometric Composition

Chemical composition of the tailing waste is presented in Tables 5.2 and 5.3 representing large difference in chemical compositions in the same tailing.

5.3.2 Scanning Electron Microscopy

SEM scans of the tailing waste deposit samples (Fig. 5.2) are presented and there are clearly visible the non-homogenous nature of this deposit. This heterogeneous structure of the one tailing waste deposit, which also represents the situation in all five observed tailing waste deposits is presented below.

From the samples taken from the different stages of mineral processing in Trepca, it can be concluded that there are different metals concentrations in the waste according to the technologies applied. As shown in Fig. 5.2a the sample taken from the site where the waste is deposited in the first half of the last century contains larger amount of lead, even 6.51% as the mineral processing technology was unefficient. The bright

Table 5.2 Chemical composition of waste deposit Gornje polje sample Dudin Krs

Element	O	Al	Si	S	Ca	Fe	Zn	As	Ag	Cd	Sb	Hg	Pb	Total
mass%	47.31	0.69	2.27	11.62	4.34	25.73	0.21	0.97	0.00	0.00	0.36	0.00	6.51	100.00

Table 5.3 Chemical composition of waste deposit Gornje polje sample Rudare

Element	O	Al	Si	S	Ca	Fe	Zn	As	Ag	Cd	Sb	Hg	Pb	Total
mass%	47.78	0.29	1.00	15.79	2.51	31.24	0.00	0.00	0.00	0.00	0.42	0.00	0.97	100.00

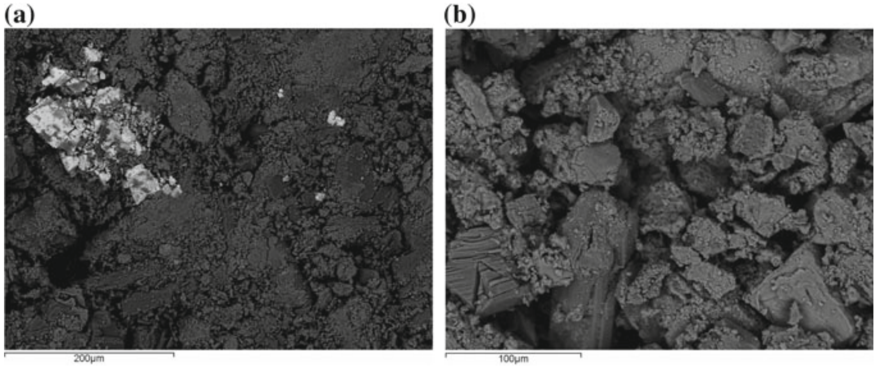
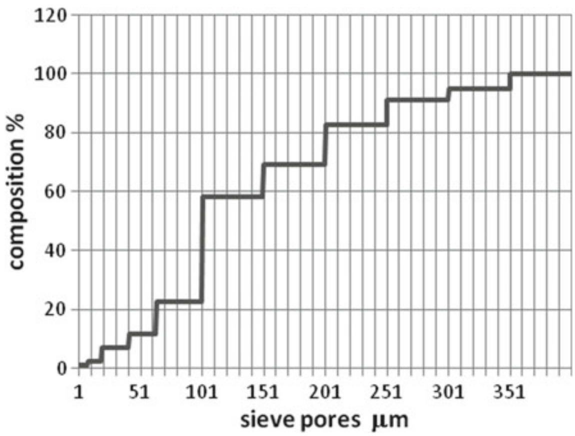


Fig. 5.2 SEM-EDS images of tailing waste deposit Gornje Polje in two locations: **a** Dudin krs and **b** Rudare

pattern on the SEM image represents lead particles. The second sample is taken from the site where the waste is deposited from 1950–1983. and the metals recovery was increased due to the modern technology applied, so the lead concentration didn't exceed 1%, as shown in Fig. 5.2b.

As the mineral processing is the process of metal's concentration, the ore is crushed, than milled to the average grain size of 0.1 mm in diameter, so the mineral grains are opened to be exposed to the flotation agents. After the years of storage on the open air, some of the particles are aggregated, and others are even smaller, being exposed to the wind and rain, Fig. 5.3. The most of the particles are larger than 10 μm in diameter, so the MAC for Total Solid Particles will be applied (Djokic et al. 2012b).

Fig. 5.3 Granulometric composition of the tailing waste deposit



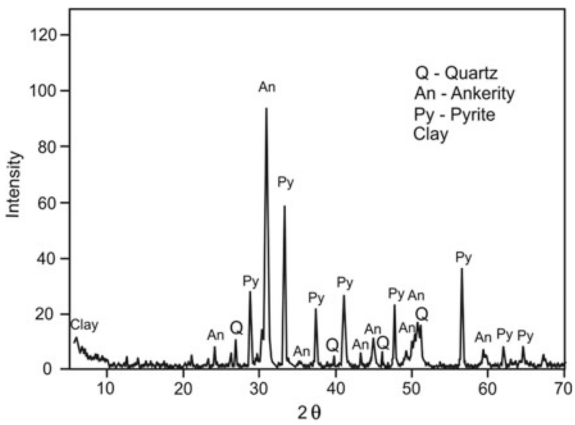


Fig. 5.4 X-ray diffractometry of the tailing waste deposit

5.3.3 X-ray Powder Diffraction

The composite sample of tailing waste is composed by several crystallized phases, as shown in Fig. 5.4. There are minerals of quartz, ankerite, pyrite, and there is some presence of clay minerals. As the concentrations of other metals compounds are small, they could not be detected by XRD analysis.

As the X-ray diffractomery analysis showed the presence of Ca, Mg, Mn, Fe in a form of carbonates as, there are several peaks of Ankerite plotted, it can be concluded that Ca, Mg, Mn, and some amount of Fe, listed in Tables 5.2 and 5.3 are actually carbonates, as the Carbon can not be detected by SEM-EDS. Also, the presence of quartz and clay minerals explains the amounts of Al_2O_3 and SiO_2 in the tailing waste deposit.

5.3.4 Water Quality

River Ibar quality was tested for heavy metals content in two different locations-before and after the tailing waste deposit Gornje Polje. In order to assess the quality according the EU Water Framework Directive, the Calcium content was determined.

For the concentrations of heavy metals EQS values depend on the hardness of water, which is expressed through the concentration of calcium and is divided into five categories according to the Annex III of the same Directive: (Class 1: <40 mg $CaCO_3$/l, class: 40 to <50 mg CaCO3/l, Class 3: 50 to <100 mg $CaCO_3$/l, Class 4: 100 to <200 mg $CaCO_3$/l and Class 5: ≥200 mg $CaCO_3$/l).

According to this division, based on data analysis, presented in a graphic in Fig. 5.5, the water of the river Ibar in the municipality of Zvecan, except in exceptional cases, one of the leading class III, and applied the standards of quality of surface water class III. Class III surface water can be used for irrigation, recreation,

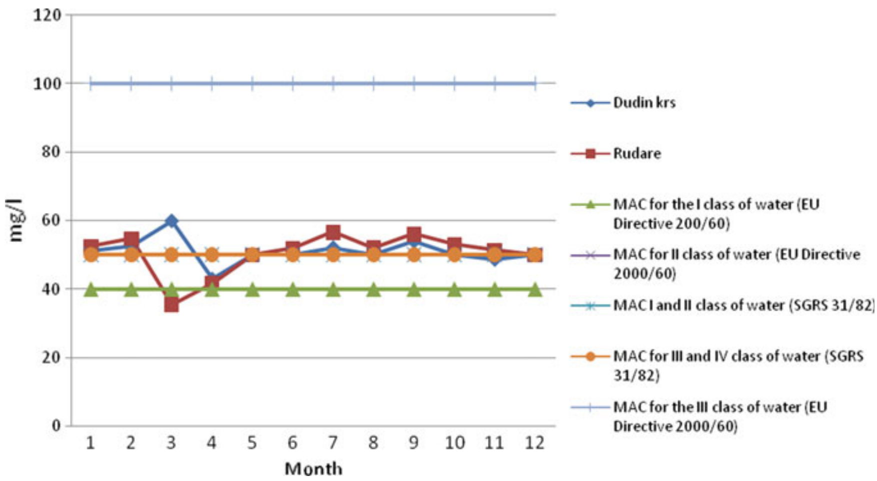


Fig. 5.5 Calcium concentrations in the river Ibar samples

industrial use, in energy production, mineral extraction and as a transport medium. Figure 5.6 shows the values obtained for lead concentration. Having considered the results from the river Ibar testing (Milentijevic 2013) it can be concluded that the values of the analyzed heavy metals in most cases exceed the values prescribed by the EU Directive 2000/60, on the basis of the UNECE, 1996 Guidelines on Water-Quality Monitoring and Assessment of Transboundary Rivers, while the values for Pb are constantly above the MAC, throughout year. The lead concentration peak was measured after the river passes the tailing waste deposit location (red line), and it is significantly higher than the value measured on the location before the tailing (blue).

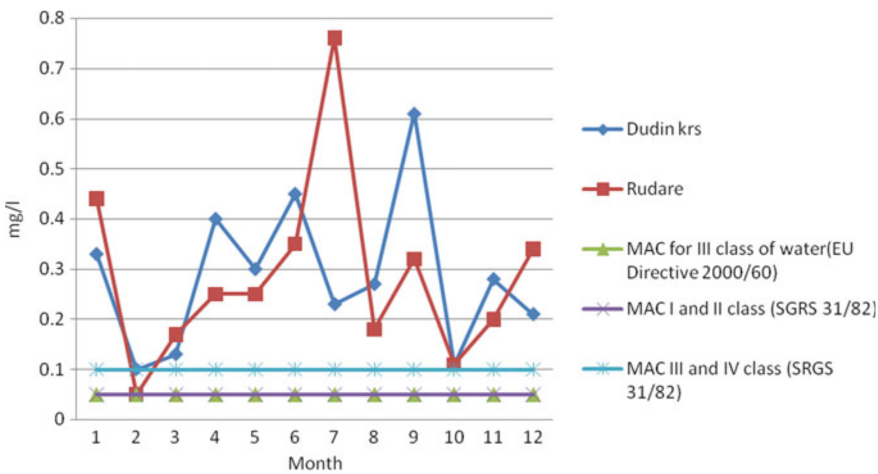


Fig. 5.6 Lead concentrations in the river Ibar samples (Color figure online)

That corresponds with the data obtained for the alluvium lead concentrations along the Ibar river before and after the floods 2014 (Barac et al. 2016)

Environmental Quality Standards (EQS) are given in Annex II of EU Directive 2000/60 are expressed as the total concentration in the whole sample of water. For the concentration of heavy metals EQS refers to the concentration of dissolved substances, i.e. the liquid phase of water samples obtained filtration.

The obtained values of heavy metals in the water of the river Ibar are quite negative, because almost all of the analyzed heavy metals: Cu, Fe, Pb and Zn exceed the EQS.

The situation on the terrain requires the statement that the flotation tailing waste deposit is the primary source of water pollution of the river Ibar in the municipality of Zvecan. First, the uncontrolled disposal of waste or incidental situations, both physically and chemically, directly affects the life and development of flora and fauna directly in the river and river bed, and on the river bank. There are also possible damages that may arise from large inundated by a wave of Ibar, and unprofessional work on flotation tailing waste deposition. Hazards that may be caused by the breakdown was complete destruction of flora and fauna in the bed of the river Ibar, endangering buildings and towns downstream from the barren land and permanent contamination of wells and heavy metals in the flooded area. As a measure of protection of the water of the river Ibar is proposed to technical and biological rehabilitation and remedy of the flotation tailing waste deposit.

For the purpose of the heavy metals particles plume simulation there was a need for the different meteorological data processing methods (Swhli et al. 2018). As the measurements were performed at a relatively small distance and under the actual climate conditions for the defined period, it was necessary to define the approximate dusting under different climatic conditions. By analyzing the data for wind speeds, directions and frequencies, it can be concluded that the winds have changed their frequencies over the last 20 years (Djokic et al. 2012b). In 1999, the weather was mostly stable, and just 7.0% of the winds had a speed of more than 3.6 m/s. Southern winds were the strongest and northeastern winds were the most frequent, i.e., 20% of the winds came from this direction. Just 1% of the winds were stronger than 8.8 m/s. In 2010, 21.1% was in the wind class 3.6–5.7 m/s, and 2.8% of the winds had a wind speed of more than 5.7 m/s. Southern winds were the most frequent, but southwestern winds also increased in frequency and speed. This is usually the case in the summer, when strong hot winds blow from the Mediterranean area, with hot and dry weather. For the purpose of simulation in assumed larger wind classes and frequencies the wind data from the Fig. 5.7 are used.

In extreme weather conditions, the wind speed larger than 10 m/s is expected, and there are no data on pollution in these climatic conditions. The potentially unstable weather was taken into consideration for modelling and simulation. The distance of 5000 m from the source of pollution was set for discrete distance calculations.

Simulation was performed by using Gaussian Plume Air Dispersion Model AERMOD. AERMOD was using the calculations for the complex terrain data, taken from the In this case the plume is modeled and impacting and following the terrain.

AERMET first use the terrain characteristics as albedo, surface roughness and Bowen ratio, and meteorology data (wind speed, wind direction, temperature, and

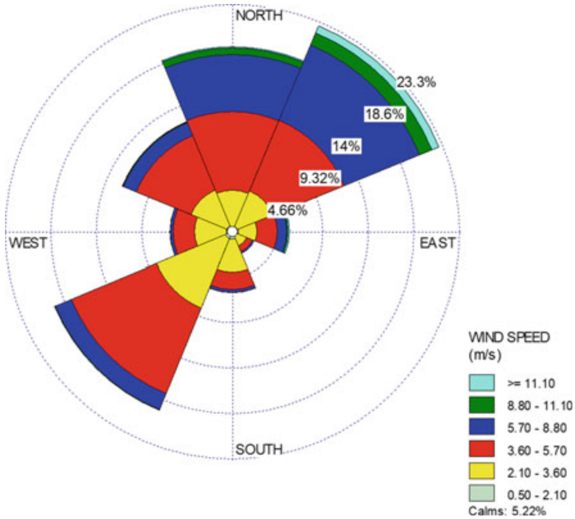


Fig. 5.7 Wind rose used for simulation

clouds). AERMET calculates the PBL parameters: friction velocity (u*), Monin-Obukhov length (L), convective velocity scale (w*), temperature scale (*), mixing height (z i), and surface heat flux (H). These parameters are used to calculate vertical profiles of wind speed (u), lateral and vertical turbulent fluctuations (v, w), temperature gradient (d/dz), potential temperature ( ), and the horizontal Lagrangian time scale (TLy).

After the calculation the air dispersion model is presented in Fig. 5.8. Red line shows the impact zone, and the pollution data are more than 20 times higher than allowed concentrations.

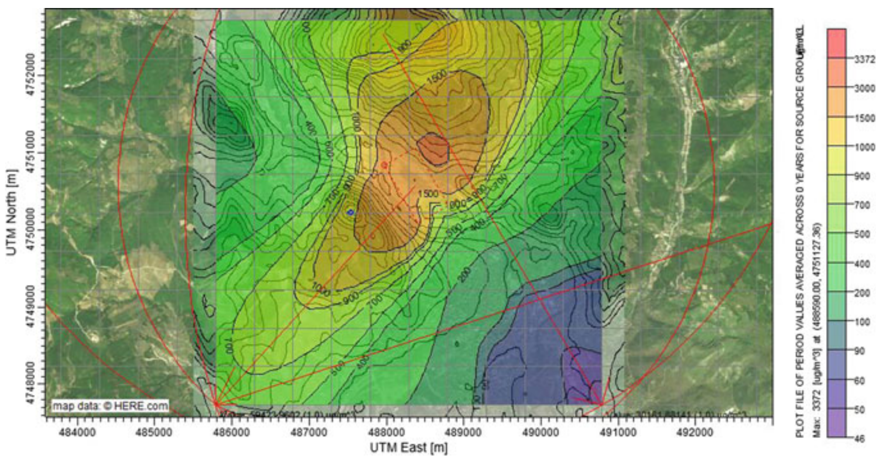


Fig. 5.8 Calculated PM10 concentrations in wind speed 11.1 m/s (Color figure online)

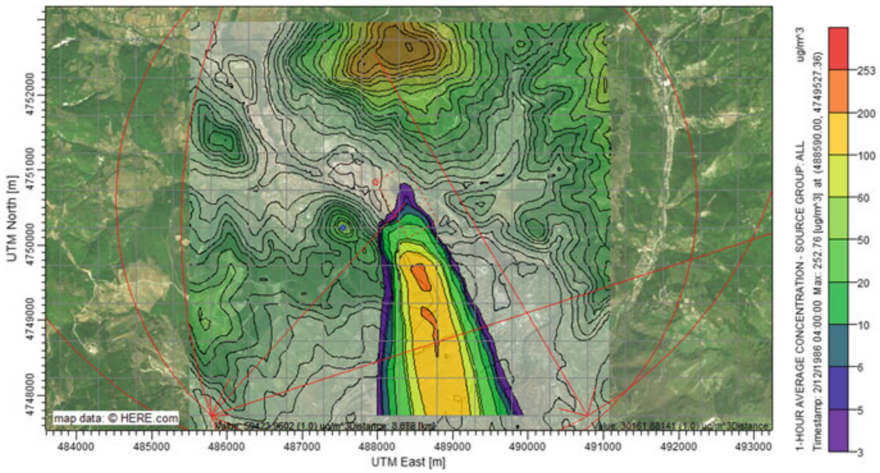


Fig. 5.9 Simulation with daily average data

In order to observe separate situations and the difference in dispersion in stable and extreme weather, the simulation with daily average data was presented in Fig. 5.9.

Comparing the impact of certain criteria to the environment was based on relevant data obtained in the field. The characteristics of the analyzed flotation tailing waste deposits are shown in Table 5.4. In Table 5.4, analyzed criteria which were used as input data for matrix formatting and quantification for coupled comparison of criteria according to the Saaty scale are presented (Table 5.5). Those data are than included into the calculations by AHP and PROMETHEE methods, by common steps in calculation process.

Based on results of the calculation done by AHP and PROMETHEE methods, final alternative rank was given-tailing ponds according to their negative impact to the environment.

Matrix with double comparison is formed by AHP method based on previously set criteria (Table 5.5). Weight coefficients for each criterion are calculated by mutual comparison and based on Saaty's scale (Table 5.1). Criteria are being added values by direct and inverted procedure in span from 1 to 9.

By valuing each criterion, coefficient weight of criteria was gained and are shown in Table 5.6. For the purpose of control of gained results, calculations of the *CR* are done. Results obtained confirmed that decision is consistent because its value is less than 0.1, or its value is 0.082062 (Table 5.6).

For individual criteria, weight coefficient values, consistency index (*CI*) and consistency rate (*CR)* for all five tailings were obtained by the APH method (Table 5.7). For criterion C1, the distance of water supply sources, the tailing A3 Žitkovac 0.4740 has the greatest value of weight coefficient, and A4 Tvrđanski Do 0.0715 has the minimum value. For criterion C2, vicinity of settlement, A5 Tvrđanski Do 0.4041 has the greatest value of weight coefficient, and A1 Žarkov Potok 0.05546 has the

Table 5.4 The characteristics of the analyzed flotation tailing waste

Tailing Ponds / Criteria	Žarkov Potok-A1	Gornje Polje-A2	Žitkovac-A3	Tvrđanski Do-A4	Bostanište-A5
Vicinity of the water source—C1	No	50 m—wells	50 m—wells	12 km—wells	12 km—wells
Vicinity of the settlement—C2	About 500 m	About 200 m	About 100 m	About 50 m	About 50 m
Vicinity of agricultural area—C3	About 500 m	About 200 m	About 50 m	About 50 m	About 50 m
Vicinity of permanent water flow—C4	About 100 m, Ibar	About 50 m. Ibar	About 50 m, Ibar	About 50 m, Ibar	About 70 m, Ibar
Quantity of deposited material—C5	9,961,113 t	26,344,212 t	7,594,932 t	1,442,812 t	5,641,612 t
Occurrence of the flooding water sources—C6	No	Yes	No	No	No
Activity of the tailings—C7	Active	Not active	Not active	Not active	Active
Geological environment—C8	Alluvial	Alluvial	Alluvial	Alluvial	Alluvial
	4 m	4 m	4 m	4 m	4 m
General slope of the terrain—C9 (%)	8	0	0	7	8
Tailing maintenance—C10	No maintenance	No maintenance	No maintenance	No maintenance	No maintenance

minimum value. For criterion C3—the vicinity of agricultural environments—tailing A4 Tvrđanski Do 0.30954 has the greatest value of weight coefficient, and A1 Žarkov Potok 0.0373 has the minimum value. For criterion C4—the vicinity of waterstream—the tailing A4 Tvrđanski Do 0.3107 has the greatest value of weight coefficient and A1 Žarkov Potok 0.0837 has the minimum value. For criterion C5—the amount of deposited material—A2 Gornje Polje 0.4851 has the greatest value of weight coefficient, and A4 Tvrđanski Do 0.0420 has the minimum value. For criterion C6—the existence of torrential watercourses, the greatest value of weight coefficient has the tailing A2 Gornje Polje 0.4285, while the remaining tailings have the same value, 0.1428. For criterion C7, tailing activity, A1 Žarkov Potok and A5 Bostanište 0.3636 both have the greatest value of weight coefficient and the value of the remaining three tailings is 0.0909. For criterion C8, geology, all tailings have identical weight coefficient which is 0.2. For criterion C9, general slope of a region, A4 Tvrđanski Do and A5 Bostanište 0.2889 have the greatest value of weight coefficient, and the A2 Gornje Polje 0.0723 has the minimum value. For criterion C10—maintenance of tailings—all five tailings have identical value which is 0.2.

Table 5.5 Double comparison matrix of the criteria according to the Saaty scale

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	1	2	2	5	4	7	5	6	8
C2	1	1	2	2	4	4	5	6	7	8
C3	1/2	1/2	1	2	5	5	5	6	7	8
C4	1/2	1/2	1/2	1	2	2	5	4	6	7
C5	1/5	1/4	1/5	1/2	1	1	5	4	7	6
C6	1/4	1/4	1/5	1/2	1	1	5	4	5	6
C7	1/7	1/5	1/5	1/5	1/5	1/5	1	3	3	4
C8	1/5	1/6	1/6	1/4	1/4	1/4	1/3	1	3	5
C9	1/6	1/7	1/7	1/6	1/7	1/5	1/3	1/3	1	2
C10	1/8	1/8	1/8	1/7	1/6	1/4	1/4	1/5	1/2	1

Table 5.6 Weight coefficient criteria and their level of consistency

Criteria	Coefficient	*CR*
C1	0.214389322	0.082062
C2	0.2083418	
C3	0.179621064	
C4	0.117821399	
C5	0.083593285	
C6	0.080421814	
C7	0.041623037	
C8	0.036710749	
C9	0.02131439	
C10	0.016163141	

According to the conducted estimation with the application of the AHP method, the criterion C1, distance from the source of water supply, 0.2143, has the greatest value of weight coefficient and the criterion C10—maintenance of tailings, 0.0162—has the minimum value.

Alternatives have been evaluated and a quantified matrix of decision making has been formed (Table 5.8) by application of the PROMETHEE method for evaluation of environmental influence of tailing ponds. In this process, certain criteria have a quantitative structure, while others are qualitative. Consequently, certain criteria (C1, C2, C3, C4, C5, C8, C9) are stated quantitatively, while others are stated qualitatively. The application of qualitative and quantitative scales provides confidence that all criteria are well arranged in the best manner possible.

After quantified matrix of decision making was provided, analyzed alternatives (tailing ponds) were evaluated using Visual PROMETHEE software. This resulted with a rank order of alternatives. Multi-criteria ranking method PROMETHEE introduces qualities of positive, negative and net flow. The results obtained from positive, negative and net flow are presented in Table 5.9.

Numerous activities of the local population are taking place in relatively close proximity to these tailing ponds, despite the very precarious situation. Often, the local population has created facilities and taken part in activities, which are not safe so close to tailing ponds. For example, at about 50 m from some landfills there are wells used for irrigation and water supply, while some fields and streams are also only 50 m away from some landfills. Generally, all of the five treated tailings were formed in places that can have harmful effects on the surrounding ecosystem. The situation described here was meant to conduct an analysis and ranking of the tailings by the degree of potential danger to the living environment.

The ranking of the analyzed alternatives is given in Figs. 5.10, 5.11 and 5.12. using the PROMETHEE method.

In Fig. 5.10, the final ranking of analyzed tailing ponds is given. This figure is based on net flow Phi. The upper half of the given scale (colored in green) represents positive Phi value, and the lower half (red) represents negative Phi value. Alternative

Table 5.7 Display of maximum values of comparison matrix (λmax), consistency index (*CI*), random index (*RI*) and consistency rate (*CR*) for analyzed tailing ponds

C	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
P										
λ_{max}	5.08	5.46	5.12	5.46	5.34	5	5	5	5.04	5
CI	0.02	0.11	0.03	0.11	0.08	0	0	0	0.01	0
RI	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
CR	0.01	0.10	0.02	0.10	0.07	0	0	0	0.01	0

C criteria, *P* parameter

Table 5.8 Quantified matrix of decision making (evaluation matrix)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Unit	m	m	m	m	T	Yes/no	Yes/no	M	%	Yes/No
Max/min	Min	Min	Min	Min	Max	Max	Max	Min	Max	Min
Weights	0.214	0.208	0.180	0.118	0.084	0.080	0.042	0.037	0.021	0.016
Preference function	Linear	Linear	Linear	Linear	V shape	Level	Level	Linear	Linear	Level
A1	0	500	500	100	9,961,113	No	Yes	4	12	No
A2	50	200	200	50	2,634,421	Yes	No	4	0	No
A3	50	100	50	50	7,594,932	No	No	4	0	No
A4	1200	50	50	50	1,442,812	No	No	4	10	No
A5	1200	50	50	70	5,641,612	No	Yes	4	10	No

Table 5.9 PROMETHEE flows

Alternatives	Ph+	Ph−	Ph
A1	0.4019	0.2155	0.1864
A2	0.3157	0.2496	0.0661
A3	0.3071	0.3172	−0.0100
A4	0.3467	0.3606	−0.0140
A5	0.2983	0.5268	−0.2284

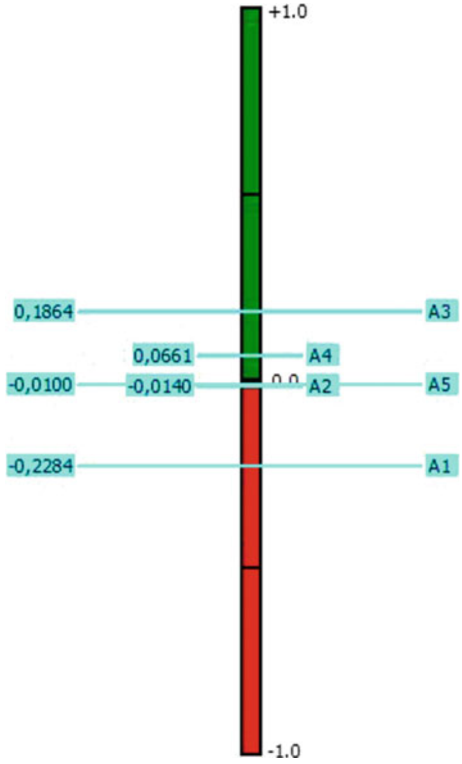


Fig. 5.10 Final ranking. Tailings—A1-Žarkov Potok; A2-Gornje Polje; A3-Žitkovac; A4-Tvrđanski Do; A5-Bostanište (Color figure online)

A3 (Žitkovac) is at the top of the analyzed alternatives, preceding A4 (Tvrđanski Do), while A2 (Gornje Polje) and A5 (Bostanište) are about the same negative Phi values. At the bottom of the list is the alternative A1 (Žarkov Potok). Values of the Phi flow for these alternatives are given in Fig. 5.10.

Figure 5.11. shows a diamond PROMETHEE solution. This solution shows partial PROMETHEE I and final ranking PROMETHEE II in a two-dimensional model. The PROMETHEE diamond solution is presented with the dot on (Phi+, Phi−) flat. The flat is at an angle of 45° so that the vertical dimension (red-green axis) corresponds to Phi net flow. A cone is drawn for every alternative. Cones A2 and A5 overlap, which indicates that these two alternatives are closely congruent, while the alternative A2

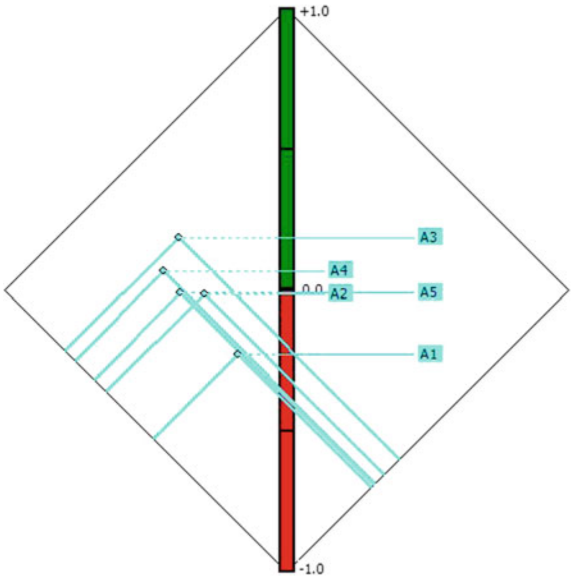


Fig. 5.11 PROMETHEE diamond solutions. Tailings—A1-Žarkov Potok; A2-Gornje Polje; A3-Žitkovac; A4-Tvrđanski Do; A5-Bostanište (Color figure online)

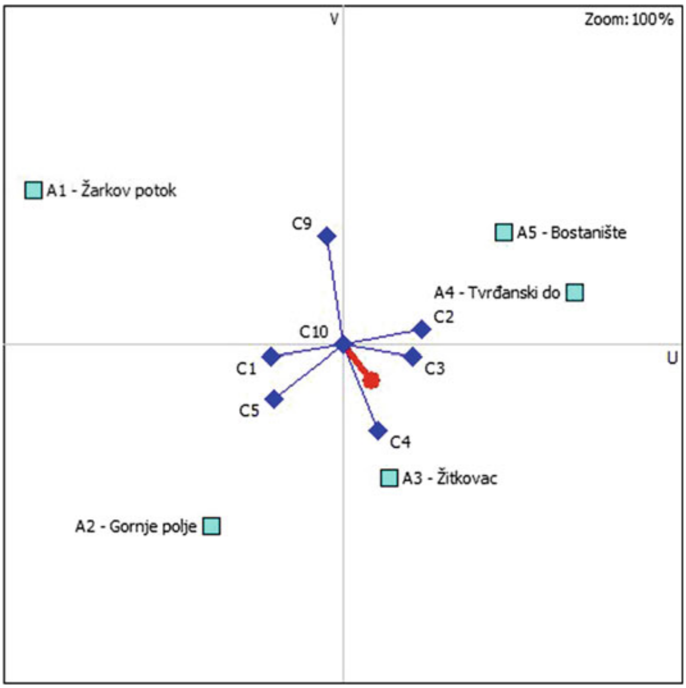


Fig. 5.12 GAIA plan for tailing ponds (Color figure online)

Table 5.10 The rank of solutions according to the AHP and PROMETHEE methods

Rank	AHP	PROMETHEE
A3—Žitkovac	1	1
A4—Tvrđanski Do	2	2
A5—Bostanište	3	3
A2—Gornje Polje	4	4
A1—Žarkov Potok	5	5

has the advantage in partial ranking PROMETHEE I. The highest priority alternative is A3 (Žitkovac), and the lowest is alternative A1 (Žarkov Potok).

In Fig. 5.12, the GAIA plan is shown (Geometrical Analysis for Interactive Assistance), which is a descriptive addition to the PROMETHEE ranking. Every alternative is presented with a dot found on the GAIA plan. The position of these alternatives is connected with the marks of a set of criteria. Each criterion is presented with the axis from the center of the GAIA plan. The orientation of these axes shows how these criteria are interrelated. Alternative A4 and A5 are similar because they are closer to each other, whereas the other alternatives are completely dissimilar. Criteria with similar preferences are C5, C1 and C2 and C3, conflicting criteria are C9 and C4. The determination axis (red axis) suggests the alternative A3 tailing Žitkovac has the least favourable impact on the surrounding ecosystem.

With implementation of estimation by using the AHP and PROMETHEE methods, with the aim of ranking the impact on the environment, the ranks are obtained according to their negative impact (Table 5.10). The comparative analysis of the negative impact on the surrounding ecosystem shows that the least favorable tailing pond is A3 Žitkovac, and that the least negative impact has the alternative A1 Žarkov Potok. Three remaining tailings have the following order of unfavorable impact on the environment: A4 Tvrđanski Do, A5 Bostanište and A2 Gornje Polje

It should be noted that other methods of multi-criteria analysis (VIKOR, TOPSIS, ELECTRE) also should be used to verify the results and the final decision.

5.4 Conclusion

This chapter analyzed and ranked the hazard on the surrounding ecosystem of five flotation tailings which are in the MMCC "Trepča," located to the north of Kosovo and Metohija. The analysis was conducted for the following tailings: Žarkov Potok, Gornje Polje, Žitkovac, Tvrđanski Do and Bostanište, considering the chemical composition of the deposited tailings, as well as their locations on the river banks. These tailings are a major source of pollution in these areas of natural beauty and historical significance. The pollution simulation in extreme weather conditions, including floods, showed that all five large industrial waste deposits would cause devastation of the environment in the case of natural disasters.

The result obtained using multi-criteria analysis ranking the impact on the environment of five analyzed tailing ponds with the application of the AHP and PROMETHEE methods showed a certain reality, which is in accordance with the situation on the terrain. According to this analysis, the most problematic tailing pond is Žitkovac, and then Tvrđanski Do, Bostanište, Gornje Polje and finally Žarkov Potok. Application of the results can be used in the decision-making process for prioritizing the rehabilitation of the tailings in the course of response planning and preparedness in the natural disaster risk management.

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Chapter 6
Contemporary Approaches to Natural Disaster Risk Management in Geotechnics

Elefterija Zlatanović, Zoran Bonić and Nebojša Davidović

Abstract Geodynamic natural phenomena, such as landslides and earthquakes, are among the most hazardous natural threats to human lives and property. Usual landslide triggers are floods and heavy rainfall, in which case speed of onset is mostly rapid and damage to structures and systems can be severe (buildings may be buried or villages swept away). In addition, transportation networks, with embankment and cutting slopes, retaining structures, bridges, and tunnels as their integral parts, are considered to be of paramount importance when the risk under strong earthquakes is considered, since accessibility of roads affects the speed and the scope of the emergency measures to be provided in the very immediate post-earthquake emergency and relief operations, and since the earthquake-induced damages to the infrastructures could severely affect the economy of a region due to the time required to restore the functionality of the network. Prevention measures and activities are the best mean of protection of human lives and social goods. Natural disaster prevention arrangements are of long-term character with permanent governmental and professional activity for the needs of establishment of consistent scientific bases and their practical application in prevention and mitigation of disaster risk. In this respect, the contemporary tools in prevention of landslide occurrence, as well as in reduction of seismic risk for foundation structures and, in particular, for tunnel structures as crucial elements in transportation network, are presented in this chapter, with a special emphasis on the state-of-the-art hazard analysis, geotechnical and construction strategies of prevention and mitigation of adverse natural hazard effects, as well as on development of monitoring and early-warning systems.

Keywords Landslides · Earthquakes · Foundations · Tunnels · Risk management · Hazard analysis · Prevention · Mitigation · Early-warning system

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6.1 Introduction

Taking into account that *hazard* (or cause) is 'a potential threat to humans and their welfare', *risk* (or consequence) is 'the probability of hazard occurrence', and *disaster* is 'the realisation of hazard', then *disaster risk management* may be defined as the process of systematic application of management policies, procedures, and practices to the tasks of identifying, analysing, assessing, treating, and monitoring risk (Fig. 6.1a). It involves:

– a formal, quantitative evaluation of potential injury or loss over a specified period of time;
– the prospect of future malperformance of a safety or security systems.

Many so-called "natural" hazards have both natural and human components. While hazard can exist even in an uninhabited region, the risk can occur only in an area where people and their possessions exist.

Emergency is realisation of a hazardous event, which requires the organisation and response of the society other than in normal condition. *Emergency management* (Fig. 6.1b) comprises measures such as organised analysis, planning, decision making, and assignment of available resources with an aim to:

– prevent,
– mitigate (lessen the effects of),
– prepare for,
– respond to, and
– recover from the hazard effects (Milutinović 2006).

For building a culture of natural disaster risk management, the greatest energy should be devoted in building the three pillars of sustainability:

– leadership development (people asset);
– capacity development (physical asset);
– awareness development (public awareness, training, and education programs).

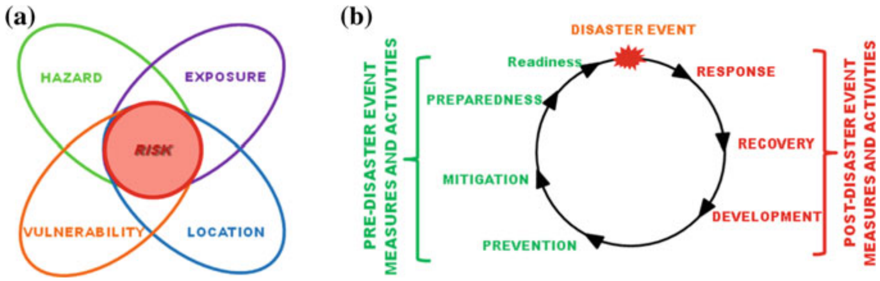


Fig. 6.1 Natural disaster risk management: **a** components of risk assessment; **b** emergency management cycle

Preventive measures and activities are the best mean against natural disasters and of protection of human lives and social goods.[1,2] Prevention arrangements are of long-term nature comprising constant governmental and professional activities, in order to establish consistent scientific bases and their practical application in prevention and mitigation of natural disaster risk.

In this respect, the chapter is dealing with the risk management considering hazardous geodynamic natural phenomena (landslides and earthquakes) and discussing several important aspects of problems related to geotechnical engineering:

– the up-to-date approaches to identification, analysis, and assessment of risks imposed by natural disasters involving geodynamic events;
– the treatment of these risks by application of the contemporary design, geotechnical, and constructional measures for slopes and associated supporting structures, foundations, and tunnel structures;
– the monitoring of the risks along with the development of the appropriate monitoring and early-warning systems.

6.2 Potentially Hazardous Geodynamic Natural Phenomena

Natural hazard events have both immediate and longer term effects upon people, physical structures, and economic activities. Geodynamic natural phenomena, such as landslides and earthquakes, are among the most hazardous natural threats to human lives and property. The recent studies have revealed that these hazardous natural phenomena resulted in the greatest number of human deaths, as well as in the highest economic losses, when compared to other natural disasters (Fig. 6.2).

6.2.1 Landslides—Characteristics and Special Problem Areas for Emergency Management

– Speed of onset is mostly rapid; warning period may vary; little or no warning may be available if the cause is earthquake; however, some warning may be assumed in the case of landslides arising from continuous heavy rain; minor initial landslips may give warning that heavy landslides are to follow; natural movement of land

[1]"Building a culture of prevention is not easy. While the costs of prevention have to be paid in the present, its benefits lie in a distant future. Moreover, the benefits are not tangible; they are the disasters that did not happen" (Kofi Annan, Secretary General United Nations 1999).

[2]European Union experience—for every €1 invested in disaster prevention, €4 to €7 are saved in disaster response (http://ec.europa.eu/echo/files/aid/countries/factsheets/thematic/disaster_risk_management_en.pdf).

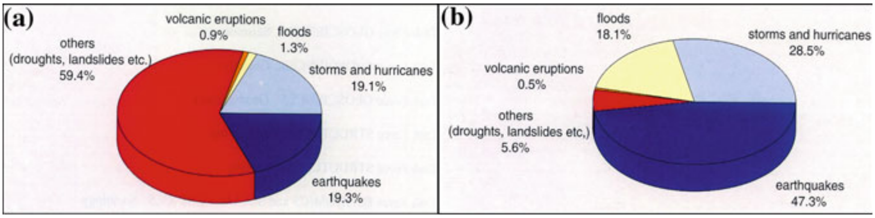


Fig. 6.2 Natural disasters worldwide 1960–1995: **a** death toll (3,000,000); **b** economic losses (439 billion US$) *Source* Munich Re 1996 (Milutinović 2006)

surface can be monitored, thus providing long warning of future possibility of landslides;

– Damage to structures and system can be severe (building may be buried or villages swept away); rivers may be blocked, causing flooding; crops may be affected; sometimes areas of crop-producing land may be lost altogether (e.g. in the major slippage of surface soils from a mountainside); when landslides are combined with very heavy rain and flooding, the movement of debris (e.g. remains of buildings) may cause high levels of damage and destruction;
– Search and rescue actions are associated with difficulties in access and movement in affected areas; risk of follow-up landslides may hamper response operations;
– Rehabilitation and recovery may be complex and costly; in severe cases it may not be possible and/or cost-effective to rehabilitate the area for organised human settlement.

6.2.2 Earthquakes—Characteristics and Special Problem Areas for Emergency Management

– Earthquake onset is sudden, usually no warning; following a major earthquake, secondary shocks may give warning of a further earthquake activity;
– Major effects arise mainly from violent ground movement (vibration), fracture, or slippage; especially they include widespread loss of or damage (usually very severe) to structures, lifeline systems, essential services, and life support systems, as well as considerable casualty due to lack of warning;
– Severe and extensive damage, creating the need for urgent counter measures, in particular search and rescue, and medical assistance;
– Difficulty of access and movement;
– Response problems may be severe, extensive, and difficult (e.g. rescue from a high occupancy building collapses, or in a circumstances where additionally a chemical or radiation hazard exists, etc.);
– Victim identification may often be very difficult;

– Recovery requirements may be very extensive and costly; recover from the seismic hazard effects may possibly take 5–10 years or even more.

6.2.3 General Counter Measures

While the characteristics, nature, and extent of effects vary according to the particular natural hazard and the particular physical characteristics of the area affected, the most of counter measures are somewhat 'generic', and are based mainly on set of measures aimed at impending the occurrence of a disaster event and/or preventing such an occurrence having harmful effects (*prevention*), and/or set of measures and activities aimed at reducing the impact of a disaster on a nation or community (*mitigation*). Whilst it may be possible to prevent some disaster effects, other effects will unavoidably persist, but they can be reduced provided appropriate measure is taken.

- Typical *non-structural measures*:
  - Development and improvement of legal framework (emergency/disaster legislation, land-use regulations, building regulations) and institution building;
  - Development of research and training centres, as well as continuous education and improvement of knowledge of scientists, engineers, and planners;
  - Development and installation of warning systems;
  - Public awareness and training.
- Typical *structural measures*:
  - Construction of structures to resist the forces generated by environmental hazards;
  - Strengthening of existing structures to make them more resistant against the environmental hazard forces.

The structural measures shall be developed based on:

– Adequate site planning;
– Assessment of forces created by the potential environmental hazards;
– The planning and analysis of structural measures to resist such forces;
– The design and proper detailing of structural components;
– Construction with suitable materials;
– Good workmanship under adequate supervision.

In the subsequent sections, the contemporary achievements in prevention of landslide occurrence, in investigation of the punching of columns through footings which is the newly-considered phenomenon both under static and dynamic conditions, and in reduction and mitigation of seismic risk for tunnel structures as crucial elements in transportation network are presented, highlighting the state-of-the-art approaches to assessment of forces induced by the potential hazard, geotechnical and construction strategies of prevention and mitigation of adverse natural hazard effects, as well as development of monitoring and early-warning systems.

6.3 Contemporary Approaches to Risk Management for Landslides

Landslides belong to the greatest hazards for the population, material property, and environment. As the population expands, both in terms of habitation and usage of areas, the risks of the emergence of landslides and considerable damage also increase (Fig. 6.3).

In order to minimise the risk of human casualties and material damage, it is necessary to have institutions, which would react timely and efficiently. This comprises detecting of the signs of sliding, issuing warnings to the population and competent institutions, evacuation, and eventually, remediation of the damage.

6.3.1 Preventive Measures for Landslides

For the purpose of prevention of potential landslides, it is necessary to implement preventive measures in the most efficient way. The preventive measures include:

Fig. 6.3 Landslides on the slopes and inclines (Protić and Bonić 2018)

– *Mapping of the landslides into the existing maps*. In the critical situations, it is necessary to predict what areas would be at the highest risk. There must exist a National Cadastre of landslides, which would be used as a basis for production of prediction maps.
– *An Early Warning System*. It is a method of geotechnical monitoring used for the assessment of stability of inclines and slopes. It includes various techniques of instrumental observation and monitoring in the real time. The system must be connected to the Emergency situation sector of the local self-governments and at the national level.
– *Education and capacity building*. Training of the local emergency centres and wider public for reporting and recording of landslides in the territories of local self-governments is a significant step in the organised social action focused on mitigation of natural disaster effects. One of the best ways to inform the population on the importance of a systematic approach to the problems related to the landslides is to present the principle of good and bad practice and provide specific instructions and advice during the training.
– *Improvement in the legislative power*. Observation of legal regulations in the area of space and urban planning, research and remediation of structures and land are the foundations for reducing the hazard of landslides for the population, material and other property, both at the state level and the level of cities and municipalities. For that reason, it is important to engage professionals and companies registered for landslide inspection and remediation.

With adequate preventive measures, and with functioning of a global system and data bases, the onset of soil movement would be observed more easily and the system would react on time and warn the competent services.

Starting from all this, it is necessary to form a contemporary data base about the processes and phenomena, whose existence and effects can indirectly or directly endanger the stability and function of the civil engineering structures over time, for the purposes of designing and construction of new and maintenance of the existing structures, especially for the housing buildings and the structures of transportation infrastructure. The basis should contain: an inventory of (registry) of phenomena, their history of development, maps of hazards and risks, data on investigation and success of remediation, quality and quantity assessment of the hazards for an area and structures in it, data on the monitoring during construction and operation, as the prevention for timely discovery of instability phenomena and timely undertaking of adequate remedial measures.

The characteristic example is the Tamara cyclone, which hit Serbia and surrounding countries in 2014. In the period from 13th to 18th May 2014 Tamara cyclone hit southeast and central Europe, causing floods and landslides. Serbia and Bosnia and Herzegovina sustained the greatest damage due to the fact that the rainfall exceeding the historical records. Namely, in some localities, the amount of rainfall in three days of May (14th–16th of May) exceeded the monthly average rainfall for more than four times. Until 20th of May, no less than 62 persons lost their lives. The rainfall set the torrential floods and rockslides into motion, and numerous rivers from the Sava

(a) (b)

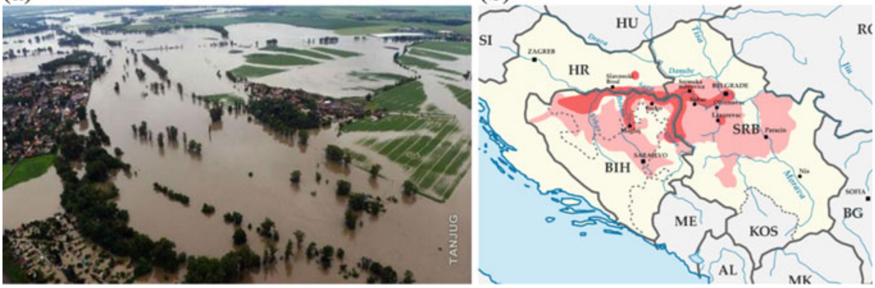


Fig. 6.4 Tamara cyclone: **a** flooded areas in Serbia; **b** areas in which landslides occurred (www.tanjug.rs)

and Morava basins flooded (Fig. 6.4a). Over 2000 landslides occurred (Fig. 6.4b). According to the official data, over 1.6 million people were affected in Serbia and Bosnia and Herzegovina.

Considering that the reaction units in emergency situations in Serbia are the crisis municipal centres, a number of municipalities proclaimed an emergency during the Tamara cyclone. However, the lack of an appropriate landslide cadastre and prediction maps of landslide hazard for most of the Serbian territory, or at the level of large territorial units (municipalities/cities), made the operation of emergency centres difficult, when an urgent reaction in the affected areas was necessary.

For that reason, a campaign of mapping and recording of landslides was conducted by the most eminent competent institutions dealing with this issue. Mapping of the landslides was organised at the level of municipalities and coordinated so that all the municipalities have even criteria and forms for registering of landslides and damage assessment. For every recorded landslide, the following data needed to be entered: exact location, type of phenomenon, dimensions of phenomenon, sketch of the predicted land cross-section, motion mechanism, activation date and previous activity status, as well as the relative and quantitative assessment of hazard and damage level. Yet, given that the data on the landslides were collected by various institutions, the reports differed to a great extent, and considering that the field campaign was focused on the most critical locations, many small landslides remained unregistered.

Regarding that landslides are a great hazard and that the competences of the governmental bodies and public institutions in the Republic of Serbia are divided, there was a need to collect and integrate the data into a single system according to the standards and requirements of the European Union, and to make them publicly accessible to mechanical search services. In that sense, it was necessary to produce uniform reports on such events and use them for the most contemporary hazard analysis and to develop an early warning system. This is a systematic approach to the issue of control and remedy, which provides a more quality spatial planning.

For that reason, completion of the landslide cadastre in certain municipalities was organised in the framework of the project “Harmonisation of data on landslides and training of local self-governments for their monitoring" under the working title "BEWARE" (BEyond landslide aWAREness), which began in May 2015 (Abolmasov et al. 2015). It is a sub-project of the UNDP initiative for improvement of vitality and readiness for a response to emergency situation in the Republic of Serbia, financed by the Government of Japan, and coordinated through the UNDP Office in the Republic of Serbia for assistance and renovation of the flooded areas and the Ministry of Mining and Energy of the Republic of Serbia. The goals of the BEWARE project are:

- Contribution to the methodology of acquiring, processing, and production/completion of a data basis of landslides through harmonisation and standardisation of data; recording of landslides in target municipalities: production of the map of hazards and risks.
- Strengthening of governmental bodies, primarily of the Ministry of Mining and Energy and the Geological institute, for regular landslide monitoring in agreement with the good practice in EU states.
- Production of BEWARE (GIS—geographic information system) web protocol, which represents a platform for inspection and reporting of landslides, and accompanying material including the hazard maps.
- Building personnel and material–technical capacities of involved municipalities, which can regularly monitor and register landslides in their territories, which is an active participation in completion of the national database of landslides.

A very important role in terms of sustainability of the project is given to the representatives of local self-governments, who are trained for registration of current and future emergence of instability in the territory of their municipalities and cities. For this purpose, appropriate equipment and material was provided and necessary training was conducted. The equipment of conducting of the Project consisted of one tablet device with pre-installed BEWARE android application, one navigation device, and a computer with appropriate software. The task of the user—representative of a local self-government is to record the emergence of a landslide by making a field visit, by locating and memorising the landslide using tablet, and by filling in the accompanying form of the cadastre list and taking photographs of the location. For the purpose of obtaining as real data on a landslide as possible, it is recommended to visit and record the main scarp and toe of the landslide, as well as different characteristic elements, deformations and ridges, wells, and damage on the buildings and infrastructure. The project was realised in 27 target municipalities, which were the most affected by the landslides in 2014 (Fig. 6.5a). Distribution of registered landslides by municipalities, in which the BEWARE project was realised, is displayed in Fig. 6.5b.

The BEWARE project, allows, among other things, formation of a global database, which can be continuously completed and updated by the trained personnel from the local self-governments. This provides timely information about the changes, which could indicate the onset of danger, so as to react in a proper way and on time.

Further field investigations and analyses are taken over by the appropriate state institutions, such as the Geological Institute and other, which make the prediction

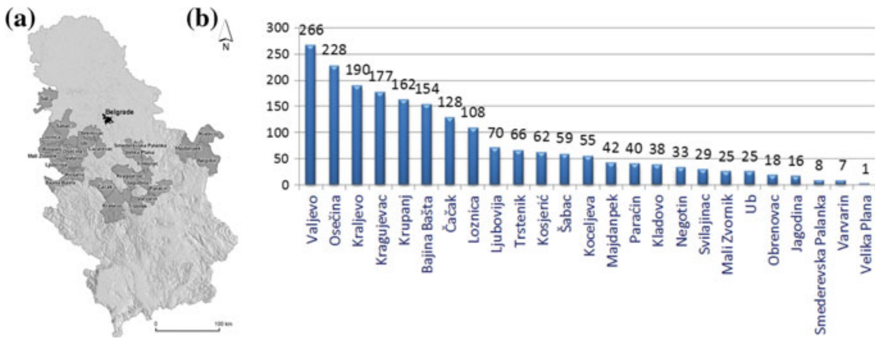
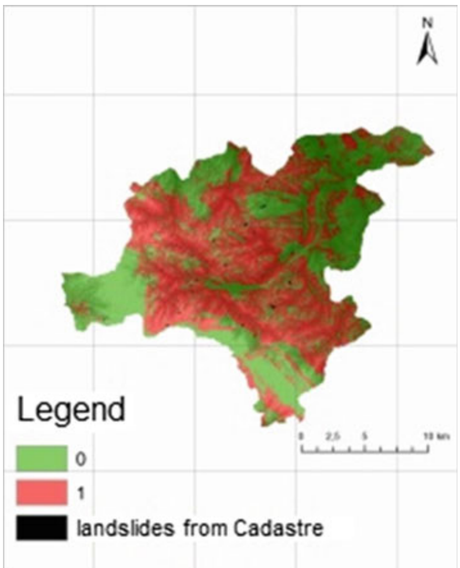


Fig. 6.5 BEWARE project: **a** municipalities in Serbia where the project was realised; **b** number of registered landslides by municipalities in which the project was realised (Abolmasov et al. 2015)

maps of hazards and risks. Hazard comprises probability of emergence of a dangerous event (landslide in this case) with specific characteristics, in a specific time, and place. The risk is the measure of expected losses due to the hazard, which took place in a specific area during a specific time interval. The expected losses refer to injuries and human casualties, and material damage.

An example of the hazard map is given for the municipality of Krupanj, which sustained the most damage from landslides from all the mentioned municipalities. The map was made using the AHP method (Analytic Hierarchy Process) and it is displayed in Fig. 6.6.

Fig. 6.6 Hazard map for the municipality of Krupanj (Krušić et al. 2015)



The AHP method, as an expert or empirical method, belongs to the so-called multi-criteria analysis (Marjanović et al. 2013), and it uses simple matching of important factors (geological, geomorphological, climatic, hydrological–hydrogeological, and environmental factors) based on a quantitative assessment of their impact on the sliding process (using a predefined scale for quantification). The mentioned factors affect the final model through their weighted coefficients (points), whereby each value indicates the impact of the individual parameter and all the factors are normalised (scaled to the same scale, in this case 0–100%, i.e. 0–1). Since their impact is simultaneously determined, they demand mutual evaluation, that is, quantification of each individual member in respect to any other. Assessment is carried out by experts who have experience with a given type of landslide in a given area of research, independently from one another, in order to harmonise their criteria. In this way, the weighted average coefficients for each of the factors are obtained. By their simple summation in the GIS environment, a finite quantitative model of landslide susceptibility for a given terrain in a given area is obtained. It can be classified into a qualitative model with specified classes, for example, a class of high, medium, and low susceptibility. Finally, it is necessary to evaluate the model by comparing the final model with the cadastre of landslides (by comparing the spatial distribution of the landslide from the cadastre and, for example, the class of high susceptibility to sliding). The described AHP method procedure facilitates reduction and control of subjectivity in assessment of input parameters. Considering the hazard map for the municipality of Krupanj (Fig. 6.6), the definite land model (susceptibility to sliding) has been defined upon the following input parameters: altitude, exposition to sun, energy of relief, slope inclination, distance from the border of units with different hydro-geological function, distance from water courses, vegetative cover, and geology.

Slopes can also be monitored by a number of modern methods: Aeria photogrammetry, radar shooting, and today the most commonly used method is where the field equipment is installed on the landslide, from which it is possible to read the data on the movement of certain points. Using the obtained data on movements of points on the landslide and registered scarps it is possible to reconstruct the potential sliding surface, which is of prime importance in the landslide remediation.

The limitations of traditional deterministic approach in slope stability analyses are that it does not consider the uncertainty of input parameters and does not provide information on the probability of slope failure. The newer approach is based on a probabilistic concept, where each input parameter is defined by the range of possible values and a probability distribution function. The results of a number of performed comparative stability analyses clearly indicate the advantages of the probabilistic approaches, which is therefore increasingly applied in practice (Davidović et al. 2012b, 2015).

Considering embankment and cutting slopes along transportation networks, construction with suitable materials and good workmanship under adequate supervision are of paramount importance among preventive measures against sliding occurrence. Moreover, by virtue of a number of contemporary slope-stability software, the slope stability analyses both under static and dynamic conditions are indispensable nowadays in the design stage (Davidović et al. 2012a, 2014).

6.3.2 Remedial Measures for Landslides

The remedial measures are procedures bound to minimise the damage and restore the situation into its original condition. Permanent rehabilitation measures are a series of activities that are carried out after detailed geotechnical research of the terrain and the elaboration of the rehabilitation project with the aim of permanent stabilisation.

As water is the most common cause of landslides, the most effective permanent remedial measures involve the drainage of water from the surface and outside the body of the landslide. And here are very important measures that involve the development of drainage trenches and channels or the installation of horizontal drainage pipes, whereas in the first stage (emergency operation) only drainage channels can be made, and then, by setting drainage pipes in them, they become permanent measures of rehabilitation.

In addition, permanent rehabilitation measures include various support structures: retaining walls made of stone, concrete, reinforced concrete, and of reinforced soils, gabions, anchors, diaphragms, retaining structures on micropiles, etc. (Prolović et al. 2011; Davidović et al. 2017).

Diaphragm represents a thin flexible wall in the ground, built by special technology (Bonić et al. 2015b). Diaphragm construction is most often done by protecting the sides of the trench by not classically bracing it, but by using slurry. The clay suspension (slurry) is a mixture of clay and water. Working with the slurry requires a special system for its mixing, purification, insertion into the trenches, and capture during the construction of the trench, which makes the procedure for securing the sides of the trench very expensive. However, there are frequent cases when the geotechnical conditions at the given location are not so complex, that is, when the foundation pits are of smaller depth, in a cohesive soil, without presence or with a poor supply of groundwater. In such locations, construction of diaphragms can be considered with a simpler technology.

Bonić et al. (2015a) proposed a technical solution for the construction of diaphragms according to a simplified procedure that allows the quick and easy execution of works based on the system of construction of successive lamellas. The solution envisages the construction of the diaphragm lamellas up to 4.00–6.00 m deep, 2.00–2.50 m wide, and with thickness of 0.40–0.60 m and exceptionally up to 1.20 m. These limits have been adopted for the following reasons. The depth of the excavation is limited by the average values of the short-term excavation depth without the special securing of its sides, but it is also limited by the maximum depth of excavation using the universal excavator. Eventually, larger depths can also be excavated in materials with higher values of cohesion. The recommended width of the lamella is within the minimum range for diaphragms for two reasons. First, in this way, a minimum front of vertically excavated material without a support is achieved, which maximises the arc effect of the surrounding soil upon excavation. Owing to this effect, considerably longer short-term excavation depths without the special securing are also often achieved. In addition, the aforementioned average values of the dimensions of the lamella correspond to the volume of the mixer by which the concrete is brought to the construction site, thus allowing the fastest and the most economical construction of one lamella and the diaphragm as a whole. Of course, these dimensions can be changed and adapted to geotechnical and construction conditions at a given location.

In order to form the ending part of the lamella and the joint with the next lamella, it is envisaged to produce a special finishing sheet pile of ferrocement, although it can also be made of other materials (steel, various composites, etc.), which represents practically the only anticipated formwork. The sheet piles are 1 m long and of U-shaped cross-section, with two or more stirrups, for better connection and joint work of adjacent lamellas, as well as for better resistance to water seepage. The bonding of the lamellas of the diaphragm is reinforced by the formation of a special vertical bond beam, which couples the two adjacent lamellas. An additional monolithisation of the diaphragm can be achieved by creating a common header at the top of the diaphragm.

The technology of construction of diaphragms comprises the stages (Fig. 6.7):

– Excavation of the trench by the excavator up to the designed depth;
– Placing the pre-assembled reinforcement cage in the trench by the excavator;
– Placing the pre-prepared finishing sheet pile by inserting it into the bent sheet-metal guide-frames on the reinforcement cage by the excavator;

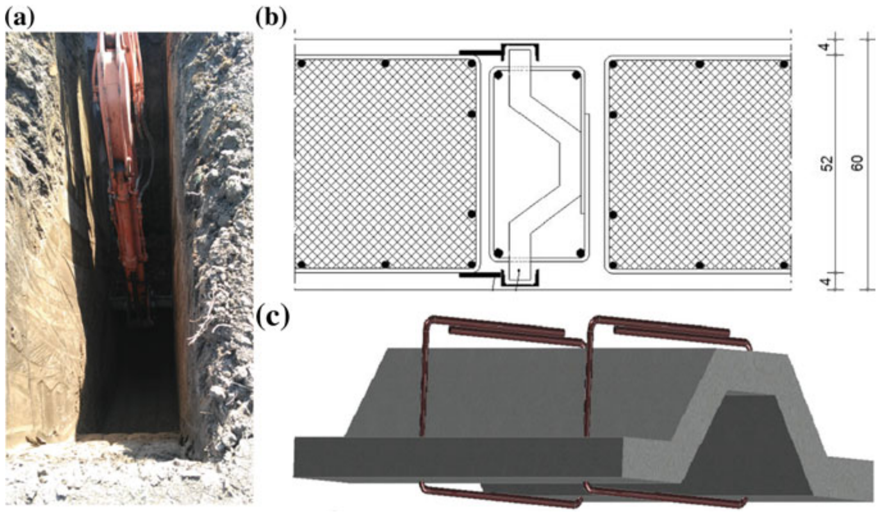


Fig. 6.7 Newly-proposed technology for the diaphragm construction in cohesive soils: **a** narrow trench excavation; **b** joint of adjacent lamellas (view from above); **c** finishing sheet pile (Bonić et al. 2015a)

– Filling the lamella with fresh concrete mass into which the additive for accelerated binding is added;
– When the fresh concrete mass is sufficiently hardened, the next lamella is dug up.

It should be noted that all the above-mentioned operations on the diaphragm construction are performed from the surface of the field, outside the trench, which is a significant fact in terms of the workers' safety considering working conditions in narrow excavations.

6.4 Contemporary Approaches to Risk Management for Foundation Structures

Control of the punching of columns through footings is mandatory part of the design of reinforced concrete footings exposed to notable concentrated forces through the columns. Behaviour of column footings and foundation slabs under load depends in general case on the soil characteristics, type, characteristics of the material of the footing, and intensity of the load. Typically, high concentrated loads in the columns may lead to the abrupt failure of those footings, i.e. punching the column through the footing, which is the specific phenomenon for the static conditions and, in particular, when the structure is exposed to an earthquake excitation (Fig. 6.8). Although foundations have essential influence on the behaviour of the structure and to the soil, standards do not pay enough attention to their analysis, and in some standards the specific details of the foundation analysis are not even mentioned. Complexity of behaviour of the soil and complexity of the subsoil–structure interaction lead to the fact that in majority of the standards is adopted the empirical method of design of the punching shear resistance of reinforced footings and reinforced foundation slabs.

Fig. 6.8 Damage to the slab due to the punching of the column through the foundation (Wallace et al., ND)

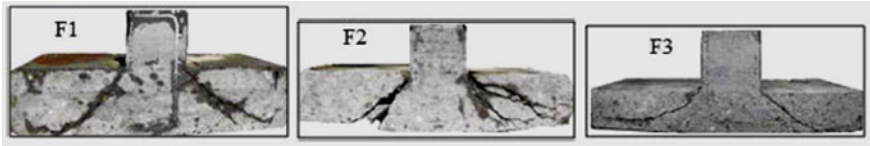


Fig. 6.9 Saw-cut of the failed footings (Bonić et al. 2017)

Recently, the punching shear resistance and punching behaviour of the reinforced concrete footings and foundation slabs have been investigated by experimental testing program on real soil, in in situ conditions, conducted from 2009 to 2014 (Bonić et al. 2012), by comparison of experimental and calculation results (Bonić and Folić 2013), as well as by comparison of testing results with numerical simulations in ANSYS (Vacev et al. 2015) taking into account the materially nonlinear behaviour of soil, concrete, and reinforcement (Bonić et al. 2010a, b). The influence of the main parameters, such as compressive strength of concrete, flexural reinforcement ratio, shear slenderness of the footing, soil reactive pressure distribution, stiffness of the soil–footing system, and mechanism of footing punching were in the focus of these studies (Fig. 6.9).

The key result of the conducted parametric studies was determination of the factors, whose influence is dominant in assessment of column footing punching. In addition, a modification of the punching capacity expression in Eurocode 2 is proposed (Bonić et al. 2017), which can contribute with its application to daily engineering practice.

6.5 Contemporary Approaches to Seismic Risk Management for Tunnel Structures

Historically, underground facilities have experienced a lower rate of damage in comparison with surface structures, and initially, tunnel structures were designed with no regard to seismic effects. Namely, being confined by the surrounding medium (soil/rock), these structures have long been assumed to have good seismic performance. Therefore, in a quite long time, tunnel damages did not take enough attention as it was the case with surface structures. Nevertheless, some underground structures have experienced significant damage in recent large earthquakes, including the 1995 Kobe earthquake in Japan, the 1999 Chi–Chi earthquake in Taiwan, as well as the 1999 Kocaeli and the Duzce earthquakes in Turkey (Fig. 6.10). As the tunnel number and its earthquake-induced damage and failure increased, the widely accepted idea that tunnels and underground structures are invulnerable to earthquakes has appeared to be illusive, and this problem has attracted the attention of experts and scientists around the world, reviving the interest in the associated design and analysis methods.

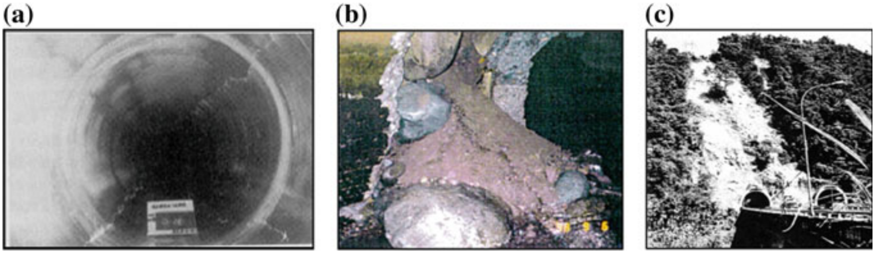


Fig. 6.10 Seismically induced tunnel damage: **a** Kobe earthquake, Japan, 1995 (Lanzano et al. 2008); **b** Mid North Iwate earthquake, Japan, 1998 (Johansson and Konagai 2007); **c** Chi-Chi earthquake, Taiwan, 1999 (Hashash et al. 2001)

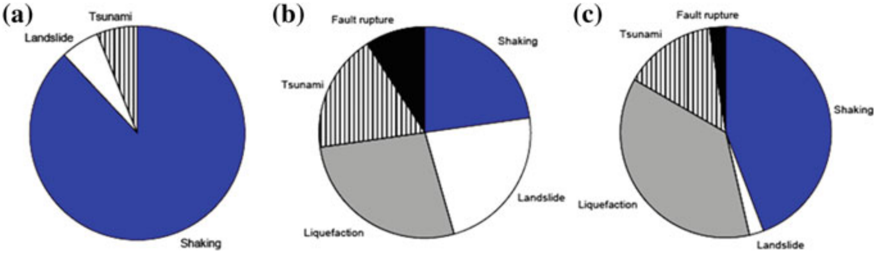


Fig. 6.11 Primary causes of damage in 50 world earthquakes in the period from 1989 to 2003: **a** buildings; **b** transportation systems; **c** utilities (Bommer et al. 2006)

Summarising the results based on the damage reports of 50 destructive earthquakes around the world in the period from 1989 to 2003, Bommer et al. (2006) have shown that, while the primary contributor to the damage of buildings is ground shaking, when it comes to transportation systems and utilities ground failure (liquefaction, slope instability, and fault displacement), as the secondary effect of seismic shaking, becomes more important and needs more serious attention (Fig. 6.11).

6.5.1 State-of-the-Art Approaches to Assessment of Tunnel-Lining Forces Induced by the Seismic Hazard

In the first attempts of assessing the seismic response of tunnel structures the so-called *free-field deformation approach* was used, in which ground deformations due to seismic waves (in the absence of a structure or excavation) are estimated and the tunnel structure is designed to accommodate these strains (it is assumed that the structures experience the same strain rate as the ground in the free-field). Although this approach can enable a first-order estimation of the anticipated deformation of the structure, however, it does not account for the interaction of the tunnel structure with the surrounding ground. The presence of a tunnel structure considerably modifies the free-field ground motion leading to a different seismic response of the tunnel lining. The interaction effects between a structure and surrounding ground layers sometime can change strong ground motion, which is input to the structure, thus causing larger external forces to the structure. This phenomenon is related to the combined effects of *kinematic interaction* and *dynamic (inertial) interaction*. The kinematic interaction is influenced by the inability of a structure to match the free-field deformation, since the stiffness of the structure impedes a development of the free-field motions. The dynamic interaction is caused by the existence of structural mass that makes the effect of inertial force on the response of the surrounding ground. In the case of tunnel structures, the inertial interaction is less important than the kinematic one, because the mass of the structure is negligible against that of the surrounding environment. Therefore, analysis of the tunnel–ground interaction, concerning both the tunnel and the ground stiffness, is required in order to find the accurate tunnel response, which represents the basis of the contemporary *soil–structure interaction approach*. Besides the ratio of the ground and the lining stiffness, another aspect which sensibly affects the response of the tunnel is the shear stress transmission at the ground–lining interface. Numerous approaches are commonly based on the assumption that the soil is perfectly bonded to a structure (*no-slip condition*). However, the contact between the soil and the structure is usually imperfect, since slippage as well as separation often occur in the interface region (*full-slip condition*). In many situations in practice, the condition of a *partial slip* exists. Nevertheless, solutions are usually derived for the two extreme contact conditions: full-slip and no-slip. It is the usual practice to consider both of the extreme cases and apply the more critical one.

The comparative analytical and numerical studies on the soil–tunnel structure interaction effects considering representative of two main soil classes—stiff soil of good conditions and soft saturated soil of poor conditions (Zlatanović et al. 2014, 2015) indicated that the importance of the relative rigidity between the tunnel and the ground is the predominate factor that influences the soil–structure interaction (SSI) effects, which should not be omitted in analysis of the dynamic response of tunnel structures, having in mind that the interaction effects between structure and surrounding medium can result in larger external loading to the structure. These effects are the most prominent for the case of flexible linings in soft soils. Larger deformation is caused in the softer ground subjected to larger strong ground motion due to the smaller stiffness (Fig. 6.12).

Numerous approaches are commonly based on the assumption that the soil behaves in a linear elastic manner. However, the soil region immediately adjacent to the tunnel structure can experience extensive strain level, thus causing the coupled soil–tunnel system to behave in a nonlinear manner. Accordingly, there was a need to modify the linear approach in order to provide a reasonable estimation of the ground response under seismic impact, in which case the soil is cyclically loaded. Experimental results have suggested that some energy is dissipated, even at a very low strain level, thus indicating that the damping ratio of a soil is never zero. It is

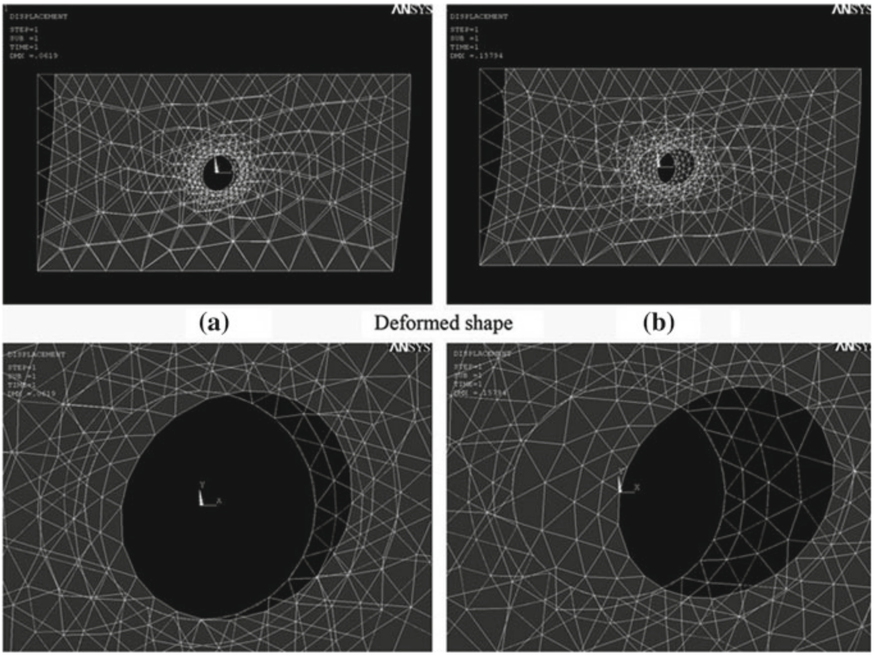


Fig. 6.12 Earthquake-induced ovaling deformation of the circular tunnel cross-section (displacement enlarged 25 times): **a** dense sand; **b** soft clay (Zlatanović et al. 2015)

also suggested that both the soil's shear modulus and the damping ratio are dependent on the shear-strain level. The results of the analyses related to the comparison of the seismically induced soil–tunnel structure interaction effects considering linear and nonlinear soil behaviour (Zlatanović et al. 2016) drawn the conclusion that linear analysis underestimates the soil shear strain, and consequently also underestimates the soil displacements induced by seismic shear-wave propagation, producing a significant underestimation of the tunnel lining's cross-sectional forces. Nonlinear analysis, on the other hand, due to a prediction of a significantly larger soil shearing (soil displacements), results in a higher relative displacement between the top and the bottom of the circular tunnel cross-section compared to the linear analysis. This leads to significantly greater ovalisation of the tunnel structure (Fig. 6.13), and therefore, to higher values of the internal lining forces. In addition, it seems that the linear analysis can result in a more conservative estimation of the internal forces in the tunnel lining, as the peak acceleration and the level of soil nonlinearity increase, which is a consequence of the constant soil shear modulus and the constant damping ratio assumption typical for the linear soil behaviour.

Contemporary development of computer software and the finite element method (FEM) concept has provided a powerful tool toward investigating the seismic response of tunnels. Considering that the dynamic FE analyses are quite complex and they require large computer capacities, a simplified approach is needed, i.e.

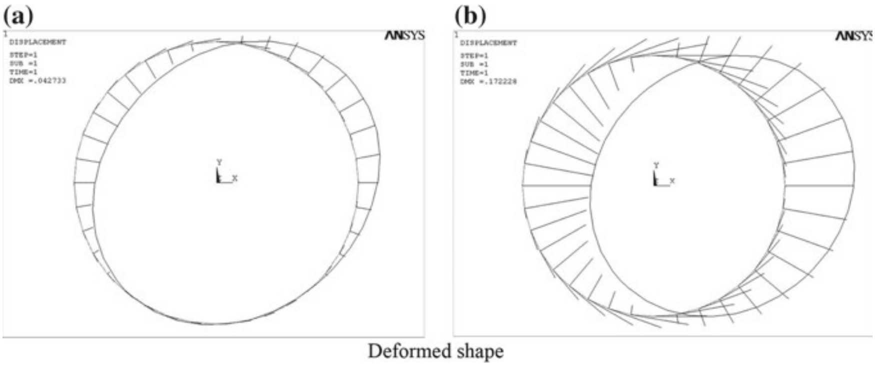


Fig. 6.13 Earthquake-induced ovaling deformation of the circular tunnel cross-section: **a** linear SSI analysis; **b** nonlinear SSI analysis (Zlatanović et al. 2016)

certain assumptions and idealisations considering numerical models must be made (Zlatanović et al. 2013). Although the models may be simple, they should be able to capture the most significant aspects of the seismic response of tunnels. In order to estimate the ability of numerical models to simulate the soil–structure interaction effects, numerical analyses have been performed with the aid of the software ANSYS (Zlatanović et al. 2017), comparing the discrete beam–spring and the continuous finite element models (Fig. 6.14). Unlike the beam–spring model that cannot analyse static and dynamic effects simultaneously except by simple superposition, whose results do not yield a correct solution in a comprehensive way, the continuous FE model allows to account both for static and dynamic loads in a single analysis and gives results that are in a good agreement with the real physical state.

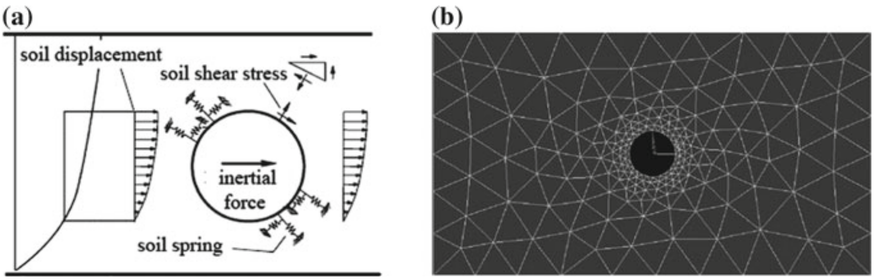


Fig. 6.14 Numerical simulation of the soil–tunnel structure interaction effects: **a** discrete beam–spring model; **b** continuous FE model (Zlatanović et al. 2017)

6.5.2 Contemporary Laboratory Equipment for Experimental Testing

Development of research centres and implementation of shaking tables in experimental research of tunnel structures in terms of seismic impact are also very important segments of preventive measures in seismic risk management. However, geotechnical models cannot be placed directly on a vibrating platform. Over the past two decades, several research groups around the world have been working on the development of laminar shear boxes, which will enable shear strains of the model due to earthquake action, which are of particular importance in nonlinear analyses, to be identical to deformations of prototype in real conditions. Laminar boxes can be of a rectangular cross-section (Fig. 6.15a) and of a cylindrical shape (Fig. 6.15b).

Laminar shear box (Chunxia et al. 2008) consists of a number of rigid frames. Each of the frames rests on individual bearings, which are connected to the outer frame, so that the weight of the box through these bearings is transferred from the platform to the outer frame. This arrangement allows full utilisation of the shaking table's shear capacity. For the case of one-dimensional shaking, the bearings, which are connected to the outer frame, prevent unwanted movements in the transverse and vertical direction, allowing only free displacements in the longitudinal direction. Also, the bearings allow very smooth relative movements of the frames relative to each other, which impose the laminar box to deform in a shear beam manner, thus following the deformation shape of the soil model in the box. This leads to the mitigation of the effect of the restricted lateral spread created by artificial boundaries of laminar box that do not exist in the prototype condition. The base of the box, made of steel plate, must be firmly connected to the platform before the test itself, either by screwing or welding, and should be sprinkled with a coarse sand layer in order to

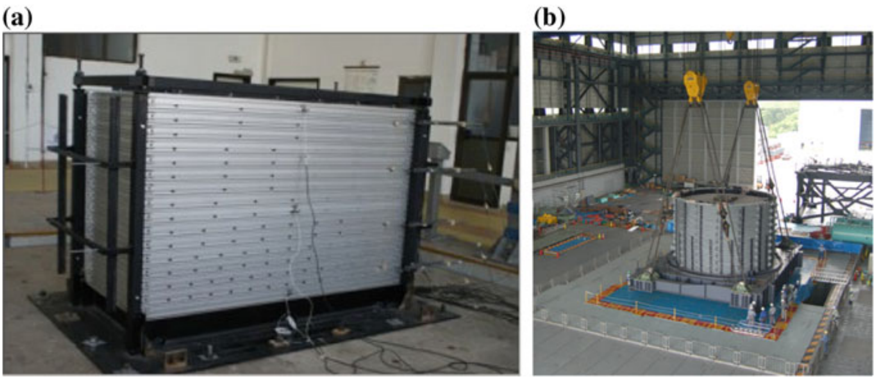


Fig. 6.15 Laminar boxes: **a** rectangular laminar box [Soil Dynamics and Dynamic Testing Laboratories, Institute of Earthquake Engineering and Engineering Seismology (IZIIS), University "Ss. Cyril and Methodius" of Skopje, Republic of Macedonia (www.iziis.edu.mk)]; **b** circular laminar box [used in Japan on the largest shaking table in the world, which can simulate 3D soil movements (Suzuki et al. 2008)]

prevent the occurrence of slipping at the contact of the soil model and the base of the box. The interior of the laminar box should be coated with a thin layer of flexible latex, which prevents the penetration of the soil into the gaps between the frames, as well as has a waterproofing role in the case of testing the saturated soil model. Laminar boxes can be adapted to a wide range of tests in the field of geotechnical earthquake engineering (amplification, liquefaction and cyclic mobility phenomenon, excess pore water pressure generation, dissipation rates, soil–structure interaction, etc.). The model can be equipped with various sensors: strain gauges, accelerometers, velocity meters, earth pressure transducers, pore-water pressure transducers, transducers for measuring displacements, settlement meters, and load cells.

6.5.3 Geotechnical and Construction Strategies to Mitigate Seismic Effects on Tunnel Structures

The damage to subway tunnels during the Hyogoken-Nanbu (Kobe) Earthquake in Japan in 1995 has stimulated a sharp rise in research activities considering possible measures for mitigation of seismic effects on tunnel structures.

(1) *Soil improvement techniques*—"*Jet grouting*"

In spite of the fact that there is no possibility of designing a tunnel that would completely resist large deformations of soil induced by earthquake, however, techniques of stabilising the surrounding soil such as densification, reinforcement, or grouting can to a great extent be effective in mitigating the consequences of seismic effects.

Jet grouting represents an efficient soil stabilisation technique that is applied in the most diverse geotechnical conditions, from soft clays and silts to sands and gravels. The essence of the technology is the use of a jet of the water cement mixture, which under pressure fragments the soil and mixes with it in situ, thus forming a column that represents a mixture of earth and binding material. The resulting columns in the array, the so-called "soilcrete", are characterised by high compressive strength and low water permeability. The diameter of the columns depends on the speed of rotation and rise of the drilling tool. It is the safest method that over the last two decades is increasingly widespread around the world as a very fast procedure, which can be applied in the vicinity of existing structures without interrupting their service and results in significant cost savings (Hayward Baker Inc. 2004).

In tunnel construction, the jet grouting technique is used to stabilise the ground around the tunnel excavation, in particular at the tunnel crown, which is of particular importance in the application of the tunnelling method when the entire face of a tunnel profile is excavated. Soil reinforcement can be achieved by vertical columns (Fig. 6.16a), horizontal columns that form a protective arch under whose protection the tunnel profile can be excavated (Fig. 6.16b), or inclined columns (Fig. 6.16c). This soil improvement technique can be used both for the construction of new and for the seismic retrofit of existing tunnel structures.

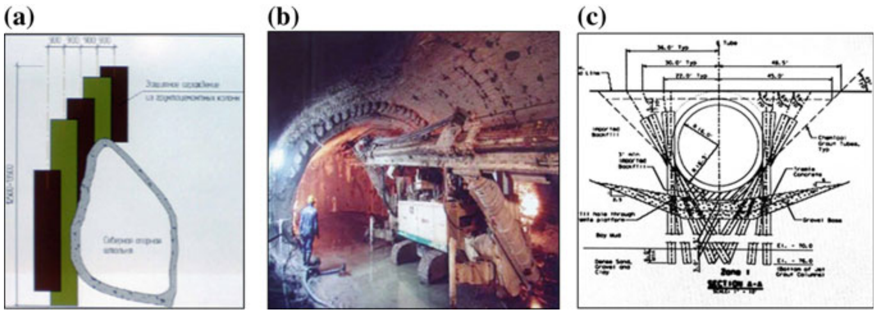


Fig. 6.16 Soil improvement around tunnel by the jet-grouting technique: **a** vertical columns (Абрамчук et al. 2004); **b** horizontal columns (ROTEX OY 2006); **c** inclined columns (Dash et al. 2003)

(2) *Tunnel flexible joints and ductile tunnel lining design*

In the case of tunnel structures, sudden changes in stiffness are quite often considering both the construction itself and the surrounding medium. These changes usually occur:

– at the contact of tunnels with accompanying objects, such as transit stations;
– at locations of connection or crossing of two or more tunnels;
– in the case of heterogeneous geological structure of the surrounding ground;
– in places of local restrictions on tunnel structures from movements.

At these locations, differences in stiffness may yield a difference in movements of certain parts of the structure or different layers of the surrounding medium, which can cause the concentration of stress at these points (additional moments and shear stresses). The most suitable solution in these situations is the application of flexible joints, usually in the form of flexible steel plates or polymeric materials. These joints are particularly useful for connecting the tunnel portals with the remaining part of the structure (Hashash et al. 2001).

In order to enable tunnel structure to adapt to the anticipated movements of the surrounding ground, it must have a certain ductility, which can be achieved by jointed (segmented) tunnel linings, among which there could be distinguished straight-jointed liners (Fig. 6.17a) and staggered-jointed liners (Fig. 6.17b). By segmented linings, the reduction of the moment in tunnel structures up to 50% may be achieved (Mizuno and Koizumi 2006). The segments are connected in the ring by the longitudinal (segment) joints, whereas the rings are assembled in the tunnel lining by the transverse (circumferential, ring) joints. Steel dowels are often used as joints in combination with rubber seals in order to ensure the waterproof ability of the structure. Differences in the stiffness between the lining segments and the connecting joints greatly affect the internal forces in the segments of the tunnel lining. Due to the existence of a large number of joints, dynamic properties of the tunnel structure, and therefore the interaction of the structure and the soil, can be very complex.

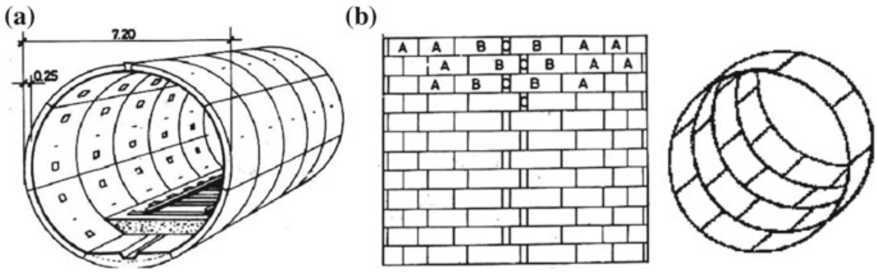


Fig. 6.17 Types of jointed tunnel linings: **a** straight-jointed linings; **b** staggered-jointed linings (Popović 1987)

(3) *Seismic isolation of tunnels*

One of the measures for mitigating the seismic effects on tunnels is the coating of the tunnel structure with isolating material, in order to minimise the shearing forces at the interface of the tunnel lining and the surrounding ground. The seismic isolation material has to be long-lasting and stable in terms of settlements. In the case when the tunnel structure passes through two layers of soil with different stiffness, at the contact of two layers, apart from flexible seismic joints, the tunnel should also be provided with isolation from the surrounding ground, which ensures the reduction of forces in the tunnel structure, and consequently, mitigation of earthquake-induced deformation of the tunnel (Lanzano et al. 2008).

Kim and Konagai (2001) investigated the effect of expansion and contraction of materials based on silicone, rubber, and bitumen for seismic isolation of tunnels. The ability of contraction and expansion of isolating material greatly contributes to a better seismic isolation effect considering tunnel structures. The conclusion of these studies is that materials characterised by low values of the Poisson's coefficient and shear modulus show the best seismic isolation effect. In the case of bituminous materials, however, the appearance of softening with increasing strains is noted.

The results of the analysis performed by Keshvarian et al. (2004) showed that the rubber-based isolation of great thickness and length results in the most efficient reduction of the internal forces and stresses in the tunnel lining, as well as of the amount of displacements in the tunnel structure and the surrounding ground. Based on these results, it is concluded that composite tunnel linings of concrete and rubber are very efficient in absorbing the energy released during seismic activity.

Hasheminejad and Miri (2008) carried out analyses of different variants of the multilayered cylindrical tunnel lining. In the first case, the polymeric isolation layer was placed between the tunnel structure and the surrounding ground. In the second case, the isolation was placed at the inner surface of the tunnel structure. In the third case, the polymer damping layer was constrained by a substantially stiffer layer of concrete. Polymers of different attenuation characteristics were considered. According to the results of the analysis, the viscoelastic isolating material of a low shear modulus value for the third case of structural arrangement is proved to be the most efficient from the aspect of seismic isolation effect, in particular for the case of S-wave propagation perpendicular to the longitudinal axis of the tunnel. In the case of wave propagation parallel to the axis of the tunnel, especially in the range of medium and high frequencies, the stress concentration caused by dynamic influences drastically increases, which points to the need for further research in the field of seismic isolation of tunnels.

6.5.4 Intelligent Monitoring of Seismic Damage of Tunnels

In the study of Bairaktaris et al. (2000), a fibre-optic-based deformation monitoring system is presented. The main advantages of fibre-optic sensors over conventional seismic deformation sensors are that they reduce connectivity problems significantly, offer galvanic isolation essential to modern computer-based systems, and their sensitivity is better than that of conventional strain gauges. This greatly improved operational sensor system can be integrated into a reinforced concrete tunnel. The sensor can be either embedded into the structure or be retrofitted onto the surface of the structure to be monitored. The uniqueness of the technology is the use of carbon composite materials for fibre-optic sensors, which have numerous advantages such as: excellent resistance to aggressive chemical environments (e.g. the alkaline environment of concrete), excellent mechanical behaviour, flatness so they can easily be placed on the surface of civil engineering structures, and very low total volume that enables sensors to be embedded in concrete without perturbing the structure.

The Intelligent Seismic Monitoring System consists of the *Deformation Monitoring System* (it uses fibre-optic sensors for providing real-time measurements of the deformation of the tunnel lining and the rail track) and the *Decision Support System* that is the core of the system (it comprises a seismic stability module, a serviceability module, and an expert system). The *Seismic Stability Module* records deformation at critical lining locations, and based on it, assesses the remaining dissipative capacity at these locations and signals a warning the tunnel to be shut down if this capacity is not sufficient for the tunnel to sustain expected aftershocks. The module receives measurements of the deformations in critical sections of the tunnel in real time and reconstructs the corresponding hysteresis loops. The relevant energy terms are computed, so that the current state of damage can be assessed. The *Serviceability Module* receives real-time measurements of rail deformations and estimates the safe speed of train. The *Expert System* coordinates the modules, provides easy access to the system via a user interface, and takes care of the maintenance of the database.

6.6 Concluding Remarks

Geodynamic natural phenomena, such as landslides and earthquakes, are among the most hazardous natural threats to human lives and property. One of the basic principles in the modern approach to natural disaster risk management is the tendency towards the strengthening of preventive measures, which results in numerous advantages, both in terms of safety and in economic terms. Natural disaster prevention arrangements are of long-term character considering permanent governmental and professional activity for the needs of establishment of consistent scientific bases and their practical application in prevention and mitigation of disaster risk.

When it comes to geotechnical engineering, over the past decade or two, a great progress has been made in the field of preventive and mitigation measures in managing the risks of landslides and earthquakes, primarily due to the advancement of computer technology that, consequently, has enabled the development of contemporary methodologies and software for relevant and reliable risk analysis and assessment, modern laboratory equipment for conducting very serious and complex research, modern design strategies and construction technologies, as well as contemporary monitoring and early-warning systems. Although a major step forward in this field has been achieved over the past period, however, there are still many necessities and opportunities for further research in this area.

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Chapter 7
Flood Risk Management Modelling in the River Ibar Catchment Area

Srđan Jović and Jelena Đokić

Abstract In this paper, there are presented the risk assessment modeling of all rivers in the River Ibar Catchment that have been flooding or have a potential for flooding of agriculture land, houses, roads, bridges, and other objects. For each river, those flooded or potentially flooded surfaces are presented by category of risk (high risk, medium risk, and low risk) as well as the causes of the flooding and recommendations for short term and long term activity protection against floods. All inputs for the flood risk assessment (water cycle analysis, lake-level prediction, evapotranspiration, climatic conditions) were simulated by using different modeling techniques. By analyzing the locations and vicinity of the human activities, it sets the river priority for intervention. This is enabled by the information presented through the Geographical Information System Elements (GIS) of the Water Framework Directive. Although the information presented by GIS depends on the availability of the spatial and field data, it is a valuable tool in risk assessment in determining the cumulative sensitivity of the specific region to the floods.

Keywords Floods · Evapotranspiration · Evolutionary algorithm · Sensorless estimation · Neuro-fuzzy approach · GIS

7.1 Introduction

Floods take place almost every year in North of Kosovo*. Recently, the floods have happened in approximately the same locations in 2013, 2014 and 2015. Luckily, there were no human victims, but there were significant damages on infrastructures, agriculture and roads. It was evaluated that any consequences of floods could have been avoided if basic principles of safe behaviour had not been ignored. Recommendations on flood prevention mainly include necessary measures that should be taken to physically prevent the devastating impact of floods. Necessary preventive measures should also be taken at the legislative level and in legislation enforcement.

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The climate change has made profound changes in water cycles and produced serious water problems and water crisis in many areas. The main reason is that the structure and the parameters of the water cycle have evolved under the influence of human activities and consequently resulted in the reduction of runoff water resources. In order to understand the changes in the water cycle in the changing climatic conditions, the scientists should analyze the overall water cycles. Human cycle of water was investigated by identifying potential exposure pathways for water contamination, as well as understanding the potential impact of contaminated water in the case of floods. This study area is in the specific situation having some five mining waste deposits situated along the river Ibar, which contain toxic and hazardous substances from the lead and zinc ore processing (Milentijevic et al. 2013).

In the more detailed analysis, the enhanced activity of the water cycle as important part for protecting the photosynthetic apparatus was investigated (Weng et al. 2008). The relation between natural and social aspects of the water cycle was analyzed and some four aspects of dualistic water cycle evolution were discussed in Qin et al. (2014). Water storage is significant for understanding water cycles of global and local domains and for monitoring climate and environmental changes (Xu et al. 2013). Actual evapotranspiration is a vital process of the water cycle that links land surface water balance and land surface energy balance (Itier et al. 1992; Gerla 1992). Evapotranspiration plays a key role in simulating the hydrological effect of climate change (Xu et al. 2016; Blum and Gerig 2006). In Zhao et al. (2013), the evapotranspiration estimation methods applied in hydrological models were summarized. The dominant role of transpiration in comparison with other components of evapotranspiration was illustrated in vegetation in the annual cycle (Buchtele and Tesar 2009). Decreasing trends in annual precipitation and potential evapotranspiration could lead to a decrease in actual evapotranspiration in the basin (Gao et al. 2012). The importance of estimation of actual evapotranspiration was recognized a long time ago (Rana et al. 1997), and the estimation model is tested on the field. How evapotranspiration and water availability had changed in the changing climatic conditions in Northern Euroasia has been evaluated in (Liu et al. 2014). In the water science, the estimation of evapotranspiration is extensively investigated topic (Dong et al. 2016). A long term precipitation analysis and estimation of precipitation concentration were done by using support vector machine method (Gocic et al. 2016). In order to reduce water losses, the evapotranspiration, evaporation, and seepage losses in arid and semi-arid region were investigated (de la Paix Mupenzi et al. 2012). The emphasize was also put on the better analysis of the water cycle and monthly average evapotranspiration in the area (Morari and Giardini 2001). Estimating the evapotranspiration is based on different climatic parameters such as air temperature, vapor pressure, and humidity. The reliability of the estimation of the reference evapotranspiration by simplified pan-based approach, that do not require data on relative humidity and wind speed, was analyzed by comparing the estimated results with the lysimeter measurements on the field (Trajkovic et al. 2010). The monitoring process generates a large number of data. The application of artificial neural networks in the forecasting the reference evapotranspiration has been used for a long time now

(Kisi and Yildirim 2005). Neuro-fuzzy approach (Jang et al. 1997) was used for the process of modelling, as evapotranspiration has a strong fluctuations during the year.

Lake-level prediction is very important for sustainable management of local and regional water resources (Tongal and Berndtsson 2014; Shafaei and Kisi 2016). However, reliable prediction of groundwater level is also essential for water resource management (Gong et al. 2016). Modeling lake-level fluctuation is essential for planning and designing of hydraulic structures along the lake coasts (Sanikhani et al. 2015). This issue becomes important, as traditional lake-level fluctuations is changed due to the climate change (Kakahaji et al. 2013). Prediction of water-level fluctuations in lakes is a necessary task in hydrological and limnological studies (Vaheddoost et al. 2016).

Soft computing methods became very useful tool for solving different engineering problems (Verplancke et al. 2008; Meng and Xia 2007; Cai et al. 2010). One of the most often used soft computing methods is Support Vector Regression (SVR) approach. However, the SVR approach is highly dependent on the proper selection of the parameters. There were many strategies proposed for the parameter selection, but most of the strategies are restricted for linear cases or prone to local minima. Soft computing approach was also used for sensorless estimation of the lake level (Jovic et al. 2018b).

A watercourse of the river Ibar downstream of the artificial lake Gazivode is largely impacted by the lake. The lake Gazivode was constructed in the 1970s. Its purpose was to regulate the river Ibar flow, produce electricity and irrigate Kosovo plain for agriculture production. The final result of the study should be a detailed analysis of the flood risk in the research area.

7.2 Methods and Materials

7.2.1 Study Area

This section presents the respective information regarding the existing environmental and social baseline conditions of North Kosovo and summarizes the information currently available, which may potentially be affected by the floods in the four municipalities Leposavic, Zubin Potok, Zvečan and Kosovska Mitrovica.

The detailed baseline characterization will be used as input to identify possible project impacts and assess their acceptability in terms of environmental and social effects. This part is based on existing data and information and includes a description of the environmental and socioeconomic conditions baseline.

7.2.2 Physical Environment

Project is affecting four municipalities, which are located in the north part of Kosovo. This particular part of Kosovo is specific for its geographic, social and environmental features.

Kosovo varies in elevation from 265 to 2656 m above mean sea level (amsl), with approximately 77% of its area lying between 500 and 1500 m amsl. Higher altitude areas, above 1500 m, cover approximately 6% of the area and are significant from a biodiversity standpoint. Kosovo is very diverse geologically, with volcanic, metamorphic, and sedimentary rocks of varying ages and origins present. The soils are generally nutrient-rich, providing a good growth medium for natural plants and crops. Limestone is located in several parts of Kosovo and has weathered to form a distinctive topography that includes numerous caves. Soils derived from limestone and ultra-basic serpentine rocks have chemical characteristics that restrict plant growth to specially adapted species that are often restricted to these soil types. Many stretches of rivers have been severely disrupted by sand and gravel mining and attempts to control river flooding with artificial levees.

The study concerns four municipalities, which are located in the north part of Kosovo*. This particular part is specific for its geographic, social, and environmental features. This region is geographically located in 420 53″ N and 200 53″ E, and it has altitude between 508 and 510 m. It has around 154 km^2. Dominant forms of relief are volcanic cone in the form of Zvecan hill (797 m in height) and firth of river Sitnica into river Ibar. From the east, north, and west, the region is surrounded by mountains Kopaonik, Rogozna and Mokra Gora. Through the region, three main rivers are flowing: Ibar, Sitnica, and Ljusta. This represents a very good geographical position for all human activities, industry, and agriculture (Fig. 7.1).

7.2.3 Climatic Conditions

The morphological, i.e., hypsometric characteristics of the terrain have impacted Northern Kosovo climate characteristics. The Climate is temperate-continental to mountain climate. The mountain ranges of Mokra Gora, Rogozna, Suva Planina and southern and south-western slopes of Kopaonik have their specific impacts in climate characteristics. For the analysis of the parameters, the data of precipitations, temperatures, sunshine, wind, and humidity are obtained from the climatology stations Kopaonik, Novi Pazar, Mitrovica, and Pec, surrounding the terrain. These parameters are used for the analyzed period from 1961 to 1999. From 1999 until 2014, the data were obtained from the meteorological stations presented in Table 7.1.

Fig. 7.1 Location map of study area according to the topographical map (Google Earth 2019)

Also, for the precipitation analysis the data from Climatic Atlas are used. In that time the precipitation stations were numerous in this region (Ribarići, Brnjak, Režala, Kosovska Mitrovica, Banjska, Vlahinje, Leposavic and Lesak).

Air Temperature

The influence of the mountain range is obvious in the analysis of the temperature regime. The air temperature in the highest parts is reaching −30 °C, during the winters. So, the average temperature in the research area varies from 3.7 (CS Kopaonik) to 11.4 °C (CS Peć). The coldest month is January, with mean temperature from −4 °C CKS Kopaonik) to 10 °C (CS Peć). August is the hottest with mean temperature varying from 13 °C (CS Kopaonik) to 22.1 °C (CS Peć).

The altitude, micro-climate, and spatial distribution of the relevant climate stations reflect the conditions on the site, so the data are valid for this research terrain. As shown in the Fig. 7.2 the minimum and maximum daily temperatures keep the correlation throughout the year, what is significant for the water level estimation.

Precipitation and Humidity

Based on the available data, it can be seen that there are relatively small oscillations of precipitations during the year, or that the precipitations are evenly distributed throughout the year. That is very good from the hydrology point of view, as that stable regime enables stabile regime of the ground waters. The average precipitations for the region are 600–855 mm on the mountain slopes Kopaonik, Mokra gora, and Suva planina, in strong winters the number of days with snow is up to 180, effecting significantly the ground waters. Most of the precipitations are recorded in April, May, and October. Based on the collected data for the minimum relative humidity in

Table 7.1 Meteorological stations surrounding research terrain

	Longitude (°)	Latitude (°)	Altitude (m)	Distance (km)	Direction	Direction	Station Name	Country Name
1	20.7	43.7	217	91.1	351	N	Kraljevo	Serbia
2	21.9	43.33	202	96.9	59	NE	Nis	Serbia
3	21.65	41.96	239	121.6	148	SE	Skopje-petrovac	North Macedonia
4	22.28	42.51	1176	122.7	110	E	Skopje	North Macedonia
5	19.28	42.43	52	139.7	249	W	Podgorica	Montenegro
6	19.25	42.36	33	145.1	247	SW	Podgorica-Golubovci	Montenegro
7	20.7	41.53	1321	151.9	185	S	Lazaropole	North Macedonia
8	22.18	41.75	327	166.3	139	SE	Stip	North Macedonia
9	23.38	42.65	595	206.6	97	E	Sofia-(observ.)	Bulgaria
10	21.36	41.05	589	208.6	169	S	Bitola	North Macedonia

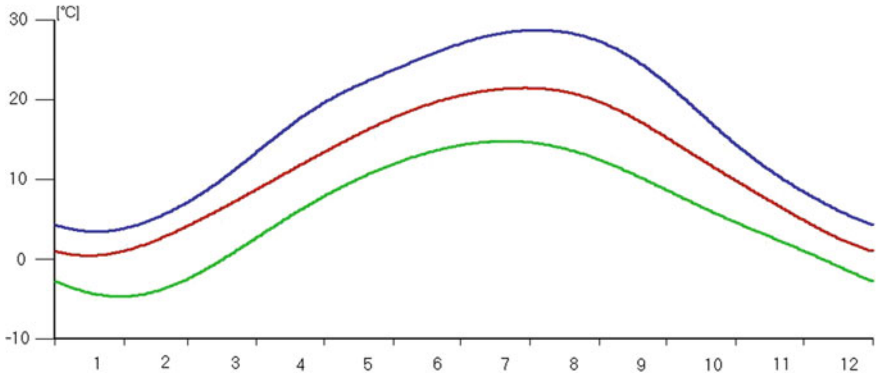

Fig. 7.2 Graphic presentation of the temperature regime in North Kosovo, minimum (green), maximum (blue) and mean (red) (Color figure online)

Table 7.2 Statistic data for daily precipitation and evapotranspiration in Northern Kosovo Region

Day	Prec.	Prec.	Prec.	PET	PET	PET
	Best (mm)	Low (mm)	High (mm)	Best (mm)	Low (mm)	High (mm)
Mean	8.35	5.54	13.48	1.92	1.63	2.21
Min.	10.00	0.00	2.25	0.35	0.01	0.66
Max.	42.40	31.95	66.56	3.99	3.59	4.48

the region of interest in the last 20 years (Djokic et al. 2012), it can be concluded that the periods of heavy rains in April and May are followed by extreme dry weather in late July and August.

The results from Table 7.2 are presented in the graphic presentation in the Fig. 7.3 while Kosovo's precipitation map is presented in Fig. 7.4.

Solar Radiation

Kosovo has, on average 2066 h with sun per year or approximately 5.7 h per day. The highest insolation value is in Pristina with 2140 h for one year, while Peć with the smallest insolation value of 1958 h, Uroševac with 2067 h and Prizren with 2099 h. The maximum insolation in Kosovo occurs during July, while the lowest insolation occurs in December.

Distribution of general solar radiation for Northern Kosovo is given in Table 7.3.

Throughout the year the sunshine hours are presented in Fig. 7.5.

Wind

Considering the terrain properties in the North Kosovo*, and the study area of the river Ibar valley, the winds are relatively slow, and do not have influence on the occurrence of floods. The annual wind velocity statistics is presented in the Table 7.4.

Data collected on daily basis are presented in the graphic presentation in Fig. 7.6. As shown in the figure, the most of the winds are concentrated in July–August, in

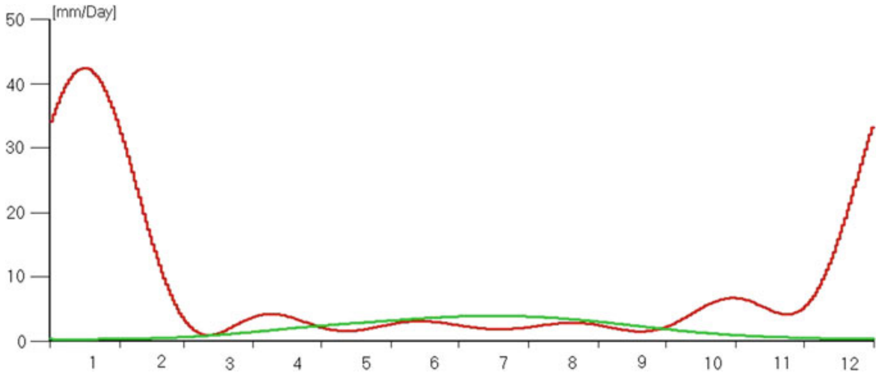

Fig. 7.3 Average daily precipitation (red) and evapotranspiration (green) in the North Kosovo (Color figure online)

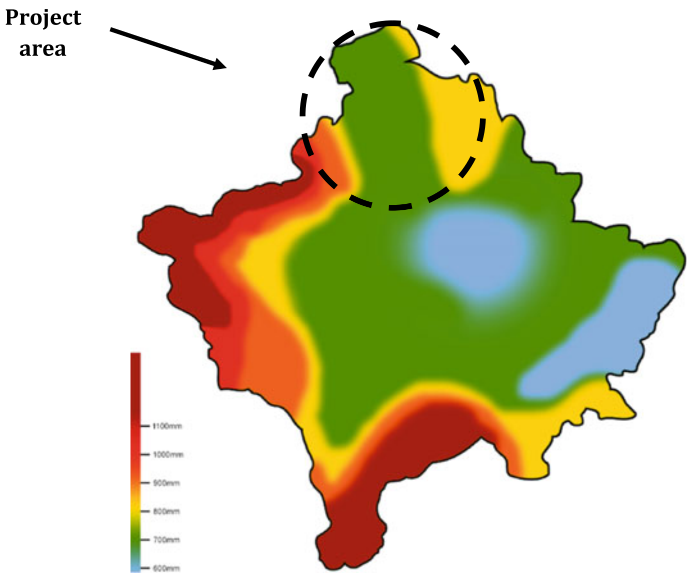

Fig. 7.4 Precipitation distribution of Kosovo

Table 7.3 Sunshine fractions and Sunny hours in North Kosovo* region

Day	Sun Fr. Best (%)	Sun Fr. Low (%)	Sun Fr. High (%)	Sun Hrs. Best (h)	Sun Hrs. Low (h)	Sun Hrs. High (h)	Day Len. (h)
Mean	30.333	22.273	38.923	3:57	3:01	4:55	2:09
Min.	9.35	0	21.74	0:50	0:00	1:57	8:56
Max.	54.5	50.05	60.9	7:45	7:07	8:30	5:15

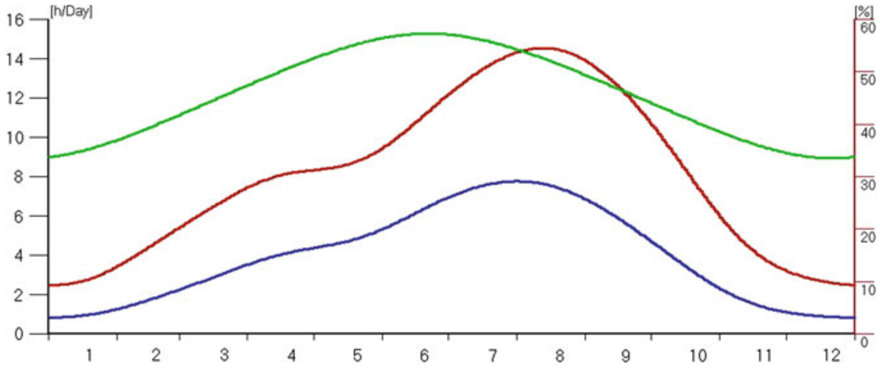

Fig. 7.5 Annual sunshine cycle in Northern Kosovo Red: Sunshine fraction [%], Green: Daylength [h], Blue: Sunshine hours

Table 7.4 Wind velocity distribution in km/h throughout the year in North Kosovo*

Day	Vapor Best (hPa)	Vapor Low (hPa)	Vapor High (hPa)	Wind Best (km/h)	Wind Low (km/h)	Wind High (km/h)
Mean	10.617	9.068	12.165	3.42	1.01	6.14
Min.	4.98	4.01	5.84	2.25	0	4.53
Max.	16.9	14.82	19.09	5.55	3.52	7.92

the north-south direction, bringing hot weather from the south along the river Vardar valley, and contributing the river pollution from the surrounding industrial toxic waste deposits by fumigation (Milentijevic et al. 2013).

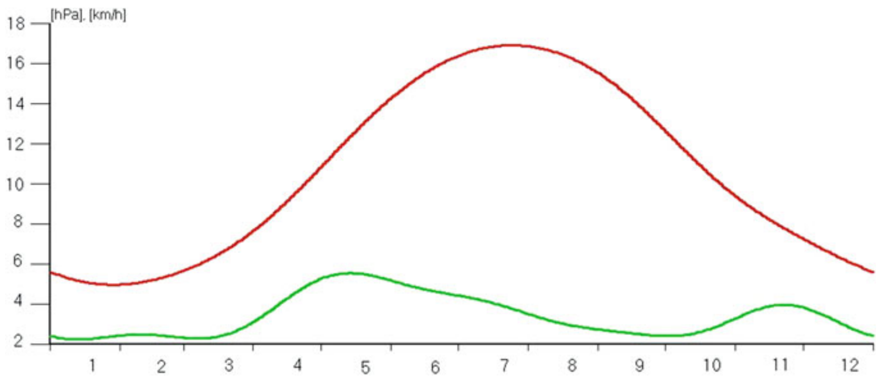

Fig. 7.6 Wind velocity in Zvecan municipality (red) and water vapour pressure (green) (Color figure online)

7.2.4 Hydrographic Data

The region of the North of Kosovo is in the region of Ibar Catchment Fig. 7.7. The spring of Ibar is on the territory of South-Eastern Crna Gora (Montenegro). In the area from Ribarice to Gazivode the river forms accumulation lake, whose waters are used for irrigation through the system Ibar—Lepenac, for water supply in Mitrovica region and electricity production. The Ibar catchment belongs to Black sea catchment, and it occupies the surface of 3593 km^2 that is one-third of Kosovo.

The direct catchment of Ibar includes the streams of the northern part of Mokra gora and Suva mountain, southern and south-eastern slopes of Rogozna and the region of southern and south-western Kopaonik on the right bank of Ibar, on the north side of the line Mitrovica—Stari Trg (peak Oštro Koplje, 1789 m), to the ore bodies Šatorica, Jelakce and Belo Brdo. The total surface of the direct Ibar catchment in Kosovo is 754 km^2. The catchment area is characterized by mountain relief with deeply cut Ibar valley and its tributaries. The largest altitude difference is 1339 m in Kopaonik region and in Suva planina area where the difference is 1283 m. Along the flow through Kosovo in 50 km, Ibar river is flowing downhill with an altitude difference of 209 m (659–450 m).

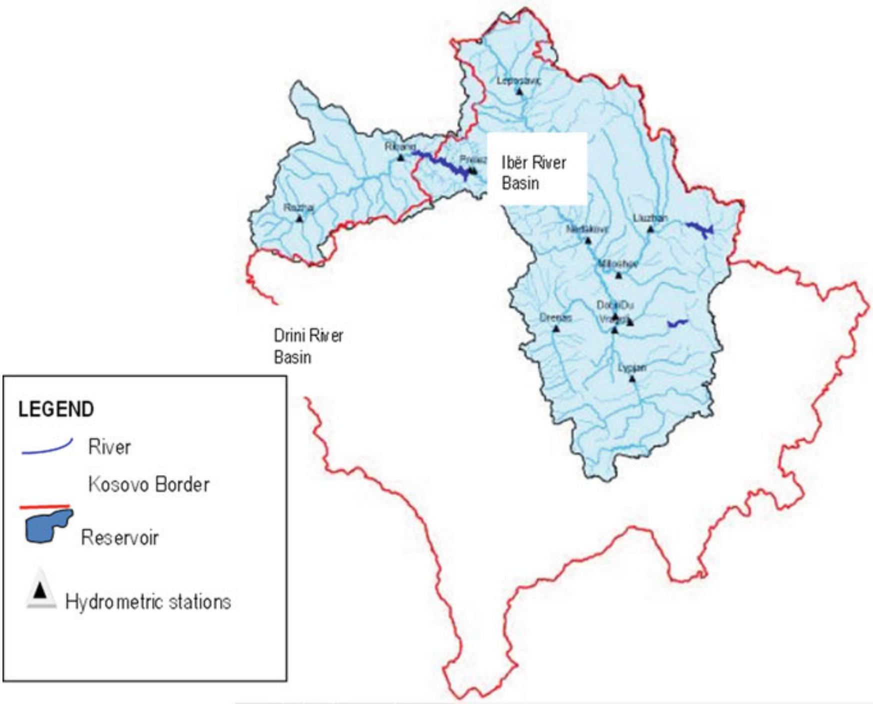

Fig. 7.7 The Ibar River Basin in Kosovo*. *Source* World Bank Document: Water Security for Central Kosovo No. 71850, 2011

On the west from Mitrovica, the Ibar catchment is developed in credo flysch, and on the northern slopes of Suva Mountain in Palaeozoic schist. On the north of Mitrovica, in the catchment, there is a predominant area of serpentines and peridotites (ultra basic massive) with penetration of eruptive rocks (dacite and andezite) as well as the minor zone of diabase-horn formations near the village Slatina. There is also some participation of Pliocene and Quarterly terraces, 5 km upstream from Mitrovica, near villages Žabare and Vinarce. The alluvial deposit has some small occurrence, in the plane as well as in profile. In the area of Vinarce, the depth of alluvium is just 5 m, and under this layer, there is credo flysh. In the village of Pridvorica the water nonpermeable clay layer occurs after just 4.5 m of alluvial deposit. Significant tributaries of the Ibar river are: Brnjačka, Čečevska, Sitnica, Banjska, Bistrica, Vučanska, Sočanska (in upper stream Mošnička, where there are no living organisms), Leposavska (collecting all mining waters from the mines Žuta Prla, Koporić and Jelakce), Jošanička, Drenska (cathing mining waters from the pit Belo Brdo) and Srpska Bistrica.

The hydrology properties of the region are analyzed, with data of flow in three water measuring profiles at the Ibar river (profiles: Batrage, Perlez, and Leposavić), for the observing period from 1991 to 2000. The characteristic flows are given in Tables 7.5 and 7.6.

7.2.5 HEC-RAS Hydrology Calculations

The HEC-RAS is numerical software for hydrology calculations (Kalaba et al. 2014). It is widely used in one-dimensional water surface profile calculations in case of steady and unsteady river flow regimes. Also, it contains components for one-dimensional sediment transport/movable boundary and river water quality numerical calculations (Kalaba et al. 2014).

As previously mentioned, the aim of this study was the preliminary analysis of the terrain and creation of the model for the further water quality and water flow analysis of the river Ibar flooding capacity between the artificial lake Gazivode and the city of Leposavic. The only major tributary of the Ibar in this area is the river Sitnica, and it flows into the Ibar beyond the observed section. In the studied sections, the river Ibar flows the series of dams which starts with the Gazivode, located at the end of the 24 km long artificial lake Gazivode, and the Pridvorica located around 2.3 km below the Gazivode. There is only one bridge, located between the Pridvorica and the village Zubin Potok, and it was not taken into mainly through the alluvial plain which is shortly interrupted after the village Varage, and nearby dam Trepča, in the length of approximately 2 km. The dam Trepca is the third in account in this analysis. The path of river reach is taken from topographic map loaded into the HEC-RAS geometric data editor. The reach starts few meters downstream of the dam Pridvorica, at the elevation of 578 m, and ends few meters upstream of the dam Trepca, at the elevation 553 m. Since the reach length is 6.67 km, sixty-eight initial cross-sections, labeled 0–67, were positioned at every 100 m. The distances between cross-sections

Table 7.5 Flow characteristics for Prelez for the observing period from 1991 to 1999

Catchment: Z. Morave		River: Ibar	Profile: Prelez	Waters observation method: limnigraf				Start: 1934	Elevation: 542.6		Km from the confluence: 182	Surface km^2: 1109		
Months		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Year	Q (m^3/s)													
1991	NQ	1.32	1.56	1.32	1.32	3.14	1.56	1.68	4.82	4.38	7.32	8.4	3.94	1.32
	SQ	2.26	3.48	1.78	6.21	7.16	6.75	5.31	6.09	8.83	13.1	11.3	5.65	6.49
	VQ	65.1	49.5	30.6	83.4	68.1	68.1	99.3	53.6	84.6	80	70.2	69.1	99.3
1992	NQ	2.4	1.7	1.4	2.0	2.0	1.4	1.4	1.4	3.0	2.4	2.0	2.0	1.4
	SQ	13	2.54	2.68	2.86	2.43	1.99	2.44	2.52	5.91	3.95	4.07	2.52	3.92
	VQ	70.1	3.6	3.2	4	3.2	2.4	6.6	3.2	63.7	42.4	14.2	3.2	70.1
1993	NQ	4.52	5.3	2.6	2.4	1.7	1.7	1.55	0.92	0.81	0.92	2.8	1.7	0.81
	SQ	15.3	29.2	10.8	5.18	2.71	2.32	2.65	3.12	1.47	1.7	7.26	6.83	7.23
	VQ	66.9	81.2	71.1	8.25	4	3.6	47.6	9.57	3.0	4.52	38.4	16.4	81.2
1994	NQ	1.7	2.0	1.03	1.03	0.92	0.81	0.81	1.03	0.64	0.92	9.57	1.4	0.64
	SQ	2.28	13	1.51	1.5	1.39	1.26	2.6	2.48	1.28	10.3	28.4	17.1	6.86
	VQ	3.0	112	50.2	2.0	2.2	15.1	41.6	38.4	27.1	35.2	80	78.9	112
1995	NQ	1.4	1.14	1.03	1.7	1.55	2.6	2.4	1.55	1.4	1.03	0.92	1.14	0.92
	SQ	1.83	1.67	1.46	3.74	4.59	3.73	6.94	2.36	2.5	4.74	5.06	13.3	4.35
	VQ	2.4	2.0	30.7	33.3	28.2	26.5	75.6	29.4	50.2	62.7	58.7	70.1	75.6
1996	NQ	1.15	1.81	1.39	3.46	2.56	0.99	0.83	1.39	0.99	0.99	1.94	2.2	0.83
	SQ	11.8	13.6	13.9	7.11	5.73	2.45	1.66	1.61	1.33	1.81	2.08	68.7	11.0
	VQ	61.6	62.7	26.5	78.9	78.9	54.9	5.3	1.94	1.55	2.2	2.2	95.6	95.6

(continued)

Table 7.5 (continued)

Catchment: Z. Morave		River: Ibar	Profile: Prelez	Waters observation method: limnigraf				Start: 1934	Elevation: 542.6		Km from the confluence: 182	Surface km^2: 1109		
Months		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Year	Q (m^3/s)													
1997	NQ	0.83	1.22	1.22	1.15	1.22	19.9	6.44	1.02	0.83	0.96	0.96	0.96	0.83
	SQ	54.8	29.7	3.45	1.41	23.4	39	12.6	16.2	4.05	1.16	1.03	1.05	15.6
	VQ	62	59.9	26.4	2.38	49.4	74	16.5	55.6	19.4	14.4	1.09	1.09	74
1998	NQ	1.02	1.02	1.02	1.02	0.74	0.74	0.74	0.74	0.74	0.79	0.74	18.9	0.74
	SQ	1.19	1.11	1.07	1.06	0.84	0.8	0.84	0.80	0.78	0.91	2.78	19.9	2.7
	VQ	1.36	1.22	1.22	1.15	0.96	0.96	0.96	0.96	0.83	1.02	9.28	20.9	20.9
1999	NQ	18	2.16	1.22	1.02	57.8	49.4	47.3	0.96	0.57	18	18	12	0.56
	SQ	19.3	14.6	1.51	5.25	75.8	51.6	51.3	29.6	33	19.2	19.3	15.4	28.1
	BQ	20.9	19.9	2.16	14.4	93.6	53.5	53.5	53.5	53.5	19.9	19.9	19.9	93.6

Table 7.6 Flow characteristics for Leposavić for the observing period from 1991 to 1999

Catchment: Z. Morave		River: Ibar	Profile: Leposavić	Waters observation method: limnigraf				Start: 1934	Elevation: 445.3		Km from the confluence: 131		Surface km^2: 4701	
Months		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Year	Q (m^3/s)													
1991	NQ	9.34	10.01	18	17	24	15.2	–	7.24	7.88	9.72	12	12.8	–
	SQ	12.3	22.0	33	45.7	33.3	21.4	–	8.79	10.5	13.5	18.8	21.8	–
	VQ	33.7	119.0	74.3	126	102	70.6	–	15.2	34.3	45.7	60.7	55.4	–
1992	NQ	13.2	13.2	11.6	14.8	10.9	11.6	10.1	8.2	7.56	7.88	8.96	11.6	7.56
	SQ	22.6	17.7	15.1	53.4	13.8	13.7	13.3	9.61	9.67	9.34	18.3	18.1	17.8
	VQ	59.9	56.3	29.5	135	23	28.5	38.1	37.4	38.8	11.2	72.0	56.3	135
1993	NQ	11.2	12.0	13.2	16.5	12.0	9.72	7.24	6.6	6.28	7.56	8.96	11.2	6.28
	SQ	20.8	32.0	36	41.9	17.0	11.5	8.24	7.81	7.3	7.91	11.0	16.6	18.1
	VQ	58.0	61.6	125	91.0	40.4	50.5	15.6	25.9	14.8	8.2	15.6	64.2	125
1994	NQ	20.0	21.0	12.4	12.0	11.6	10.1	9.72	5.64	6.28	–	–	–	–
	SQ	21.0	32.7	14.8	17.5	16.2	10.9	12.3	7.13	7.09	–	–	–	–
	VQ	23.0	51.8	22.5	53.6	24.0	12.8	66.2	9.34	8.2	–	–	–	–
1995	NQ	6.28	14.4	12.4	18.0	16.8	11.2	8.58	8.96	11.2	10.5	16.0	21.5	6.28
	SQ	13.7	18.2	15.1	45.9	29.1	14.5	13.7	11.2	15.9	16.2	24.5	40.3	21.5
	VQ	36.0	30.0	22.5	152	38.8	17.6	40.9	28.0	51.8	41.6	55.4	91.6	152
1996	NQ	16.8	18.8	23.5	36.0	19.2	7.56	7.88	7.88	9.72	12.4	13.2	37.4	7.56
	SQ	27.6	56.8	40.7	74.2	29.3	12.4	9.48	9.28	16.4	15.4	45.5	75.1	34.2
	VQ	74.0	244	118	156	53.6	19.2	15.6	19.2	33.6	34.8	163.0	206	244

(continued)

Table 7.6 (continued)

Catchment: Z. Morave		River: Ibar	Profile: Leposavić	Waters observation method: limnigraf				Start: 1934	Elevation: 445.3		Km from the confluence: 131		Surface km^2: 4701	
Months		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Year	Q (m^3/s)													
1997	NQ	50	20.5	18	44.4	26	16	17.6	11.2	8.96	10.5	11.6	13.6	8.96
	SQ	88	34.2	37.7	91.5	43.5	27.4	20.3	21.9	13.4	13.7	13.8	26.9	36
	VQ	226	56.3	81.9	177	83.6	41.6	27	33	21.5	23	23.5	76.6	226
1998	NQ	13.6	14.4	16	16	15.2	6.92	4.5	6.28	9.72	14.4	16.8	29	4.5
	SQ	16.3	31	23.6	20.9	21.1	13.3	6.03	7.45	15.3	21.6	32.1	59.4	22.3
	VQ	19.2	94.3	60.6	53.6	30	22	8.96	8.96	21.1	43	63.8	174	174
1999	NQ	33.6	40.2	–	–	–	–	–	–	–	–	–	–	–
	SQ	76.5	102	–	–	–	–	–	–	–	–	–	–	–
	BQ	225	320	–	–	–	–	–	–	–	–	–	–	–

were adjusted, first to reach proper length, and afterward to achieve an appropriate position of each cross-section. Before the interpolation to a maximum distance of 20 m, additional cross-sections were added to all positions where it was necessary due to a sudden change in flow geometry. The geometry of cross-sections used in calculations was based on the WebGIS data (Kalaba et al. 2014). The Ibar river flow was analyzed from the thermal capacity evaluation point of view (Kalaba et al. 2014). In this study, the data on the turbine discharge from the hydroelectric power plant Gazivode was 30 m^3 s^{-1} will be used for calculation. The measurements were performed with precision and water flow meter P-770-M with probe Mini Water 6050-1008. The average velocity between the turbine discharge at Gazivode and the village Suvi Do is 1.12 ms^{-1}.

7.2.6 Neuro-Fuzzy Modeling

The neuro-fuzzy network represents the combination of neural networks and fuzzy logic methodology. The fuzzy methodology is the main part of the neuro-fuzzy network. The network has five layers. Each of the layers has a specific task in the estimation process. The main advantage of the neuro-fuzzy network is fuzzification of the input data and application of membership functions as fuzzy functions. By this way, one can avoid errors in experimental data. The neuro-fuzzy network is training by a back-propagation learning algorithm. Three statistical indicators were used to measure the neuro-fuzzy estimation accuracy. These factors were the root mean square error (RMSE) and the coefficient of determination (R^2). These two factors could fully measure the prediction accuracy of the neuro-fuzzy network.

7.3 Results and Discussion

The Ibar River flows through eastern Montenegro, Serbia and Kosovo, with a total length of 276 km. The river begins in the Hajla Mountain, in Rožaje, eastern Montenegro then passes through Kosovo and flows into the West Morava River, Central Serbia, near Kraljevo and to the Black Sea drainage basin. Its drainage area is 8059 km^2, the average discharge at the mouth 60 m^3/s. The river is not navigable. In its middle course, the river passes through Gazivode reservoir and Zubin Potok municipality, reaching the city of Kosovska Mitrovica. There it makes a sharp, elbow turn to the north flowing through Zvečan and Leposavić municipalities, entering Serbia at the village of Donje Jarinje. At Gazivode, the river is dammed, creating the artificial lake (area 11.9 km^2, altitude 693 m, depth 105 m).

Right on its elbow turn, the Ibar receives its longest (right) tributary, Sitnica. After its elbow turn and receiving the Sitnica, the Ibar flows through rather a narrow riverbed under the western slope of the Kopaonik Mountains. There it receives numerous tributaries were coming from mountain slopes. The biggest of them are rivers Drenska, Tvrdjanska, Jošanička, Leposavska, Sočanska, Bistrička, Vučanska, Banjska. During the rainy season, which usually occurs in April, May and sometimes in November, the water flow in the Ibar increases and represents a hazard for low-lying areas.

7.3.1 *Neuro-Fuzzy Model for Water Flow Calculation*

The series of climatic parameters were used as input parameters for the neuro-fuzzy modeling process. The first parameter was air temperature, the second parameter was vapor pressure, and the third parameter was humidity. In this study the reference evapotranspiration is analyzed based on several input parameters which represent weather parameters. There was a need for estimation which weather parameter has the highest influence for the reference evapotranspiration. The algorithm is based on evolutionary computation or genetic computation (Jovic et al. 2018a). After the estimation, the evapotranspiration was measured experimentally by weighing lysimeter. The soil weight was measured, and the change in water storage in the soil was modeled based on the weight change. Evapotranspiration was estimated as the weight changing with precipitation addition and percolation substitution. The percolation shows the movement and of fluids through porous materials. The used data was collected from WorldBank dataset for all countries in the European Union (Ilic et al. 2017).

In this study, the values of air temperature, vapor pressure, and humidity were used for generating the neuro-fuzzy model. Table 7.7 shows the statistical parameters of the input data. The neuro-fuzzy network was trained with the collected data from Table 7.7. Three bell-shaped membership functions were used for each input separately since the bell-shaped functions have the highest generalization capability. RMSE and R^2 were used as statistical indicators for the neuro-fuzzy prediction accuracy. Table 7.8 shows the statistical results for the neuro-fuzzy estimation for all vegetable months (April–September). It can be noted that the RMSE varies between 0.02 and 0.08 mm/day. The highest correlation coefficient could be observed for August. The lowest correlation coefficient could be noted for May. It is clear that the neuro-fuzzy model has good agreement with the experimental data for the vegetable period.

Table 7.7 Statistical parameters for neuro-fuzzy training process

Input parameters	Statistical parameters				
	Min.	Max.	Mean	Standard deviation	Variation coefficient
Air temperature (°C)	5.2	19.5	11.3	0.70	0.05
Vapor pressure (kPa)	0.6	1.3	1.00	0.06	0.04
Humidity (%)	44.8	88.7	77.96	2.13	0.06

Table 7.8 Performance statistics for the months in vegetable period

Indicator	Months					
	April	May	June	July	August	September
RMSE	0.08	0.07	0.02	0.05	0.07	0.06
R^2	0.91	0.92	0.95	0.95	0.98	0.94

7.3.2 Flood Risk Assessment

Flood hazards and flood prevention or mitigation measures can be different, depending on the flood characteristics. According to the Kosovo Flood Management Framework, there are three principal types of flooding relevant to Kosovo:

1. Large-scale lowland flooding
2. Flash flooding in upland areas
3. Flooding from a Dam failure

In Leposavić, Zvečan and Zubin Potok municipalities the floods can appear in three cases that are noted above (Stanojevic et al. 2018). The first case is the flood in Ibar valley, the second the case is when the floods can happen from the rivers of the Ibar branches of the river and the third case is if the floods can happen because of the damage of the Gazivode dam. The subject of this document is to value floods of the first case and the second case, since the third case is specific and the possibility to happen is very small. All branches of this river have torrential characteristics, which mean that the imbalance between the minimum and maximum quantity of water is big. These rivers are dangerous in the time when precipitations are big and last for a short time. Therefore, residents are not prepared, and the damages are significant, in humans, objects, and agricultural lands. The information on rivers and the catchments are enabled by the data presented through GIS, and presented in Table 7.9.

Based on the field data, the risk areas are categorized into three levels of risk. The infuleced areas are listed in the Table 7.10.

Even though all river Ibar tributaries has certain flooding capacity, as seen in the Table 7.10, the focus will be on the river Ibar area. The river Ibar is the main water body in the area, and the Gazivode lake was built to manage the river. The first risk area is situated near the dam, on the Lucka river, the tributary of Ibar. The floods are frequent because of the upper part of the river bed erosion and the material deposition in the lower part. The risk areas are graded as High (red), Medium (orange) and Low (yellow) risk areas as presented in the Fig. 7.8.

However, after the dam, the river Ibar goes out of the bed and floods the agriculture land and residential area.

1. First region—downstream from the discharge of Sitnica into Ibar (5 km)
2. Second region—downstream from the discharge of Ceranjska river (7.3 km).

Because of the abundant vegetation on its banks, and non degradable waste in the water, the river becomes overloaded, forming the bottlenecks contributing the floods

Table 7.9 River Ibar catchment properties

ID1	Perimeter	River_Name	AREA_m	AREA_km
1	55,264.18	Banjska r.	75,843,819.7	75.84
2	23,132.5	Jagnjenička r.	19,987,348.31	19.99
3	7485.39	Međeđi potok	3,048,587.65	3.05
4	11,036.62	Kuševski potok	5,148,055.1	5.15
5	30,705.83	Brosovačka r.	44,430,955.25	44.43
6	14,816.25	Zubin potok	8,595,347.04	8.60
7	4954.6	Bjelevode p.	871,906.01	0.87
8	6671.93	Radovića potok	1,749,144.35	1.75
9	7868.54	Čabranska	3,366,995.89	3.37
10	13,744.58	Zupčanska_reka	7,108,909.23	7.11
11	20,048.99	Dragočevska reka	15,551,783.12	15.55
12	7662.32	Vranovićki p.	2,930,181.2	2.93
13	7963.21	Banjski p.	2,728,652.18	2.73
14	20,154.91	Varaška reka	17,178,356.21	17.18
15	26,510.91	Brnjačka reka	33,143,367.15	33.14
16	24,791.79	Čečevska reka	24,619,430.65	24.62
17	12,957.26	Koriljska r.	7,874,550.13	7.87
18	33,652.05	Koriljska r.	26,800,200.24	26.80
19	18,325.67	Seoska r.	13,379,825.81	13.38
20	38,751.45	Vučanska r.	28,809,803.21	28.81
21	31,028.85	Grkajska r.	23,330,043.17	23.33
22	45,413.27	Josanička r.	57,133,153.57	57.13
23	20,030.79	Borova r.	18,746,170.04	18.75
24	30,645.81	Vračevska r.	38,610,419.68	38.61
25	17,022.18	Trebićka r.	11,181,421.85	11.18
26	9942.76	Trifunski p.	3,934,417.53	3.93
27	6339.9	Kremenjački p.	1,871,112.67	1.87
28	34,274.51	Dobravska r.	28,364,482.8	28.36
29	40,603.23	Sočanička r.	42,176,001.62	42.18
30	27,494.19	Ceranjska r.	22,113,452.14	22.11
31	10,291.9	Veliki p.	3,928,108.81	3.93
32	61,642.8	Bistrica	161,946,124.1	161.95
33	12,632.48	Doljenaška reka	7,020,047.33	7.02
34	11,171.77	Radevački p.	4,735,101.12	4.74
35	29,809.79	Leposavska r.	27,386,129.14	27.39
36	37,738.34	Tvrđanska r.	41,721,602.79	41.72

(continued)

Table 7.9 (continued)

ID1	Perimeter	River_Name	AREA_m	AREA_km
37	43,500.66	Drenska r.	61,804,284.54	61.80
38	13,136.88	Lešanska r.	6,868,945.76	6.87
39	10,536.51	Žigoljski p.	4,128,262.85	4.13
40	12,193.84	Ostrački p.	5,840,653.24	5.84
41	28,899.58	Bistrička Reka	31,401,376.29	31.40

(Fig. 7.9). In general, water flushes topsoil from the river banks, and even larger trees are falling to the river. It can be also a risk to the bridges, and it can lead to the fractures of the pillars. In the first region, the Ibar river is situated in the middle of two roads: Regional road Kosovska Mitrovica-Leposavić and railroad. These are the boundaries of the river, preventing the outflows over the roads. The Sitnica river is bringing large quantities of deposits and increases the river bed and consequently the water level. The industrial waste deposits are situated on the river Ibar banks—Gornje polje on the right bank, and Zarkov potok and Zitkovac on the left bank of the river, polluting the river with heavy metals and discharging the toxic solid materials through erosive canals and ditches into the river (Milentijevic et al. 2013). The second region is located downstream from the Ceranjska river discharge to the river Ibar. In this section, the following rivers are tributaries of the river Ibar: on the left side-Vučanska river and Grkajska river; on the right side: Ceranjska river, Zrinjski stream, Sočanička reka and Dobravska reka. Right side of the Ibar is limited by the regional road. The river profile is reduced as those tributaries bring the sediment and woods from the surrounding mountains. In the most of the cases, the agriculture land is impacted by the flood risk, as shown in the Fig. 7.10.

7.4 Conclusion

Based on the available data, it is clear that there are two periods of large waters during the year, and those happen in the spring and autumn, as well as one period of low waters in August. By analyzing the diagrams of monthly precipitations and characteristic flows (NQ, SQ, and VQ) in analyzed water meter stations, it is obvious that large waters mainly occur as a consequence of the heaviest precipitations. The maximum daily flow is proportional to heavy rain and snow melting.

In the observed area, runoff is very large, while, the infiltration of the precipitations into the ground waters is very low. According to some reports, only 15% of the precipitation is penetrating the unconfined bed and reaches the aquifer. It is concluded that the floods have happened as a result of erosion in the upper part of the river basin and alluvial sedimentation of these alluvial in the lower part of the river. Human activities have influenced this phenomenon (waste, trees, etc.) and also their inactivity (not maintenance of the river) has been the main factor that has contributed to flooding.

Table 7.10 Risk areas in the river Ibar catchment, and possible impacted infrastructure

ID1	River_Name	Category_Risk	Risk_Area	Infrastructure
65	Bistrička Reka	High	4331.49	Agricultural land
66	Vračevska Reka	High	2771.41	Agricultural land
67	Drenska Reka-3	High	7273.04	Agricultural land
68	Drenska Reka-2	High	4022.38	Agricultural land, wells
69	Drenska Reka-1	High	4313.84	Agricultural land
70	Tvrđanska Reka	High	23,599.6	Residential buildings, road, yards, agricultural land
71	Josanička Reka	High	6689.62	Agricultural land, road, substation
72	Sočanicka Reka	High	17,213.33	Agricultural land
73	Ibar-2	High	1,124,061.76	Agricultural land, bridges, roads
74	Vučanska Reka	High	25,769.83	Agricultural land, bridge, roads
75	Ceranjska Reka	High	3394.58	Agricultural land, roads
76	Banjska Reka	High	7999.69	School, residential building, road, yards, agricultural land
77	Lučka_Reka_2	High	4544.83	School, road, business building
78	Lucka_Reka_1	High	38,817.71	Agricultural land
79	Ibar-1	High	1,308,722.14	Agricultural land, bridges, roads
80	Kozarevska Reka	High	5861.6	Residential building, road, yards, agricultural land
81	Zubin Potok	High	25,287.4	Administration building, residential building, road, yards
82	Koriljska Reka	High	8582.1	Agricultural land
83	Jagnjenička Reka	High	1109.6	Agricultural land, bridge
84	Bistrička Reka	Low	6931.53	Agricultural land
85	Vračevska Reka	Low	17,327.76	Agricultural land, bridge
86	Drenska Reka-1	Low	6617.68	Agricultural land
87	Tvrđanska Reka	Low	45,966.24	Residential buildings, road, yards, agricultural land
88	Jošanička Reka	Low	10,332.38	Agricultural land, road, substation
89	Sočanička Reka	Low	30,141.93	Agricultural land

(continued)

Table 7.10 (continued)

ID1	River_Name	Category_Risk	Risk_Area	Infrastructure
95	Vučanska Reka	Low	38,053.5	Agricultural land, bridge, roads, residential building, fish pond
96	Ceranjska Reka	Low	14,918.47	Agricultural land, roads
98	Banjska Reka	Low	13,212.38	School, residential building, road, yards, agricultural land
99	Lučka_Reka_2	Low	7558.21	School, road, business building
100	Lučka_Reka_1	Low	63,332.76	Agricultural land
101	Kozarevačka Reka	Low	8027.91	Residential building, road, yards, agricultural land
102	Ibar-1	Low	1,540,323.64	Agricultural land, bridges, roads
103	Zubin Potok	Low	32,749.99	Administration building, residential building, road, jards
104	Koriljska Reka	Low	15,125.7	Agricultural land
105	Jagnjenička Reka	Low	3467.02	Agricultural land, bridge
110	Ibar-2	Low	1,512,430.58	Agricultural land, bridges, roads
111	Lučka_Reka_1	Medium	3338.71	Agricultural land
112	Lučka_Reka_1	Medium	7280.11	Agricultural land
113	Lučka_Reka_2	Medium	433.58	School, road, business building
114	Jagnjenička Reka	Medium	137	Agricultural land
115	Koriljska Reka	Medium	2338.37	Agricultural land
116	Ibar-1	Medium	16,555.6	Agricultural land
117	Ibar-1	Medium	7656.11	Agricultural land
118	Josanička Reka	Medium	304.86	Agricultural land
119	Josanička Reka	Medium	223.23	Agricultural land
120	Josanička Reka	Medium	126.06	Agricultural land
121	Ibar-2	Medium	27,562.13	Agricultural land
122	Ceranjska Reka	Medium	406.99	Agricultural land, roads
123	Tvrđanska Reka	Medium	1909.01	Agricultural land

Fig. 7.8 Flood risk assessment of the Lucka river (Color Figure Online)

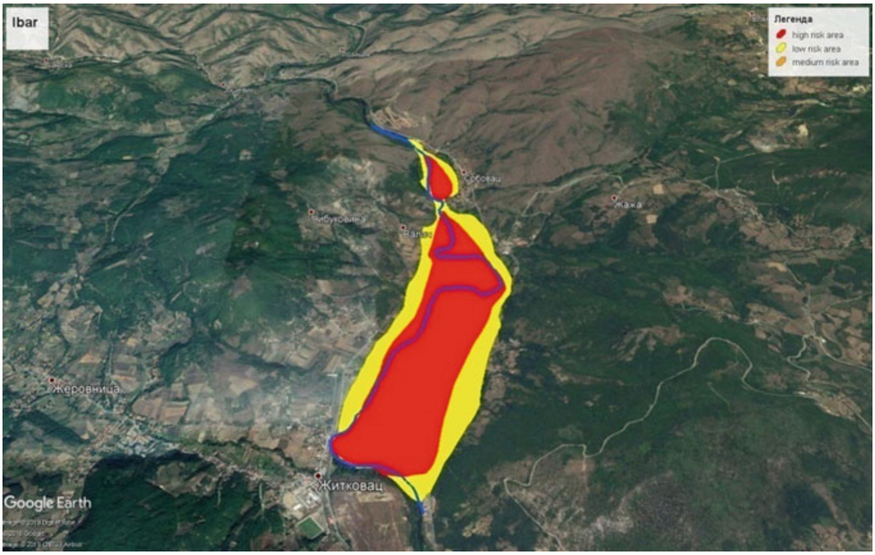

Fig. 7.9 Endangered regions in the river Ibar area downstream from the river Sitnica discharge (Color figure online)

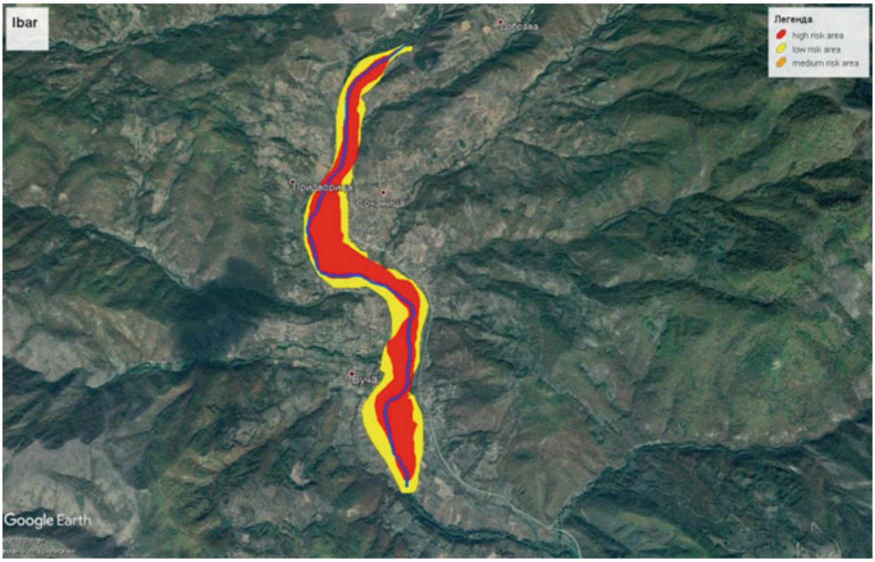

Fig. 7.10 Endangered areas downstream from the discharge of Ceranjska river and Sitnica (Color figure online)

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Chapter 8
Neuro-fuzzy Techniques and Natural Risk Management. Applications of ANFIS Models in Floods and Comparison with Other Models

Georgios K. Tairidis, Nikola Stojanovic, Dusan Stamenkovic and Georgios E. Stavroulakis

Abstract During the last decades, floods are getting more and more dangerous and they cause a lot of destruction either for human lives and/or for people's properties. Due to different climate conditions, some parts of the world present increased levels of danger from floods. For this reason, the development of a robust tool for the prediction of floods is essential for the protection of people who live in these areas. An adaptive neuro-fuzzy inference system is a hybrid fuzzy system, which is based on Sugeno fuzzy inference along with the use of artificial neural networks for training. In this work, the current literature on adaptive neuro-fuzzy inference system models, which are used for flood prediction, is reviewed. More specifically, the mode of operation of such decision-making systems, along with their major advantages and disadvantages are presented in detail. A comparison with other similar models is also carried out.

Keywords Adaptive neuro-fuzzy inference system · ANFIS · Natural disasters · Floods

Abbreviations

ANFIS	Adaptive neuro-fuzzy inference system
ANGIS	Adaptive neuro genetic algorithms integrated systems
ANN	Artificial neural network
ARIMA	Autoregressive integrated moving average
ARMA	Autoregressive moving average
BPNN	Back-propagation neural network

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CE	Coefficient of efficiency
CGF	Conjugate descent algorithm
CORR	Coefficient of correlation
D	Discrepancy ratio
FIS	Fuzzy inference system
GDX	Gradient descent algorithm
GIS	Geographic information system
GNN	Generalized neural network
HN-FIS	Hybrid neuro-fuzzy inference system
LM	Levenberg–Marquardt algorithm
MAE	Mean absolute error
MAPE	Mean absolute percentage error
MLP	Multi-layer perceptron
Mo-ANFIS	Modified ANFIS
MONF	Metaheuristic optimization neuro-fuzzy
PSO	Particle swarm optimization
R2	Coefficient of determination
RFFA	Regional flood frequency analyses
RMSE	Root mean square error
SAC-SMA	Sacramento technique

8.1 Introduction

Soft computing tools, mainly fuzzy and neural systems, are used in several applications, including natural disaster prediction and management. The correlation of input variables with output (prediction or decision) ones is based on known logical rules, in fuzzy systems, or on blind processing of mass data of examples, in the case of neural systems. Neuro-fuzzy systems represent a combination of these two approaches, where a fuzzy framework representing the basic structure of the inference system is further tuned with the usage of input-output examples and the technique of neural network training.

Fuzzy variables and sets represent an extension of classical quantities with the addition of a membership function which takes values between 0 and 1 and indicates the degree of trueness of the underlying quantity. They are similar in several ways to probability theory and support calculus rules and more complex tasks like optimization of fuzzy systems etc. In terms of prediction and control, the ability of fuzzy inference systems (FIS) to avoid sudden changes of output, for small changes of the inputs, is highly appreciated. Fuzzy systems are used in several fields; e.g. engineering, control, robotics, economics, etc. The core structure of such systems is based on the creation of membership functions, i.e. functions which indicate the degree of fuzziness of a fuzzy set, for inputs and outputs, along with a suitably defined set of verbal rules which are used by the decision-making system. The membership functions can be chosen either by the experience of the designer or even arbitrarily. The rules should be based on the knowledge of an experienced user of the system or process. When such a system is built, the designer cannot always decide the values for its parameters only by considering the available data. In this case, adaptive fuzzy systems can be used instead.

An adaptive neuro-fuzzy inference system (ANFIS) is a very popular technique which uses artificial neural networks (ANNs) and fuzzy theory simultaneously. This type of systems automatically interprets input and output information from experimental or other data in order to create a rule-based decision-making system by using the learning ability of neural network structures. However, in order to achieve adequate accuracy of predictions, an exact and representative set of training data (set of inputs and outputs) is necessary. Information about adaptive fuzzy systems and control can be found in classical monographies (Wang 1994).

The first ANFIS model was developed in the early 1990s (Jang 1993). The predecessor of ANFIS systems was a fuzzy system, modeled using generalized neural networks (GNN) and a Kalman filter in order to achieve minimum squared error (Jang 1991). Neuro-fuzzy modeling refers to the application of learning into fuzzy inference systems. The backpropagation of errors algorithm is the most commonly used technique for supervised learning, i.e. for the identification of the parameters of ANNs, and thus for ANFIS systems as well.

A well-established implementation of ANFIS is presented in the work of Stavroulakis et al. (2011). The first step is the construction of a detailed mechanical model of the total system. Subsequently, the dynamics of the system are calculated and saved. These data are used for training using the ANFIS procedure. The resulting controller can be used for the control of the whole system. Numerical results indicate the efficiency of the proposed control scheme for vibration suppression of smart beam structures under several types of excitation. It is also concluded that the control is not only efficient, but smooth as well.

It is no exaggeration to claim that neuro-fuzzy systems consist one of the more powerful tools either for control as well as for prediction. In fact, such systems can be used in a wide range of real-life applications from the control of smart structures such as beams and plates (Tairidis 2019; Tairidis et al. 2013; Muradova et al. 2017) and structural damage identification (Hakim and Razak 2013), to the trajectory control (Aissa and Fatima 2015) and dynamic morphing (Tairidis et al. 2019), even for stock market predictions (Boyacioglu and Avci 2010) and of course natural disasters predictions, such as forest fires (Ahmed et al. 2017; Bui et al. 2017; Wijayanto et al. 2017), earthquakes (Mirrashid 2014), tropical cyclones (Duong et al. 2013), etc. In the present paper, the capabilities of ANFIS for the prediction of floods will be presented in detail, since such systems have been widely used in water and floods research.

8.2 Adaptive Neuro-fuzzy Inference Systems Modelling

The architecture of ANFIS is based on a fuzzy inference system which is implemented using neural networks for the modification of its parameters. Thus, before proceeding with the ANFIS systems, a small introduction to fuzzy systems is necessary.

8.2.1 Fuzzy Inference Systems

A FIS is a simplified combination of complicated subsystems (see Fig. 8.1). More specifically, such systems consist of the following elements:

(a) A set of membership functions which are introduced through a fuzzification process on the involved parameters. They quantify the characteristics of each value taken by these parameters by defining overlapping fuzzy areas like ‘small’, ‘medium’, ‘large’ etc.
(b) A base of verbal IF-THEN rules, taking values from the previously introduced fuzzy categories.
(c) A decision-making unit, that is, an inference process.
(d) A defuzzification interface for the transformation of the fuzzy output into a classical (crisp) value which can be used further for control or prediction purposes.

The inputs are converted into fuzzy variables through the fuzzification process. Then, a set of rules is drafted, which together with the data, forms the knowledge data base. Subsequently, the decision is made by implication, and the fuzzy output arises. Finally, this value is defuzzified according to the needs of each problem. This whole process is depicted in Fig. 8.1.

The degree of fuzziness of a fuzzy variable (input or output) is defined by its membership functions. In fact, the fuzziness is a term which refers not to the logic itself, but to the vague description of the system variables. For example, we say that someone is tall, instead of telling their actual height. This fuzziness is expressed through the membership functions. The representation of these functions can be done either numerically or graphically. The graphical representations include various

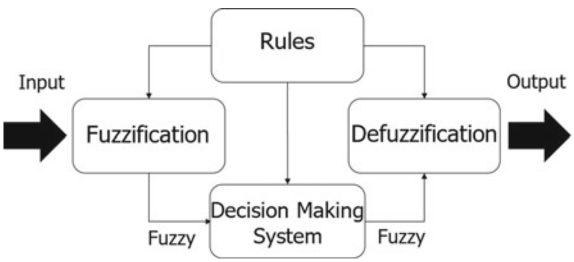

Fig. 8.1 The schematic representation of a fuzzy system

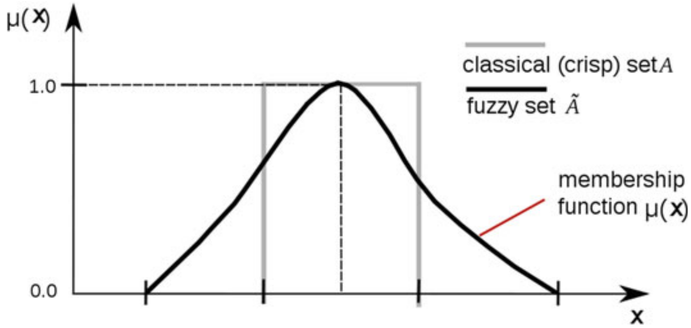

Fig. 8.2 Graphical representation of a membership function in comparison with a crisp set

forms, either symmetric or asymmetric. The most popular options include among others:

(a) Triangular membership functions
(b) Trapezoidal membership functions
(c) Bell membership functions
(d) Gaussian membership functions
(e) Sigmoid membership functions
(f) Polynomial membership functions

A graphical representation of a membership function in comparison with a crisp set is shown in Fig. 8.2.

The verbal rules can be formed by deterministic statements (e.g. velocity = high), condition statements (e.g. IF grade $\geq$ 8.5 THEN excellent) or statements without condition (e.g. GO TO). The properties of the set of rules is the fullness, consistency, continuity and interaction. A fuzzy system is usually described with more than one rules. The process of summarizing the rules for obtaining an overall conclusion is called aggregation. In the case where the rules are associated with the AND operator, the determination of aggregation is done by conjugation of the rule system taking the intersection of the individual rules. If the individual rules are associated with the OR operator, the determination of aggregation is done by the disjunction of the rule system, calculating the union of the individual rules. The methods of conjugation and disjunction are also known as methods of minimum (min) and maximum (max), respectively. An example on the interaction between fuzzy rules and the fuzzified values of two inputs to produce one fuzzy output, along with defuzzification (final crisp value) is depicted in Fig. 8.3.

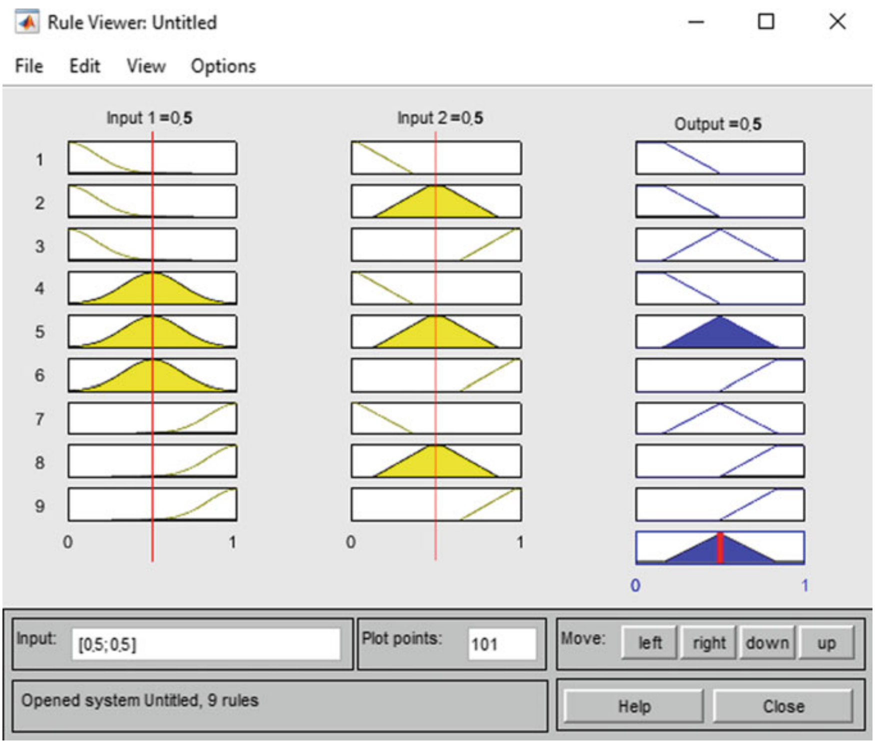

Fig. 8.3 Interaction between fuzzy rules and inputs in the fuzzy toolbox of MATLAB®

8.2.2 Adaptive Neuro-fuzzy Inference Systems

ANFIS was introduced at the University of California by Jang (1993). This type of adaptive systems consists of fuzzy rules, which, in contrast to classical fuzzy systems, are local mappings instead of global ones (Jang and Sun 1995). This feature is really important when on-line learning is considered. The learning procedure could be hybrid, i.e. the proposed model can construct input-output mappings based on both human knowledge and appropriate input/output data. However, even when human knowledge is unavailable, it is still possible to generate the rules using a learning process according to a desired performance criterion. This means that, rather than choosing the parameters of the system (membership functions, rules, etc.) arbitrarily, an automated process based on neural networks (see Fig. 8.4) can provide tailor-made values based on the available system data. Moreover, a set of rules, or other parameters of the system can be also considered in the same way (Tairidis and Stavroulakis 2019).

The modeling of these systems is quite similar to other system identification techniques, that is, a parameterized model is first considered and then a carefully selected set of training data is used for the modification/adjustment of fuzzy parameters. In case of noisy systems or when the collected data are not representative of the system,

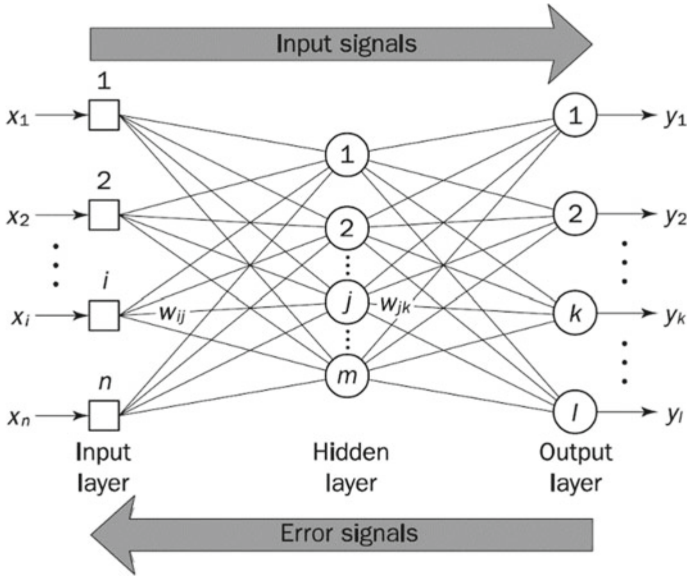

Fig. 8.4 A typical feed-forward back-propagation neural network

model validation is necessary, and can be done using another set of data, the so-called data for testing. In general, model validation is the process by which inputs on which the system was not trained, are presented to the trained model, to check the accuracy of the prediction. This is necessary because after a certain point in the training process, the model may overfit the training data. The testing data also allow the designer to check the generalization capability (robustness) of the resulting system (Tairidis and Stavroulakis 2019).

There are two methods for the generation of the initial system, that is the formation of membership functions, which are also called clusters, and the fuzzy rules. The first one applies grid partitioning on the data, while the second one categorizes the training data by using subtractive clustering.

Grid partition is one of the most common options when designing fuzzy systems, especially if the desired amount and the type of clusters is known. This method usually considers certain of the parameters of the system, such as the input variables. This strategy is affected by the curse of dimensionality; however, it works perfect for a small amount of membership functions for each input (Jang and Sun 1995). On the other hand, the subtractive clustering method is the suitable option if there is lack of knowledge for the examined system (Chiu 1994). It is a fast algorithm which estimates the number of clusters and the cluster centers in a set of data. These estimates can be used for the initialization of identification methods like ANFIS.

After loading the training data and generating the initial FIS structure, the learning process can be proceed in order to train the membership function parameters to emulate the available training data.

The backpropagation method, which is a gradient descent method, can be used for this purpose. A theoretical framework for this method can be found in (le Cun 1988). A hybrid method, that is, a combination of least-squares error method (LSE) and backpropagation can be also used. Least squares method is a standard approach in regression analysis which is used for the computation of an approximate solution in overdetermined systems. The hybrid method is based on backpropagation for the calculation of the parameters associated with the input membership functions, and least squares method for the estimation of the parameters related to the output membership functions. It is shown that the use of least-squares method for the calculation of is of great importance, since the learning time would be ten times longer without it (Jang 1993).

The number of training epochs and the error tolerance are the stopping criteria for training and are both set by the designer. The training process stops whenever one of the criteria is met, i.e. when the maximum epoch number is reached, or the training error goal is achieved. If the impact of the training error to the results is unknown, error tolerance should be set to zero.

The results of each iteration can be used as initial conditions for the next epoch in order to enhance accuracy. The training error, which occurs in the output, decreases, at least locally, throughout the learning process, which means that, the more the initial membership functions approach the optimal ones, the easier it will be for the training algorithm to converge. Human knowledge or expertise about the target system can be of great assistance in setting up these initial parameters of the fuzzy inference system. An example of ANFIS training is given in Fig. 8.5. More details are available in Tairidis (2016).

8.3 Adaptive Neuro-fuzzy Inference Systems for the Prediction of Floods

The adaptive neuro-fuzzy inference system had been extensively used for flood forecast, since it is a tool which can systematically and effectively construct forecast models. The complete strategy of building a flood forecast model by using a neuro-fuzzy network is analytically described in the work of Chen et al. (2006). For the purpose of comparison, the commonly used back-propagation neural network (BPNN) is also examined.

Namely, a neuro-fuzzy approach for flood forecasting is presented. The motivation lies primarily in evaluating the feasibility of applying a hybrid scheme to the problem, thereby providing an alternative to fuzzy and neural approaches. It is assumed that stream flow series can be estimated by using a set of if-then rules that relate future stream flows based on antecedent data. This study has assignment to illustrate the practical application of forecasting models on the Choshui River. The inputs are the level of water, rainfall levels, and travel time of the flow.

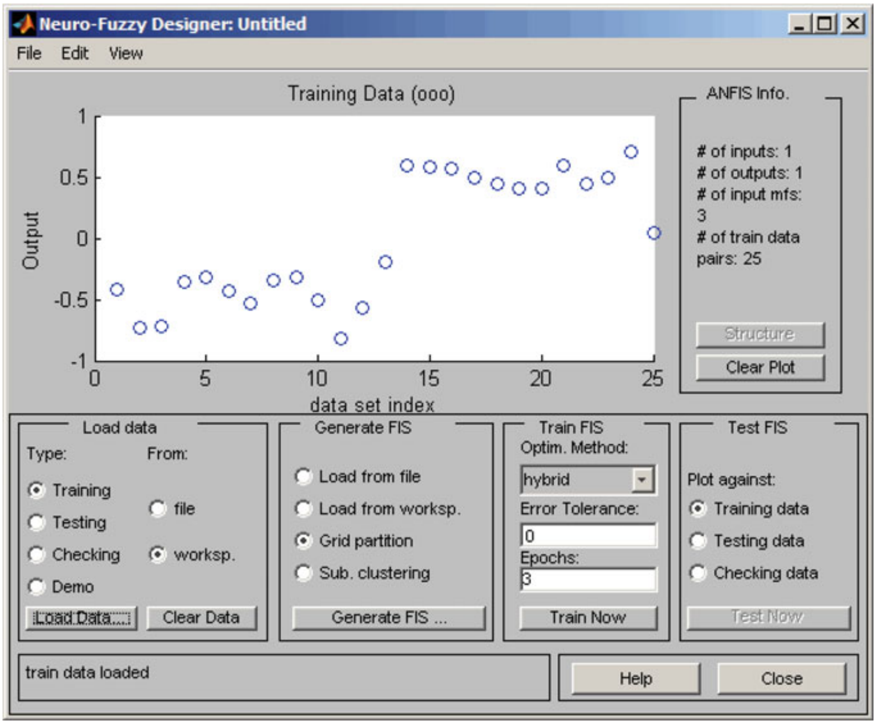

Fig. 8.5 An example of training through ANFIS of MATLAB®

Twenty-three events were used for this study. The data were divided into three independent subsets: the training, validating, and testing subsets. The training subset includes 1554 sets of data, the validating subset has 222 sets, and the testing subset also has 222 sets. First, the training subset is used to build networks and to adjust the connected weights of the constructed networks. Then, the validating subset is used to simulate the performance of the built models to check their suitability for generalization, and the best network is selected for later use. The testing data set is then used for final evaluation of the selected network performance.

The effect of rainfall on the water level varies from time to time in all rain gauging stations and cannot be identified as a solid relation, whereas the watershed's average rainfall provides other useful information for flood forecasting. The comparative results obtained by the BPNN and ANFIS provide evidence that the ANFIS can offer a higher degree of reliability and accuracy than BPNN in flood forecasting.

For further investigation, three ANFIS models, based on different input information, were built to perform one- and two-steps ahead flood forecasting. The results show that:

1. A downstream water level can be suitably estimated by just using several of the previous downstream and upstream water levels as input to the ANFIS model

2. Using the differential values, which could remove the non-stationarity of a time series, could provide better performance than the original values
3. Adding the watershed average rainfall information in addition to water-level information would enhance the forecasting accuracy.

In the work of Nayak et al. (2004), the application of ANFIS to hydrological time series modeling is presented and illustrated by an application of modelling the river flow of Baitarani river in Orissa state, India. This method does not require a priori knowledge of the model, in contrast to most of time series modeling techniques. The objective of the study was to investigate the potential of neuro-fuzzy systems in modeling hydrologic time series and to assess its performance relative to ANN and other traditional time series modeling techniques such as autoregressive moving average (ARMA). The applicability of the method is demonstrated by modeling river flow for an Indian basin.

An ANFIS model has been tested for time series modeling of river flow. The river Baitarani is one of the biggest rivers of Orissa state in India. The drainage area of this river is 14,218 km^2, while the average annual rainfall of the area reads 1187 mm. Monsoons last from June to October and nearly the 80% of the annual precipitation occurs during these months. Heavy flow is created in lower reaches during the monsoon season que to the extreme rainfall.

For the ANFIS model three inputs were used:

- Rainfall
- Evaporation
- Other exogenous variables

The analysis starts with one antecedent flow as the input vector and an ANFIS model is constructed. The input vector is then modified by successively adding flow at one more time lag, and a new ANFIS model is developed each time. The model with the best fit was trained using 6, 12, 18 years of data, for testing during the period from 1990 to 1995. From the results it was shown that all models performed in a similar way, as the root mean square error (RMSE) do not vary significantly. However, it is very important to mention that all models presented poor efficiency during training. Poor efficiency indicates that ANFIS model prediction is far from the mean values. More specifically, the model showed a training efficiency of 81.95% (increase of 27.86%) and a validation efficiency of 81.55% (gain of 11%). The correlation coefficient between the computed and observed flow series was stable during the training, as well as the validation process.

In order to have a real validation of the potential efficiency of the ANFIS model, its results were compared to traditional time series models. The performance of the ANFIS model has been also compared with an ARMA model. It was shown that the performance of both ANFIS and ANN models was similar during training and validation periods.

Moreover, although the ANFIS model was capable of preserving the statistical properties of the time series, the model might show poor performance if it is not trained carefully. The proposed model showed good performance in terms of validation using statistical indices.

Short-term flood forecasting with a neuro-fuzzy model is presented in the study of Nayak et al. (2005). Namely, the potential of the neuro-fuzzy computing paradigm to model them rainfall-runoff process for forecasting the river flow of Kolar basin in India is explored. A simple FIS and a classical ANN were used for validation. The paper demonstrates the applicability of neuro-fuzzy systems in developing effective nonlinear models of the rainfall-runoff process for short-term flood forecasting. A neuro-fuzzy model, that forecasts hourly flood discharge at a given stream flow gauge station at different lead times, has been developed for the river Kolar (a tributary of Narmada) in India.

Only one input, the rainfall, and one output, the runoff were considered; thus, a single input–single output system was developed. Most papers in the literature accounts for inputs and outputs like rainfall and runoff. Data for rainfall and runoff are also used in Kolar basin in India during the monsoon season for three years (1987–1989) between July to September. The total available data are divided in two sets; a calibration set (1987–1988), and a validation set (during 1989).

Different models for lead times of up to 6 h have been developed in the study. The parameters of the model are identified using the calibration data set, and the model is tested for its performance on the validation data set. It is evident that the slope of the RMSE versus the prediction time horizon is minimum for the ANFIS model during calibration as well as during the validation process. Moreover, it was found that while the ANFIS model forecasted the flows with a RMSE of 77.52% at 6 h, the ANN and FIS models forecasted the flows with an RMSE of 100.38% and 96.48% respectively, which is clearly bigger.

The results suggest that the value of the percent error in peak flow prediction, which is a useful index in simulating events such as floods, is within reasonable limits for the ANFIS model. It is worth mentioning that the ANFIS was able to forecast the peak flows with minimum relative error, irrespective of the magnitude of the peak flow. It is important to know whether the model is predicting higher- or lower-magnitude flows poorly, which may help in further refining the model. The foregoing discussions clearly illustrate that the ANFIS model performs better than the ANN and FIS models in modeling the rainfall-runoff process. The performance of these models was comparable at a 1-h lead time, but only the ANFIS tends to preserve the performance at higher lead times compared to the others. Although the preliminary concepts of the FIS and the ANN were developed on a different basis, they are essentially rooted in the same concepts of data driven modeling.

To sum up, the objective of the paper was twofold; one was to demonstrate the potential of the neuro-fuzzy computing paradigm in modeling the rainfall-runoff process, and second was to evaluate the relative merits and demerits of this paradigm with reference to already popular ANN and fuzzy modeling approaches. ANFIS presents good results, and in the same time it can be easily implemented by any flexible neural network simulator. Hence, its use is very attractive for the development of forecasting models.

A neuro-fuzzy-based adaptive flood warning system for Bangladesh was developed by Hossain et al. (2014). The input data have been collected using wireless sensor network. The proposed model has collected input parameters, such as rainfall, river water level and river water flow, from a specific site and send the data to decentralized node. Based on the inputs, an ANFIS model has determined the flood possibility index. The main objective of this work was to design a neuro-fuzzy-based adaptive flood warning system for Bangladesh which predicts the possibility and persistence of flood in an area. In the proposed system, a rainfall measurement sensor, a river water level measurement sensor and a river water flow measurement sensor will collect data about the condition of rainfall, river water level and river water flow respectively, and send them to a decentralized node via a wired medium.

The system generates a warning in a particular site based on the values of the three inputs and determines the flood persistence index by comparing with last ten years data. Finally, linguistic parameters such as "red", "yellow" or "green" appear on a geographic information system (GIS) map in order to show the possibility and severity of a potential flood.

A detailed application of ANFIS in river flood forecasting is presented by Ullah (2013). More specifically, the models are used to forecast common downstream flow rates and flow depths in a river system. For this purpose, three different ANFIS modes were considered; a depth–depth model, a depth–discharge model and a discharge–discharge model.

The models were used for the prediction of 1-h downstream flow rate and flow depths in the river. The ANFIS model with selected categories and membership functions are verified by autoregressive integrated moving average (ARIMA). For the validation of the ANFIS model, data from river Barak in India and river Tar in the USA were used.

The inputs of the system are the upstream depth flow, the flow rate in time, the downstream flow depth and the downstream flow rate. The whole dataset of the flood period is segmented into two categories, namely, high flows and low flows; the categories are selected such that peak flow rate has zero membership value in low flow category and minimum flow rate has no or zero membership in the high flow category.

Four statistical criteria were used in the analysis; the mean absolute errors (MAE), the coefficient of correlation (CORR), the RMSE and the coefficient of efficiency (CE). The CE and CORR values for different ANFIS models were found to be more then 0.82–0.86, while CE and CORR values obtained from the ARIMA were more then 0.81–0.83. From the comparison between ANFIS and ARIMA models, the results showed better performance from ANFIS model in forecasting downstream flow depths and discharges in the studied river system. The application of the ANFIS model was further tested with data from the Tar river, where the forecast of downstream discharge has been done using multiple inflows in basin.

In Patel and Parekh (2014), artificial intelligence techniques, such as ANFIS for the prediction of floods on the Subarmati river, Mehsana district in India, is presented. The technique was in fact a combination of the learning ability of neural networks, along with the transparent linguistic representation of a fuzzy system. Two inputs were considered for the analysis; the past discharge and the rainfall levels. These inputs are essential for ANFIS modelling in this case. Statistical indices, such as

RMSE, R, R^2 and D are presented as well. The ANFIS model was compared with the statistical method Log Pearson III. According to this method 70% of the data were used for training and 30% for testing. The output of the final model is the predicted discharge.

In this study ANFIS has been developed to run real time flood forecasting and the statistical method Log Person III was used for evaluation. From the results it is shown that the coefficient of correlation of the observed peak discharge is 0.99 from prediction and 0.98 from statistical data, which is very close. The coefficient of determination of observed peak discharge is 0.98 from forecasting and 0.97 from statistics. Also, the predicted peak discharge as shown from the coefficient of correlation is 0.89 from ANFIS, and 0.92 from the experimental data. Finally, the coefficient of determination of observed peak discharge is 0.79 from prediction and 0.84 from the values which were used for validation, which again is acceptable.

Another study on the use of hybrid neuro-fuzzy inference systems for flood event vulnerability forecasting has been conducted by Supatmi et al. (2019). More specifically, detailed information and experimental data for flood forecasting in Indonesia are provided in this study. The best access for performance predictions and vulnerabilities is sought. Three different models are considered and tested in this article; a Mandani FIS, a Sugeno FIS and a hybrid neuro-fuzzy inference system (HN-FIS). The data which are used, has been collected from the area of Bandung Indonesia, where the tropical climate is convenient for monsoon. Average rainfall is between 2000 and 3000 mm per year and temperature is from 12 to 24 °C in range, while humidity is about 78% in monsoon season and 70% in dry period.

The inputs of the model, along with their fuzzy categories (in parenthesis) for this study were chosen to be:

- Population density (very low, low, high, over)
- Altitude of the area (low, moderate, high)
- Rainfall data (low, moderate, high, extreme)

As for the outputs, one variable, which indicates how to respond when flood occurs is considered, and that is:

- Vulnerability of flood (safe, alert, danger)

Mamdani FIS is more widely used, particularly for decision support applications, and mostly refers to the intuitive and interpretability nature of the rule base. On the other hand, Sugeno FIS do not have linguistic terms, which means that the model cannot describe in an exact way how it acquires the output from the decision-making platform. The Mamdani fuzzy inference system was combined to form a HN-FIS. The major advantage of the proposed model is its capability of automatically learning and obtaining an output of fuzzy logic decision more clearly, which can exhibit human judgment reasonable.

In the work of Khasiya (2017) the prediction of flood of the river Tapi in India, using ANFIS linguistic representation, is discussed. The data which are used for ANFIS prediction in this case, are the daily rainfall data and the daily peak discharge data.

The objective of the study was to evaluate the ANFIS model with "log Pearson type III", a statistical method which is used in the forecasting of floods. The correct assessment requires accurate data for the amount of precipitation and discharge. ANFIS systems are constructed, used and tested for different models. The results are compared with the ones received by Gumbel's method.

Again, the ANFIS model has been developed to run real time flood forecasting. Three Gaussian models were used for input variables. More specifically, the model is developed using hybrid optimization method and 10 linear trapezoidal membership functions. 70% of the data was used for training, while the remaining 30% was used for testing. The RMSE, the CORR, the coefficient of determination (R2) and the discrepancy ratio (D) for the ANFIS model are 255.10, 0.993, 0.986, and 1.003 respectively for training and 924.15, 0.964, 0.945, and 0.893 respectively for validation. From the results, it can be concluded that the observed discharge is very near to the predicted values.

For Gumbel's Method, the RMSE, CORR, R2 and D are 2576.275, 0.954, 0.910, 0.677 respectively for training and 1252.875, 0.927, 0.859, 0.958 respectively for testing. As per the evaluation of the numerical results, it is shown that this latter model is very efficient, however ANFIS returned better results.

In the work of Pramanik and Panda (2009) ANNs and ANFIS are used in order to estimate the flow at downstream stretch of a river using data for upstream location. A comparison between the performance of neural networks and ANFIS was made by estimating the daily outflow of the dam which is located in the downstream region of Mahanadi river, India. In order to obtain the best input-output correlation, five different models with various input combinations were evaluated using both techniques. Among the five models which were formulated and tested:

- Models 1–4 considers discharging of water from tank without tributary
- Model 5 considers tributary inflows

Three backpropagation algorithms were used for the training process and they are:

- The Levenberg–Marquardt algorithm (LM)
- The gradient descent algorithm (GDX)
- Conjugate descent algorithms (CGF)

The influence of small tributaries on dams was not considered at first. The reason was that, there were not enough available data (e.g. on an hour basis), thus the prediction was based on daily data for the discharge of the water from tank. Later predictions include water from side tributaries and discharge from tank. All data were collected from 1997–2001 and 2002–2003. The model which considers the effect of tributaries, seems to provide the more accurate results using every possible training method. Regarding the two identification techniques, the results showed that ANFIS performs better than the ANN in terms of capturing the input-output relationship, and it could be used successfully in hydrological applications.

Neuro-fuzzy techniques such as the ANFIS can be used also for flood forecasting in urban environment. For example, in the work of Choi et al. (2012), such a technique is used to minimize the amount of uncertainties which are included in a conventional flood forecasting model with final objective, the formulation of a more accurate forecasting model of floods. The adaptive neuro-fuzzy interference system, which is a data driven model that combines a neural network and the fuzzy techniques, can decrease the amount of physical data required for constructing a convectional model. This system can predict the water level and creates a model using only observed rainfall and water levels of rivers. The inputs of the system for this study were rainfall data and the level of the water of the Tancheon basin for 7 flood events, where the level of water exceeded five meters in the period 2007–2011.

More specifically, the annual rainfall amount of Tancheon basin is approximately 1238.3 and 959 mm from June to September. The basin has a total area of 302 km^2 and total length of 35.6 km. Seven selected flood events have been included in different combinations for building the ANFIS model, and the necessary training and testing data. All these parameters are compared with RMSE. Some of the models seem to perform well; however, more data are necessary in order to achieve better accuracy.

Two different models; one based on a multilayer perceptron neural network trained with LM algorithm and radial basis, and an adaptive neuro-fuzzy inference system were considered for the modelling of flood discharge in the paper of Seckin (2011). These models were used to capture the non-linear relationship between discharge and four independent variables:

1. Drainage area
2. Evaluation
3. Latitude, longitude, return period
4. Maximum discharge

These four independent variables are also used as input variables. The input data were obtained from the Hand-book of flood frequency Analysis for peak discharges observed through river basins in Turkey.

Regional flood frequency analyses (RFFA) usually involves the identification of homogeneous regions, selection of suitable regional frequency distributions and estimation of flood quintiles. One of the most important procedures in RFFA is the delineation of the homogenous regions. RFFA method is really detailed and it usually requests a lot of data. An ANFIS model which uses Gaussian and triangular membership functions was considered. The model was trained by using a set of 380 events (training sets), while the testing was facilitated using 163 sets (gauge stations). Adaptive rates of learning were used for each network. The sigmoid and linear activation functions were used to hidden and output nodes of the neural network. A multi-layer perceptron (MLP), which used sigmoid activation function for hidden and output layers was also used.

From the results it is shown that the MLP method is more accurate compared to the ANFIS prediction model; however, further studies for the same region recommend that a greater amount of independent data should be included in the modeling set up.

A comparison between Sacramento (SAC-SMA) technique and ANFIS for real-time flood forecasting in small urban catchments is carried out in the paper of Roodsari et al. (2018). Both models are used for flood prediction in nine small urban catchments located near New York City. The models were used for reforecast stream flow for hurricane Irene and storms.

Two key decisions for flood forecasting are:

- How to treat and represent precipitation forecasts and uncertainty in these forecasts
- How to select appropriate model for best stream flow response simulation

In order to compare the capabilities of these two models for flood forecasting, both models were used to reforecast the flood hydrograph of disaster extreme historical events, hurricane Irene and another smaller storm. Namely, the prediction had been focused on the application of the models on two different events:

- Hurricane Irene (160 mm—last 36 h)
- Storm of September 23–25 (35 mm)

As for a validation period, which is associated with hurricane Irene and the studied storm, data simulation approach was used in order to account for current discharge observations. It was shown that SAC-SMA models with input parameters were allowed to vary between 10% below and above their calibration. On the other hand, ANFIS used less inputs, and the consequence was less time of calibration. The ANFIS model is proved to work better when a lot of historical data is available. However, in this research there was lack of data, thus SAC-SMA presented better performance when tested on the data of hurricane Irene. For the smaller event of the storm, ANFIS managed to do better prediction of flood forecasting.

8.4 Hybrid Adaptive Neuro-fuzzy Systems for Flood Prediction

Forecast models based on modern deep-learning techniques such as, ANNs, ANFIS and Adaptive neuro-genetic algorithms integrated systems (ANGIS) are discussed in (Mukerji et al. 2009). All models are compared with each other. First, a suitably defined ANN is developed. Then, the network is integrated into a fuzzy-logic-based inference system in order to form an ANFIS model. The development of the ANGIS model is also based on ANNs. In fact, it is an ANFIS systems, which is optimized by using genetic algorithms. All these models are used for the analysis of river Ajay.

For the development of ANN, ANFIS and ANGIS models, twenty flood events were available. Fifteen of them were selected for training, while the remaining five events were used for testing. For this paper, rainfall levels are used as inputs, while peak discharge is used for output. The annual average rainfall differs, as rainfall levels varies from 1280 to 1380 mm, while it is worth noting that 75–85% of the total rainfall is observed during the monsoon months.

One first conclusion is that all three models take similar values. However, the obtained results suggest that the ANGIS model is more efficient than the simple ANFIS or the ANN model, even if all models perform well in some cases. An important thing here is that these models cannot predict the value of discharge. This is a drawback which is common for all the discussed models.

The prediction of flood abnormalities for improved public safety using a modified ANFIS is studied in Aqil et al. (2006). More specifically, an adaptive approach is proposed to modify the traditional neuro-fuzzy model. This method uses a rule correction to replace the error of back propagation algorithm. The authors show techniques through simulation about study and flood series on the Citarum river in Indonesia. Total drainage area of Citarum river is 11,000 km^2 and the length of the river is 270 km. The average annual rainfall is between 2000 and 5000 mm per year. The temperature range varies from 18 to 24 °C. The so-called modified ANFIS (Mo-ANFIS), is a modification adopted from traditional ANFIS. The suggested Mo-ANFIS model contains sixteen rules and five layers. Mo-ANFIS is useful due to its interactive nature, flexibility approach, and evolving graphical features and it can also be adopted for any similar situation, that is to predict stream flow. The main data processing includes gauging station selection, input generation, lead time selection/generation, and length of prediction.

The inputs are: the average temperature and the average rainfall data. The data which were used for training are measured from the period 1987–1990, while the data for testing are from years 1991–2002. The forecast results show that the mean absolute percentage error (MAPE) and RMSE vary during validation. For MAPE from 2.632 to 5.650, and for RMSE from 6.957 to 11.826. The results indicate that the neuro-fuzzy model is able to identify the events for which it has been designed. This model can also serve as a tool for real time flood monitoring and process control.

Another hybrid ANFIS system for flood susceptibility is proposed by Bui et al. (2016). Namely, a new artificial intelligence approach based on neural fuzzy inference system and metaheuristic optimization (MONF) for flood susceptibility modeling in a high-frequency tropical cyclone area using GIS is developed and tested. According to this new approach, the neural fuzzy system was used to create an initial flood susceptibility model and then the model was optimized using two metaheuristic algorithms; an evolutionary genetic and a particle swarm optimization (PSO) scheme. The study covered the area of the tropical cyclone in central Vietnam.

Due to the severity of the flood problem in this area, statistical and data driven approaches have been proposed in flood studies, such as analytic hierarchy process, frequency ratio, logistic regression, weights-of-evidence, and fuzzy logic. Application of neural fuzzy models encounter some problems due to their inability to find the best values for critical weight parameters which heavily influence the prediction performance of these models. In addition, neural fuzzy models present slow training speed and sensitivity to noise in hydrological modeling. In this particular study, the inputs are:

- Rainfall
- Elevation
- Slope
- Distance of river
- Stream density

- Lithology
- Curvature

As for the output, one parameter is considered, and that is:

- Flood susceptibility

The annual rainfall of the study area varies from 1679 to 3259 mm. The rainfall is mainly concentrated in the rainy season from April to October which accounts for 88.6–93.3% of the total rainfall in yearly basis.

The results show that both MONF and ANFIS models perform very well with the training data. An important remark is that although the flood influencing factors have been selected based on analysis of flood occurrence and characteristics, however, it is logical to say that the degree of impact of these factors is different, and in some cases, there are factors which may have no influencing to the flood occurrence. Therefore, the predictive power of the influencing factors should be analyzed, and factors with no predictive capability should be eliminated.

The integration of advantages of neural fuzzy systems to a model optimized with the above-mentioned methods yields to higher efficiency of the proposed technique for flood susceptibility mapping for the tropical cyclone area of Vietnam. The result may be accommodating for planners and decision makers for sustainable management of flood-prone areas in the study area. The results show that the proposed MONF model performs above benchmark models, thus it can be concluded that the MONF model consist a new alternative tool, which can and should be used in flood susceptibility mapping.

8.5 Conclusions

From the published papers in literature (see Table 8.1), it can be concluded that ANFIS is a very powerful flood forecasting tool, as it can make predictions with high precision if trained properly, i.e. if a sufficient and representative amount of observation data is available. However, even though the accuracy is high, the predictions of the smart system still do not fully match the later measured and observed data from future events. Compared to other models, ANFIS presents better performance when large amounts of data are present and works better at shorter time intervals (e.g. up to 6 h), above which significant errors may appear. Among the several hybrid ANFIS models, MONF seems to perform better, thus it can be used as a good alternative tool in flood susceptibility mapping. ANGIS present smooth behavior as well. To conclude, ANFIS systems and its variations are widely used for flood risk prediction, however, such models do not appear worldwide. A possible reason for that could be the fact that a large amount of data, as well as long-term research are required for the full implementation of such systems, which, in most cases are hard to collect.

Table 8.1 Flood prediction using neuro-fuzzy techniques such as ANFIS and variations

Models for prediction	Reference	Inputs	Outputs
ANFIS versus Log Pearson type III	Khasiya (2017)	Daily rainfall	Daily peak discharge
ANN versus ANFIS versus ANGIS	Mukerji et al. (2009)	Rainfall	Peak discharge
ANFIS versus Log Pearson type III	Patel and Parekh (2014)	Rainfall and past discharge	Peak discharge
ANN versus ANFIS	Pramanik and Panda (2009)	Discharging water from tank with or without tributary inflows	Downstream flow
ANFIS	Choi et al. (2012)	Rainfall data Level of water	Prediction of water level
RFFA versus MLP versus ANFIS	Seckin (2011)	Drainage area Evaluation Latitude, longitude and return period Maximum discharge	Discharge
Mo-ANFIS	Aqil et al. (2006)	Average temperature Average rainfall	Stream flow prediction
ANFIS versus ARIMA	Ullah (2013)	Upstream depth flow Flow rate in time Downstream flow depth Downstream flow rate	1-h downstream flow rate Flow depths
ANFIS versus SAC-SMA	Roodsari et al. (2018)	Hourly precipitation Temperature	Flood discharge
Mamdani FIS versus Sugeno FIS versus HN-FIS	Supatmi et al. (2019)	Population density Altitude of the area Rainfall data	Vulnerability of flood
ANN versus ANFIS	Nayak et al. (2004)	Rainfall Evaporation Other exogenous variables	Peak flow estimation
ANFIS versus ANN	Nayak et al. (2005)	Rainfall	Runoff
ANFIS	Hossain et al. (2014)	Rainfall River water level River water flow	Flood warning
ANFIS versus MONF	Bui et al. (2016)	Rainfall Elevation Slope Distance of river Stream density Lithology Curvature values	Flood susceptibility
ANFIS	Chen et al. (2006)	Level of water Rainfall Travel time of the flow	Flood forecast

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Chapter 9
Collapse Prediction and Safety of Masonry Arches

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Abstract Masonry structures without mortar or with mortar of low quality are used in several infrastructures, like bridges and retaining walls Unilateral contact plays a crucial role in their stability. Limit analysis and nonexistence of solution are related to the creation of collapse mechanisms. Open source and freely available software can be used for the analysis of such structures, usually with an acceptable for post-disaster, emergency situations. Numerical results related to a recently collapsed masonry bridge demonstrate the usage of the proposed method.

Keywords Limit analysis · Masonry arches · Collapse prediction · Stability of structures · Solvability of unilateral contact problems

9.1 Introduction

Masonry arch bridges and walls are traditional structures, consisting of stone blocks and mortar. The ability of the material and the joints to transfer compressive loading, and their inability to accept reliably tensile loading are optimally exploited. The modern approach to structural analysis of masonry arches is based on limit analysis concepts or unilateral contact mechanics, after suitable simplifications. These concepts can be used for the assessment of limit load and collapse modes or existing structures after a natural disaster.

Masonry arches are examples of structures where form meets mechanical function: stones and mortar, if it exists, of relatively high strength in compression and

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limited, unreliable, practically zero strength in tension are used in such a way so that self-weight keeps them stable in place and the whole structure in a functional state. Life loading is usually a small quantity in classical heavy structures, therefore this disturbance can be accommodated. If not, for example due to an accidental loading during a disaster, hinges develop due to unilateral contact separation, the degree of indeterminacy is reduced and finally a mechanism of collapse develops.

The main purpose of this contribution is to demonstrate a different approach to static analysis of structures subjected to extreme loading cases and facilitate the usage of these techniques by indicating suitable software packages which can be used for a first and quick assessment.

9.2 Modelling and Limit Analysis of Masonry Structures

Modelling of a structure with unilateral interfaces is based on concrete tools of non-smooth and contact mechanics (Demyanov et al. 1996; Mistakidis and Stavroulakis 1998; Leftheris et al. 2006; Bolzon 2017). For rigid body or linearly deformable structures, the structural analysis problem can be transformed in known forms of mathematical programming problems, like quadratic optimization with inequality constraints or complementarity problems. Stability of a multi-block structure is based on the ability of unilateral contact joints to transfer compressive loading from the one part to the other and finally to the supports. The peculiarity of the unilateral contact mechanism is the different behaviour in compression and tension. For the whole structure self-weight in cooperation with the shape of the structure usually stabilizes the system. Any additional load could potentially lead to collapse, since the total loading may become prohibitive for the structure. In other words the arising contact problem has no solution.

For the simplest case of frictionless contact, the structural analysis problem can be formulated as a potential energy minimization which includes the unilateral contact inequality constraint (non-penetration). This is given by the relation:

$$\begin{gathered} \min_{\mathrm{u}}(\tfrac{1}{2}\boldsymbol{u}^T\boldsymbol{k}\boldsymbol{u} - \boldsymbol{P}^T\boldsymbol{u}) \\ \boldsymbol{N}_n\boldsymbol{u} - \boldsymbol{g} \leq 0 \end{gathered} \tag{9.1}$$

For the quadratic minimization problem, the Karush-Kuhn-Tucker (KKT) optimality conditions lead to the linear complementarity problem (LCP) of relations.

$$\begin{gathered} \boldsymbol{K}\boldsymbol{u} + \boldsymbol{N}_n^T\boldsymbol{r}_n = \boldsymbol{P}_o + \lambda\boldsymbol{P} \\ \boldsymbol{N}_n\boldsymbol{u} - \boldsymbol{g} \leq 0 \\ \boldsymbol{r}_n \geq 0 \\ (\boldsymbol{N}_n\boldsymbol{u} - \boldsymbol{g})^T\boldsymbol{r}_n = 0 \end{gathered} \tag{9.2}$$

The first equation expresses the equilibrium of the discretized unilateral contact problem without friction, where **K** is the stiffness matrix and **u** the displacement vector. $\mathbf{P}_o$ denotes the self-weight of the structure and **P** represents the live load vector, multiplied by a scalar load multiplier λ. $\mathbf{N}_n$ is an appropriate geometric transformation matrix and vector **g** contains the initial gaps for the description of the unilateral contact joints. The next relations represent the constraints of the unilateral contact problem for the whole discretized structure. For the consideration of the constraints, the vector $\mathbf{r}_n$ representing Lagrange multipliers is used to depict contact pressure. The problem described above is a non-smooth parametric linear complementarity problem (LCP) parametrized by the one-dimensional load parameter λ. Values for solutions in the interval $0 \leq \lambda \leq \lambda_{failure}$ are investigated.

One of the first approaches to masonry arches using parallels to contact and plasticity is given in the classical monograph of Heyman (1982). Analytical studies have been published in several classical references which will not be given here. Numerical approaches which lead to easily solvable models suitable for quick evaluation purposes, are based on rigid blocks with unilateral contact (Gilbert and Melbourne 1994; Livesley 1978; Melbourne and Gilbert 1995; Ferris and Tin-Loi 2001; Orduna and Lourenço 2005; Gilbert et al. 2006; Portioli et al. 2013). The initial model has been extended in order to cover sliding between adjacent blocks, multiple spans and multiple arch rings spandrel walls as well as masonry with finite strength. Another approach constitutes the usage of the discrete element method, see for instance Caliò et al. (2010).

The most general approach, which incorporates the previously mentioned ones, is the usage of finite element models for deformable bodies with unilateral contact interfaces (Drosopoulos et al. 2006, 2008). Solvability of the underlying unilateral contact problem and suppression of possible rigid body motions due to the absence of classical bilateral supports and the inactive contact interfaces, corresponds to collapse of the structure under given loadings (Stavroulakis et al. 1991). The ability to have an automatic and relatively quick model of the structure in the actual geometric shape using scanners, provides us with additional strength related with the evaluation of structures in deformed, partially damaged condition (Stavroulaki et al. 2016).

It should be noted that accidental loadings due to natural disasters have been studied in a few works with results that indicate the importance of computational modeling for the remaining strength evaluation of existing structures. For instance, analysis of the influence of flooding on the collapse analysis of masonry arh bridges indicates that the load-carrying capacity of a fully flooded arch bridge backfilled with cohesionless fill could typically be reduced by a factor of 1.6–1.8, or even more in specific circumstances, as it has been shown in Hulet et al. (2006). Flood and post-flood performance of historic stone bridges has been investigated in Drdácký and Slížková (2007). Discrete elements are used in Liu et al. (2018), Fukumoto et al. (2014) and Quezada et al. (2019), for the evaluation of various accidental scenarios.

9.3 Computational Tools

A general approach to consider multi-block structures with unilateral interaction is the usage of finite element or boundary element nonlinear contact analysis. Especially the usage of linear complementarity techniques and the relation with solvability investigations gives us invaluable insight into the mechanics of these structures and a rigor mathematical framework to work. Every available general purpose finite element program able to solve contact problems is, in principle, suitable for this study.

The simplified approach of rigid blocks and the transformation of the collapse analysis into a linear programming program can be used for a quick assessment of existing, mainly two-dimensional structures like bridges and vaults. This approach has been used in Ring software, which is freely available for use. http://www.shef.ac.uk/ring, (see Gilbert 2001; Gilbert and Melbourne 1994).

For three-dimensional problems the software LiABlock_3D is available. Within it, structures are represented as 3D assemblages of rigid blocks interacting at no-tension, frictional contact interfaces. The mathematical programming problems arising are solved by Mosek optimization software, while collapse load and failure mechanism are plotted (Cascini et al. 2018).

Finally two recent software packages are mentioned, which nevertheless have not been thoroughly tested till now (Chiozzi et al. 2015; Galassi and Tempesta 2019).

9.4 Results Related to Keritis Bridge

Keritis bridge, which is located in Chania, Crete, Greece, was constructed in 1912. It was used by the residents for more than 100 years and it played a crucial role in the communication of the local population during historical periods and wars. Today, it is considered to be a monument. Unfortunatelly this structure collapsed on February 25, 2019, during an extremmely high flooding.

Keritis bridge has 3 arched spans. The geometry and dimensions of the bridge are presented in Fig. 9.1. The out of plane width of the bridge is equal to 8 m. The material properties of the structure, which must be used for its structural evaluation, have been estimated and shown in Table 9.1. For the fill material, the angle of internal friction and cohesion are received equal to 37° and 10 KN/m^2, respectively. For the asphalt material over the fill, the angle of load distribution is 26.60° and the density is 18 KN/m^3. Elasticity modulus and Poisson's ratio have been estimated from similar structures, due to lack of information.

For the determination of the ultimate response of Keritis bridge, the limit analysis software RING was used. As shown in Fig. 9.2, the arches which comprise the main structural system, the fill over the arch and the abutments are simulated within the software.

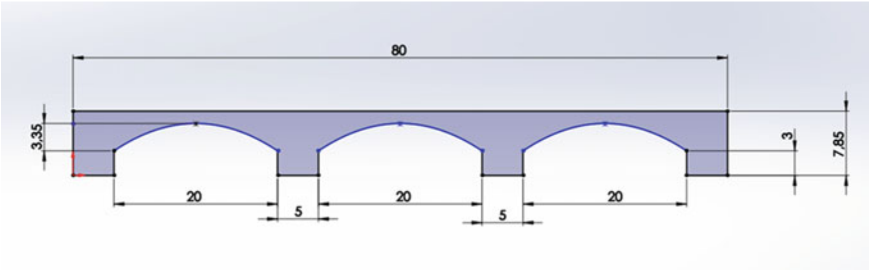

Fig. 9.1 Geometry and dimensions (m) of Keritis bridge

Table 9.1 Estimated material properties of Keritis bridge

Part of the structure	Density (KN/m^3)	Compressive strength (MPa)	Friction coefficient
Arch	19.60	5.00	0.60
Fill	19.00		0.60

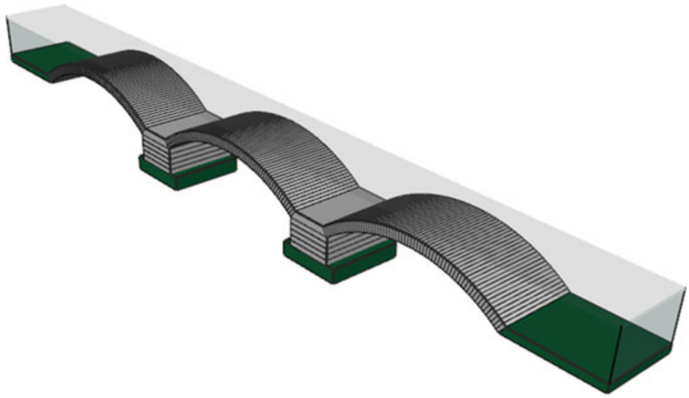

Fig. 9.2 Keritis bridge designed in RING software

To evaluate the influence of the self-weight and vehicle loading on the bridge, first each arch is independently loaded. Then, the total bridge is numerically tested. For every simulation, the ultimate safety factor λ, defined as the ratio of the ultimate load over the applied load, is calculated. For the determination of the influence of the vehicle loading, several scenarios for the positioning of more than one vehicle on each arch of the bridge are investigated.

When the first arch is considered and the self-weight loading is examined, five trial positions of a unit force are tested and the corresponding safety factors are estimated, as shown in Fig. 9.3 and Table 9.2.

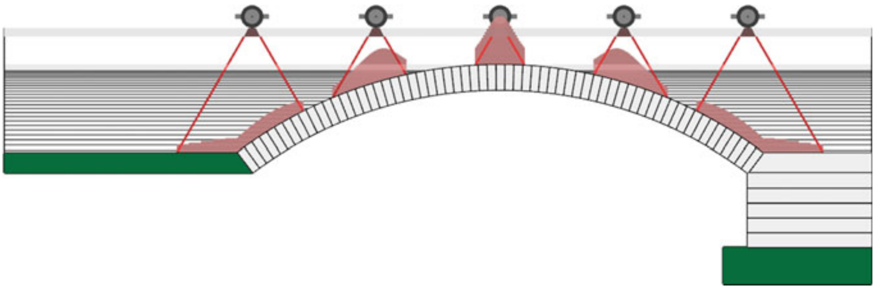

Fig. 9.3 Trial unit force positions for the first arch of the bridge

Table 9.2 Influence of self-weight loading on the strength of the first arch

Load position (m)	Safety factor λ
0	6.03E+03
5	603
10	384
15	970
20	3.1E+04

To investigate the real vehicle loading, several scenarios for the positioning of more than one vehicle shown in Table 9.3, are investigated. The length for each vehicle is considered equal to 12.3 m. A number of vehicles densely placed along the length of the bridge have been assumed.

Similar results for the second and third arches and for self-weight and vehicle loading, are given in Tables 9.4, 9.5, 9.6, and 9.7.

When the overall bridge is considered, the safety factors which are obtained for several trial positions of unit force along the spans are shown in Table 9.8. From the given safety factor values is shown that the structure is safe for self-weight loading.

When only one vehicle loading is applied to several positions of the bridge, the corresponding safety factors which are obtained, are shown in Table 9.9.

Table 9.3 Influence of vehicle loading on the strength of the first arch

Load position (m)	Safety factor λ
0.0 12.5	3.88
−9.0 3.5 16.0	5.81
−5.545 6.955 19.455	11.70

Table 9.4 Influence of self-weight loading on the strength of the second arch

Load position (m)	Safety factor λ
0	6.03E+03
5	603
10	384
15	603
20	6.03E+03

Table 9.5 Influence of vehicle loading on the strength of the second arch

Load position (m)	Safety factor λ
0.0 12.5	3.87
−9.0 3.5 16.0	5.81
−5.545 6.955 19.455	11.70

Table 9.6 Influence of self-weight loading on the strength of the third arch

Load position (m)	Safety factor λ
0	3.1E+04
5	970
10	384
15	603
20	6.03E+03

Table 9.7 Influence of vehicle loading on the strength of the third arch

Load position (m)	Safety factor λ
0.0 12.5	12.7
−9.0 3.5 16.0	6.39
−5.545 6.955 19.455	15.2

When more than one vehicle loading is considered on the bridge as shown in Fig. 9.4, the safety factor shown in Table 9.10 is obtained. This is an example of a severe load case, used to indicate the load bearing capacity of the bridge for an extreme loading scenario.

Table 9.8 Influence of self-weight loading on the strength of overall bridge

Load position (m)	Safety factor λ
0	1.71E+05
10	6.26E+04
20	1.71E+05
30	5.87E+04
40	5.87E+04
50	1.71E+05
60	6.26E+04
70	1.71E+05

Table 9.9 Influence of self-weight loading on the strength of overall bridge: one load case, see Fig. 9.3

Load position (m)	Safety factor λ
0	138
10	91.9
20	257
30	97.5
40	99
50	138
60	91.9
70	275

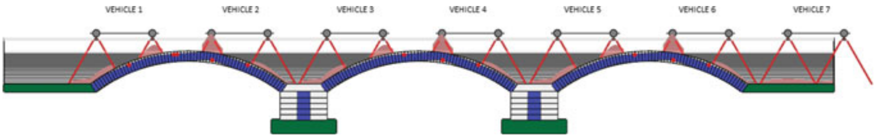

Fig. 9.4 Load case of seven vehicle forces applied along the length of the overall bridge

Table 9.10 Influence of self-weight loading on the strength of overall bridge: multiple loadings case, see Fig. 9.4

Load position (m)	Safety factor λ
0	93
12.5	
25	
37.5	
50	
62.5	
75	

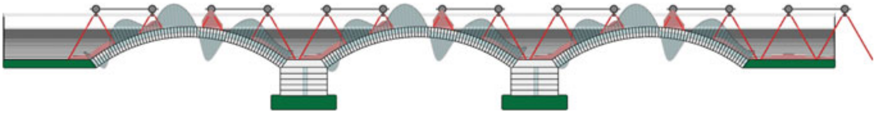

Fig. 9.5 Distribution of moments along the length of the bridge

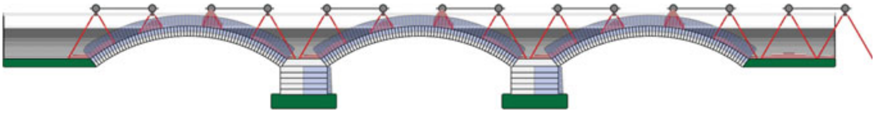

Fig. 9.6 Distribution of axial forces along the length of the bridge

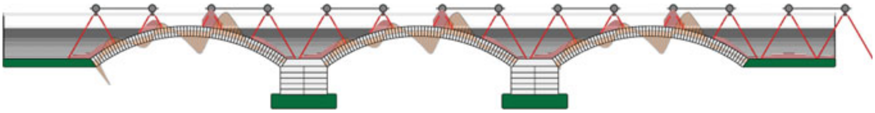

Fig. 9.7 Distribution of shear forces along the length of the bridge

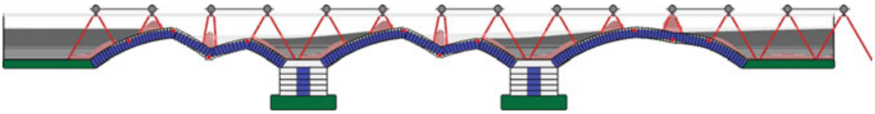

Fig. 9.8 Collapse mechanism and plastic hinges distribution obtained for the ultimate limit state

To finalize this investigation, the ultimate limit state of the bridge has been determined, by considering: (λ) $\times$ (Applied load) = (ultimate limit load), as the loading of the bridge. Figures 9.5, 9.6, 9.7, and 9.8 show the moment, axial and shear distribution along the length of the bridge, as well as the collapse mechanism, which are obtained for this ultimate limit load.

9.5 Conclusions

Methods which can be used to numerically assess the structural performance of masonry bridges and walls, under static and dynamic loading, have been presented in this article. Emphasis is posed on simplified limit analysis, which can be performed by openly available software. More detailed studies, including the application of non-linear finite element analysis and numerical homogenization can be found in the literature.

Extension to other structures can be found in the literature, e.g. Tralli et al. (2014). Using these methods collapse mechanisms and ultimate loads can be estimated quickly. Input of geometrical data can be automatized, by using modern photogrammetry techniques, for instance terrestrial laser scanners (Stavroulaki et al. 2016; Riveiro et al. 2016).

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Chapter 10
A Discrete Inspired Bat Algorithm for Firetruck Dispatch in Emergency Situations

Dimitra Trachanatzi, Manousos Rigakis, Magdalene Marinaki and Yannis Marinakis

Abstract This research considers the case where a large fire has developed beyond the possibility of suppression and resources need to be deployed to reduce the risk to critical assets. Thus, to determine an optimal deployment of the firetrucks to multiple assets in a large area, a mathematical formulation is proposed, focusing on the maximization of the aggregated value of the protected assets that are critically selected, and on the minimization of the dispatch strategy cost. Moreover, the novelty of the presented formulation is the incorporation of the CO_2 emissions of the firetrucks in the cost function, and, hence, the formulation of the Green-Prize Collecting Vehicle Routing Problem. Moreover, a hybrid Bat Algorithm (BA) is developed for the optimization of the aforementioned problem, namely the Discrete Inspired Bat Algorithm (DIBA). The effectiveness of the proposed algorithmic approach is demonstrated over computational experiments, in comparison with the results of a commercial exact solver.

Keywords Discrete bat algorithm · Prize-collecting vehicle routing problem · CO_2 emissions

10.1 Introduction

In case of an emergency situation, such as a large fire, incidences may result in the loss of or damage to houses, schools, bridges, factories and hospitals, often referred

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to as community assets. In order to prevent the loss of assets, sufficient resources are dispatched to them in a timely manner. The issue that an incident management team (IMT) faces in case of a large fire is the allocation of the available resources. The typical resource units being assigned are fire trucks, commonly referred to as tankers. When dealing with major fire disasters, especially when multiple fire points occurring in one region simultaneously, time is an indispensable and primary factor for each decision-maker. As, Martell (2007) stated: the fire management can be viewed from a supply chain management perspective as *delivering the right amount of the right fire to the right place at the right time at the right cost*. Thus, the objective of an optimal allocation is the maximization of the value of the assets protected and at the same time, the minimization of the response time and cost, subject to several constraints, and among them, the number of the available vehicles. The response time corresponds to the travel duration of a firetruck from the central station to the various points of fire. Moreover, apart from enhancing the cost-effectiveness of the fire suppression activities, the environmental sustainability should be considered in the decision-making and planning of suppression efforts. Thus, fire managers need to be able to incorporate into their response strategies, the consumed fuel amount and the impact of the corresponding CO_2 emissions of the firetrucks.

The focus of the presented research is the formulation of an asset protection problem, in case of a large fire, that takes into account the environmental cost efficiency of the dispatch planning. Thus, the Green-Prize Collecting Vehicle Routing Problem (Green-PCVRP) is proposed. In addition, a hybrid Bat Algorithm (BA) is developed for the optimization of the aforementioned problem, namely the Discrete Inspired Bat Algorithm (DIBA). The effectiveness of the proposed algorithmic approach is demonstrated over computational experiments, in comparison with the results of a commercial exact solver. The rest of the paper is organized as follows: Sect. 10.2 contains a brief literature review; in Sect. 10.3 the mathematical model of the PCVRP is described; in Sect. 10.4 the proposed mathematical formulation of the Green-PCVRP is described; in Sect. 10.5 the original BA is presented; in Sect. 10.6 the DIBA is introduced and described in detail; Sect. 10.7 contains the experimental results; and Sect. 10.8 gives the conclusions.

10.2 Brief Literature Review

The main objective of the presented research is the asset protection optimization in case of a large forest fire, where each node, in the respective problem, is associated with a prize value, i.e. the benefit of protecting the corresponding asset. Van Der Merwe et al. (2014) proposed the Cooperative Orienteering Problem with Time Windows (COPTW), and in their formulation each asset/node needs a predefined number of firetrucks to work simultaneously on it, to be protected. The same authors (Van Der Merwe et al. 2014b) presented a mixed integer programming model formulation for asset protection during escaped wildfires, with the aim of maximizing the total saved asset value. The aforementioned model, solved using CPLEX, incorporates mixed vehicle types with interchangeable capabilities and with vehicle travel times determined by vehicle specific speeds and road network information, while the protection requirements of locations/nodes are defined in terms of the vehicles' capabilities. The Asset Protection Problem (APP) after the initial work of Van Der Merwe et al., was also, solved by an Adaptive Large Neighbourhood Search (ALNS), proposed by Roozbeh et al. (2018), while their two-stage stochastic programming approach was developed to handle the unusual feature of uncertainty in the timing of changes in conditions, such as wind direction and velocity. These changes determine new time windows during which assets must be serviced and hence the optimal deployment schedule and routing of vehicles.

Another formulation was proposed by Tian et al. (2016) who pioneered a bi-objective optimization model to simultaneously optimize the total fire-extinguishing time and the total number of fire engines dispatched. They proposed a Multi-objective Hybrid Differential Evolution Particle Swarm Optimization (MHDP) algorithm to create a set of Pareto solutions for this problem, while the proposed model considers the fire spread speed as a crucial factor. Based on the latter work, Wu et al. (2017) developed an improved bi-objective integer program, containing less variables and constraints, that based on the computational experiments outperforms the work of Tian et al. (2016). Moreover, Wu et al. (2019) presented an emergency scheduling problem for forest fires with limited rescue team resources and priority disaster areas. Such, each fire point is associated with a priority level based on the severity of the fire situation and the formulated integer linear-programming (ILP) model aims to minimize the total travel distance of all rescue teams, which was exactly solved by CPLEX. Consequently, the common practice to simulate an asset protection problem, is the formulation of Vehicle Routing Problem variants that incorporate nodes with prize values, and aim at the maximization of the completed service (as is the aggregated prize from the nodes serviced) and/or at the minimization of total distance travel, i.e. fast response in case of emergency. Thus, we adopt a variation of the Prize-Collecting Vehicle Routing Problem (PCVRP).

In 2006, Tang and Wang formulated the PCVRP to solve the hot rolling production scheduling problem. The proposed mathematical formulation of the PCVRP incorporated a linear combination of three objectives: the total distance minimization; the number of utilized vehicles minimization and the maximization of the collected prizes. Thus, the model can satisfy different requirements by altering the value of the three coefficients, respectively (Tang and Wang 2006). To optimize the PCVRP, they utilized an Iterated Local Search algorithm (ILS) based on Very Large-Scale Neighbourhood (VLSN). In the same field, Zhang et al. (2009) proposed a multi-objective PCVRP-based model for the hot-rolling batch scheduling problem, that included penalty for the non-visited customers and a fixed number of vehicles, and solved it using a Particle Swarm Optimization (PSO) variant. The aforementioned problem with similar mathematical formulation was also solved by Jia et al. (2013) using a Pareto Max-Min Ant System (P-MMAS).

Hence, two variants of the PCVRP formulation have been derived from the literature: when the number of vehicles to be utilized is predetermined (PCVRP-P) and when is not predetermined (PCVRP-NP) (Long et al. 2019). In 2015, Tiwari et al.

(2015) proposed a hybrid edge recombination approach for the PCVRP-P. Subsequently, Li and Tian (2016) developed a two-level self-adaptive variable neighbourhood search for the PCVRP-NP, aggregating the multiple objectives in one function through the weighted sum method. Lately, in 2018, Long et al. studied both version of the PCVRP as a multi-objective problem, using a Pareto-based evolutionary algorithm, combined with a local search strategy. In order to handle the PCVRP-NP, they proposed a decomposition strategy that divides the problem into multiple PCVRP-P problems (Long et al. 2019). The proposed research focuses on the solution of a variant of the PCVRP-P, the Green-PCVRP, that takes into account the CO_2 emissions of the vehicles that follow the generated routes, and which, at least in our knowledge, has never been proposed and particularly, incorporating firetrucks and the action of unloading the vehicle that, actually, significantly affects the proposed objective function.

The Bat Algorithm has been utilized in the solution of several variants of the Vehicle Routing Problem (VRP). In 2015, Taha et al. proposed an adapted variant of the BA for the solution of the Capacitated VRP (CVRP). The Adapted BA, developed in that study, utilizes three parameters (frequency, wavelength and direction search), and allowing a diversity of the population, swifts between global and local search. Also, for the solution of the CVRP, in 2016, Zhou et al. (2016) presented a Hybrid Bat Algorithm with path relinking (HBA-PR), which apart from the BA logic, it integrates the Greedy Randomized Adaptive Search Procedure (GRASP) and the path relinking. Moreover, in the aforementioned approach the random sub-sequences and single-point local search are operated with certain loudness/probability. Furthermore, in 2016, Osaba et al. proposed a discrete Bat Algorithm for solving the Traveling Salesman Problem and the Asymmetric Traveling Salesman Problem, in their version bats are endowed with some kind of “intelligence”. This intelligence makes the bats follow different patterns of movement depending on the point of the solution space in which they are located, while they adopted the Hamming distance to the velocity equation for bat movement and extend an additional mechanism of 3-opt moves into local search part. Regarding the same application, also in 2016, Saji and Riffi presented a discrete version of the BA that includes the 2-opt local search technique.

Furthermore, in 2017, Taha et al. presented a discrete version of the BA for solving VRP with Time-Windows (VRPTW), which was utilized in combination with the Large Neighborhood Search (LNS), namely the BA-LNS. Their method incorporates operators that perform selective extractions of customers in an attempt to minimize the number of vehicles and the traveling distance, allowing the bat to discover a large part of the solution space. In 2018, Osaba et al. proposed an evolutionary and discrete variant of the Bat Algorithm (EDBA) for solving the VRPTW, combined with diverse heuristic operators that achieve hybridization using selective node extractions and subsequent reinsertions, as an extension of their previous work. Recently, in 2019 Osaba et al. focused on a Rich VRP (RVRP), the Clustered Vehicle Routing Problem with Pickups and Deliveries, Asymmetric Variable Costs, Forbidden Roads and Cost Constraints. They developed a Discrete and Improved Bat Algorithm (DaIBA), which employs two different neighborhood structures, that are explored depending on the bat’s distance regarding the best individual of the swarm.

10.3 Prize-Collecting Vehicle Routing Problem

The present paper is focused on the solution of the Prize-Collecting Vehicle Routing Problem (PCVRP), as such a predefined number of vehicles have to be used, i.e. a predefined number of feasible routes M have to be constructed to visit the available assets to be protected. Following the formulation presented in Li and Tian (2016), the Prize-collecting Vehicle Routing Problem can be described through a complete graph $G = (V, A)$, where $V = \{0, \dots, N\}$ is the node set and $A = \{(i, j)|i, j \in V\}$ is the set of corresponding arcs. Each node i included in the set $\{1, \dots, N\}$, represents an asset and such, specific values of prize, p_i and demand d_i are associated to it. The depot, as the initial/starting point, is denoted by node 0, and no prize of demand value is attributed to it. In addition, for each pair of nodes i, j, the travelling time between them can be expressed by their Euclidean distance, noted as c_{ij}. The symmetry of the problem defines that $c_{ij} = c_{ji}$. Furthermore, each vehicle has a maximum capacity Q and a large fixed usage cost G associated to it. Additionally, by r the task completion parameter (minimum ratio) is denoted, obtained by dividing the predetermined amount of demand by the total demand of all nodes. Finally, as N_m is considered the set of nodes that are visited by vehicle m, $(m \in 1, \dots, M)$. The following decision variables are used:

- $x_{ij}(i \neq j) = 1$ when node j is visited immediately after node i in the optimal solution, otherwise $x_{ij} = 0$, $(i, j \in N)$.
- $x_{ii} = 1$ when customer i is visited in the optimal solution, otherwise $x_{ii} = 0$, $(i \in N)$.

The mathematical formulation of the PCVRP is:

$$Minimize: \sum_{i \in N} \sum_{j \in N} c_{ij} x_{ij} + G * M - \sum_{i=1}^{N} p_i (1 - x_{ii}) \tag{10.1}$$

s.t

$$\sum_{i=1}^{N} x_{i0} = \sum_{i=1}^{N} x_{0i} = M \tag{10.2}$$

$$\sum_{i=1}^{N} x_{ij} \leq 1, \quad j = 1, \dots, N \tag{10.3}$$

$$\sum_{j=1}^{N} x_{ij} \leq 1, \quad i = 1, \dots, N \tag{10.4}$$

$$\sum_{i \in N_m} d_i (1 - x_{ii}) \leq Q, \quad m = 1, \dots, M \tag{10.5}$$

$$\sum_{i \in S} \sum_{j \in S, (j \neq i)} x_{ij} \leq |S| - 1, \quad \forall S \subset N \tag{10.6}$$

$$\frac{\sum_{i=1}^{N} d_i (1 - x_{ii})}{\sum_{i=1}^{N} d_i} \geq ratio_Q \tag{10.7}$$

$$x_{ij} \in \{0, 1\}, \quad i, j \in N \tag{10.8}$$

The goal of the objective function Eq. (10.1) is the minimization of the total cost (travelled distance and fixed vehicle usage) by taking into account the total collected prize from the visited nodes, the protected assets. Constraint (10.2) requires that each vehicle conducts a route that initiates from the depot and returns to it. Constraints (10.3) and (10.4) ensure that each node is visited at most once, while Constraints (10.5) facilitate the capacity restrictions of the vehicle. Additionally, Constraints (10.6) are used to eliminate the sub-tours for each vehicle route. Constraint (10.7) ensures the minimum ratio of demand to be covered. Finally, Constraints (10.8) specify the integrity conditions on the variables.

10.4 Green Prize-Collecting Vehicle Routing Problem

In order to incorporate the environmental impact of the firetrucks dispatch in case of a large forest fire, the objective function of the PCVRP is adjusted accordingly. The linear formulation of emission volume, as presented by El Bouzekri et al. (2013), considering a Heavy Duty Vehicle (HDV) which has average speed of 80 km/h and fully loaded weights 25 tons, is given below, where:

- $E_{ij}(q, d)$: is the CO_2 emissions from a vehicle in kg/km with the variable of load q in ton and d in km,
- e_f: is the CO_2 emissions of a fully loaded vehicle (1.096 kg/km for a HDV truck) and
- e_e: is the CO_2 emissions of an empty vehicle (0.772 kg/km for a HDV truck).

$$E_{ij}(q, d) = c_{ij} * \left[\frac{(e_f - e_e)}{Q} (q_{ij}) + e_e \right] \tag{10.9}$$

The above formulation, Eq. (10.9), is based on the percentage that the vehicle is loaded, while according to the PCVRP mathematical formulation the continuous parameter q_{ij} represents the aggregated volume of demand that the vehicle carries as it traverses from node i to node j. However, in case of a tanker firetruck, the vehicle initiates from the depot fully loaded and, progressively, as it protects the assets, the volume that carries decreases. Hence, the element of the objective function that relates to the cost minimization, i.e. the minimization of the total distance travelled, is adjusted as shown in Eq. (10.10).

$$Min: \sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{m=1}^{M} c_{ij}x_{ij}^{m}\left[\frac{(e_f - e_e)}{Q}(Q - q_{ij}^{m}) + e_e\right] + G * M - \sum_{i=1}^{N}\sum_{m=1}^{M} p_i y_{im} \tag{10.10}$$

Thus, the proposed mathematical formulation of the Green Prize-Collecting Vehicle Routing Problem (Green-PCVRP) emerges, by replacing the objective function and expanding the decision variables with respect to each vehicle/route m. In addition, a binary auxiliary decision variable y_{im} is used to define whether the node i is included into route m. Moreover, the following constraints should be included to control the parameter q_{ij}^{m}, see Constraints (10.18), (10.19) and (10.20). Particularly, Constraints (10.18) indicate the reduced cargo of the vehicle and, also, do not permit any illegal sub-tours.

$$\sum_{i=1}^{N} y_{i0} = \sum_{i=1}^{N} y_{0i} = M \tag{10.11}$$

$$\sum_{m=1}^{M} y_{im} \leq 1, \quad i = 1, \ldots, N \tag{10.12}$$

$$\sum_{i=1}^{N} y_{im} \geq 1, \quad k = 1, \ldots, M \tag{10.13}$$

$$\sum_{j=1, i \neq j}^{N} x_{ij}^{m} = y_{im}, \quad i = 1, \ldots, N \text{ and } m = 1, \ldots, M \tag{10.14}$$

$$\sum_{i=1, i \neq j}^{N} x_{ij}^{m} = y_{jm}, \quad j = 1, \ldots, N \text{ and } m = 1, \ldots, M \tag{10.15}$$

$$\sum_{i=1}^{N} y_{im} * d_i \leq Q, \quad k = 1, \ldots, M \tag{10.16}$$

$$\sum_{i=1}^{N}\sum_{m=1}^{M} y_{im} * d_i \geq Qr \tag{10.17}$$

$$\sum_{i=0, i \neq j}^{N} q_{ji}^{m} - \sum_{i=0, i \neq j}^{N} q_{ij}^{m} = d_j * y_{jm}, \quad j = 1, \ldots, N \text{ and } m = 1, \ldots, M \tag{10.18}$$

$$0 \leq q_{ij}^{m} \leq x_{ij}^{m}, \quad i, j = 1, \ldots, N (i \neq j) \text{ and } m = 1, \ldots, M \tag{10.19}$$

$$q_{1i}^{m} = 0, \quad i = 2, \ldots, N \text{ and } m = 1, \ldots, M \tag{10.20}$$

Constraint (10.11) establish the correct number of routes to be formulated. Constraints (10.12) guarantee that each node is included into a route no more than once and Constraints (10.13) ensure that each route should include at least one node. Constraints (10.14) and (10.15) ensure the continuity of the route. Finally, Constraints (10.16) and (10.17) are established to avoid the overload of a vehicle and ensure that the required ratio of capacity volume is to service by the complete solution, respectively.

10.5 Bat Algorithm

The Bat Algorithm (BA), proposed by Yang in 2010, is a nature-inspired metaheuristic algorithm based on the echolocation behavior of microbats, which can find their prey and discriminate different kinds of insects even in complete darkness. In the nature, bats emit ultrasonic pulses to the surrounding environment to hunt and properly navigate. Bats are listening to the echoes, produced by the emitted pulses and based on them they can locate themselves and also identify and locate preys and obstacles. Moreover, each bat is able to find the most nutritious areas performing an individual search, or moving towards a nutritious location previously found by any other bat of the swarm. Yang established the following approximate or idealized rules:

1. All bats use echolocation to detect the distance, and they have the ability to distinguish between an obstacle and a prey.
2. All bats fly randomly with a velocity v_i at position x_i with a fixed frequency f_{min}, varying wavelength λ and loudness A_i to search for prey. In this idealized rule, it is assumed that every bat can adjust in an automatic way the frequency (or wavelength) of the emitted pulses, and the rate of these pulses emission $r \in [0, 1]$. This automatic adjustment depends on the proximity of the targeted prey.
3. In the real world, the bats emissions loudness can vary in many different ways. Nevertheless, we assume that this loudness can vary from a large positive A_0 to a minimum constant value A_{min}.

Algorithm 1 Bat Algorithm

```
Define the objective function f(x);
Initialize the bat population X = x_1, ..., x_n;
for each x_i in the population do
  Initialize velocity v_i, loudness A_i and pulse rate r_i;
  Define pulse frequency f_i;
end for
repeat
  for each x_i do
    Generate new solutions through Equations 21, 22 & 23;
    if rand > r_i then
      Select one solution among the best ones;
      Generate a local solution around the best;
    end if
    if rand < A_i and f(x_i) < f(x_*) then
      Accept the new solution;
      Increase r_i, reduce A_i;
    end if
  end for
until termination criterion not reached;
Rank the bats and return the best of the population;
```

Following the pseudo-code of the original BA (see Algorithm 1), every bat of the population (swarm) represents one possible solution of the problem to be optimized. At first, the population is initialized and the respective parameters to each solution are defined, these are the frequency f_i, the velocity v_i, the loudness A_i and the pulse rate r_i. In the main phase, for each generation t, every bat of the population moves by updating its position and velocity following the Eqs. (10.21), (10.22) and (10.23).

$$f_i = f_{min} + (f_{max} - f_{min})\beta, \quad \beta \in rand[0, 1] \tag{10.21}$$

$$v_i^t = v_i^{t-1} + \left[x_i^t - x_*\right] f_i, \quad x_* : \ best\ solution\ in\ the\ swarm \tag{10.22}$$

$$x_i^t = x_i^{t-1} + v_i^t \tag{10.23}$$

With respect to the local search phase a new solution is found around one of the best ones, based on a random walk: $x_{new} = x_{old} + rand[-1, 1] * A^t$, where A^t is the average loudness of the swarm at generation t. Finally, the loudness A_i and the rate r_i of each bat are updated following these formulas:

$$A_i^{t+1} = \alpha A_i^t, \quad \alpha \in [0.90, 0.99] \tag{10.24}$$

$$r_i^{t+1} = r_i^0\left[1 - \exp(-\gamma t)\right], \quad \gamma > 0 \tag{10.25}$$

10.6 Discrete Inspired Bat Algorithm

The Bat Algorithm has been initially design for the solution of continuous optimization problems. Such, it could not be directly applied in the solution of the Green-PCVRP, since the representation of the solutions is made by ordinal number encoding, i.e. discrete values that represent a sequence of nodes. As an instance, considering $N = 12$ number of nodes and $M = 3$ vehicles/routes, a feasible solution could be represented in a vector as: $[1, 4, 7, 10, 8, 1, 5, 6, 2, 3, 1, 9, 1]$, where all three routes initiate from and return to node 1, the duplication of node 1 among consecutive routes in a vector is omitted for simplification. Thus, we proposed a discrete version of the BA, namely, the *Discrete Inspired Bat Algorithm* (DIBA), in which similar to previous researches, the movement equations are replaced by heuristic techniques that search the local area around a solution to retrieve a new one, that will be described in the following. Moreover, the frequency parameter f_i, in order to reduce the complexity of the algorithmic scheme, is omitted while the pulse rate r_i and loudness A_i follow the original logic.

Furthermore, the velocity parameter v_i, depends on the position of the best solution in the population, and in our proposed version, since the original formula includes the frequency parameter, it is calculated as the distance among the respective solution and the best solution in the population. As solution distance, we refer to the number of element-wise similarity among the compared solution vectors, i.e. the number of positions at which the corresponding elements in both vectors are the same. Due the selective nature of the Green-PCVRP, the population is not uniform in terms of length, and, thus, other widely-used distance measures, e.g. Hamming Distance, Manhattan Distance could not be utilized. Also, we adopt the proposal of Osaba et al. (2019), that the velocity value could be represented by the number of neighbor solutions to be found, and that the best among them represents the new solution. The complete proposed algorithmic framework, the DIBA, is presented in Algorithm 2 and the respective flowchart is depicted in Fig. 10.1.

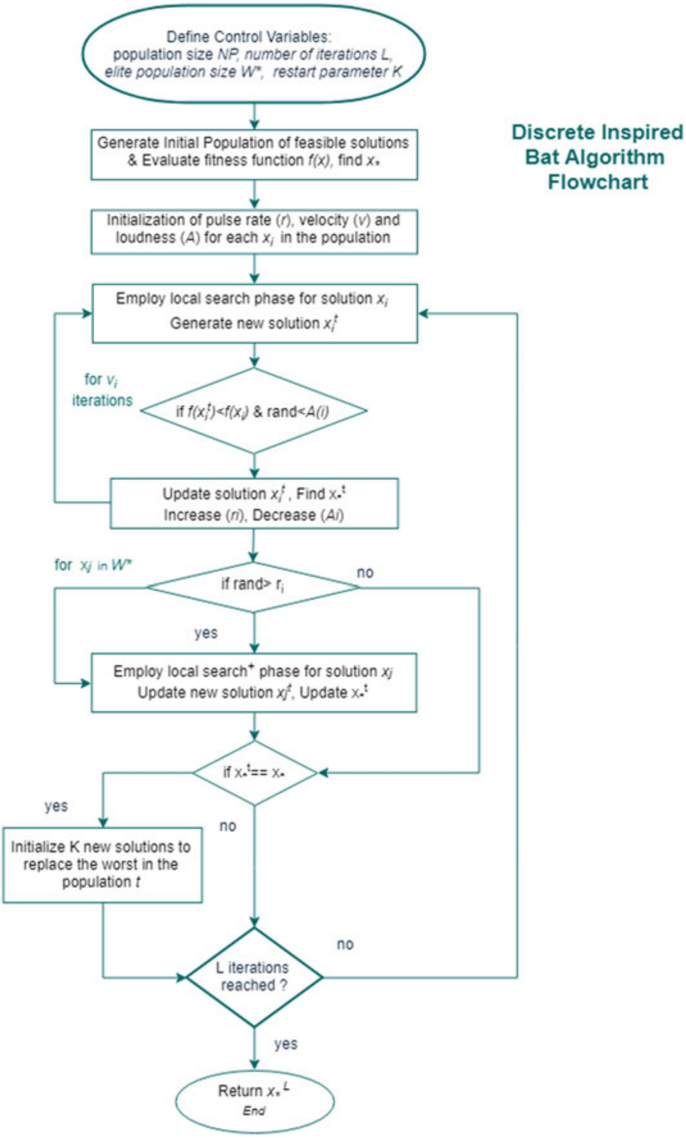

Fig. 10.1 Flowchart of the proposed DIBA

Algorithm 2 Discrete Inspired Bat Algorithm

Define: size population NP, number of iterations L, elite population size W^*, restart parameter K;
Initialize the solution population via $Initial-Population$;
Evaluate initial population $f(x)$, find best solution x_*;
repeat
  for each x_i in the population **do**
    Calculate velocity v_i;
    for a number random number of iterations $\in [1, v_i]$ **do**
      Employ the *local search phase* to generate x_i^t;
      Employ $Remove-node$;
      Employ $Reinforcement$;
      Employ $Exchange-node$;
      Evaluate x_i^t;
    end for
    if $f(x_i^t) < f(x_i) rand < A_i$ **then**
      Update $x_i \leftarrow x_i^t$;
      Decrease A_i, Equation 24;
      Increase r_i, Equation 25;
    end if
  end for
  Sort population, find x_*^t;
  Define elite population W^*;
  for each solution j in W^* **do**
    if $rand > r_j$ **then**
      Employ *local search phase+*;
      Update $x_j \leftarrow x_j^t$;
    end if
  end for
  Sort population, find x_*^t;
  if $x_*^t == x_*$ **then**
    Initialize K new solutions via $Initial-Population$;
    Replace K worst solutions;
  end if
until L iterations are reached
Rank the solutions and return the best one;

Following the proposed DIBA algorithm, after the parametrization step, the initial population should be generated and evaluated according to the fitness function, see Eq. 10.10. For that, the *Initial-Population* heuristic method is employed, see Algorithm 3. A predefined number of routes are initialized by a random node and combined to form a single vector. In order to satisfy the task completion constraint, a ratio of demand volume should be covered by the complete solution. Thus, until the aforementioned constraint is satisfied, non-included nodes in the initial solution, are inserted based on their most efficient position, in terms of distance travelled, when the rest of the imposed constraints of the PCVRP are not violated. In order to produce solutions of sufficient quality, the non-included nodes are previously sorted based on their prize value.

In the following, the local search phase is conducted, and such for a specific number of iterations the local search techniques *Remove-node*, *Reinforcement* and *Exchange-node* are implemented to each solution in the current population. The number of iterations for this phase is a random value, ranging from one to v_i, while the velocity of the solution i is calculated as described earlier.

Algorithm 3 *Initial − Population*

```
repeat
  Create M initial routes: [1 node 1];
  Combine the initial routes to vector;
  while Total capacity < Q_low do
    Create stack: sorted non-included nodes;
    for Each node k in stuck do
      Calculate the efficient position of node k;
      Correlate position to route m;
      if including node k in route m does not violate the capacity constraint Q then
        Include k and update the solution;
      end if
    end for
  end while
  Calculate the solutions' value in the objective function;
until Population NP is constructed
```

With respect to the embedded local search techniques of this phase, the *Reinforcement* aims to amplify the solution by inserting non-included, so far, nodes into the solution vector, taking into account the feasibility of the solution and the improvement of the solution's quality, while nodes to be inserted are randomly chosen, aiding to the increase of the exploration capability of the procedure. The previously employed one, is the *Remove-node* technique, during which nodes with low prize value are extracted from the solution vector, with a dual objective: (1) the fitness value of the solution could be improved, when the prize decrease offsets the new travel distance and emissions; and (2) the solution is reduced in terms of capacity Q per route, and when the *Reinforcement* is employed, different nodes could be inserted, exploiting that capacity gap.

Algorithm 4 *Remove − node*

```
repeat
  Find route m with the highest value of total distance travelled;
  Find the node k with the smaller prize in route m;
  if Reducing the capacity of route m by the prize of node k does not violate the constraints then
    Calculate new distance travelled, connecting the nodes immediate before and after k;
    Calculate the objective function of the new formation;
    if New objective function value is smaller than the initial one then
      Update the solution accordingly;
    end if
  end if
until itermax iterations reached
```

Algorithm 5 *Reinforcement*

```
Find all nodes n non-included in the solution vector;
S ∪ S + n;
Randomly perturb S set;
for each node j in S do
  Find efficient position k for n_j;
  Insert n_j in position k in the solution vector;
  Check feasibility and update solution vector accordingly;
end for
```

Regarding the *Exchange-node* local search technique, a simple iterative exchange of nodes between randomly selected routes is conducted, to further exploit the solution, with respect to all imposed constraints of the problem.

Algorithm 6 *Exchange − node*

```
repeat
  Randomly select routes: m1 and m2;
  Randomly select position in m1, node: i;
  Compute distance vector of route m2;
  Select position with the greatest distance value, node j;
  Compute total demand of both routes after the exchange;
  if New total demand values do not exceed the capacity limit then
    Calculate new distance travelled, exchanging the position of nodes i, j;
    Calculate the objective function of the new formation;
    if New objective function value is smaller than the initial one then
      Update the solution accordingly;
    end if
  end if
until itermax iterations reached
```

After the completion of the local search phase, the best neighbor solution is selected, from all generated over the conducted iterations. According to the original BA scheme, the neighbor solution is accepted following a probability based on the loudness parameter of the initial solution, even when the newly formed one is better. When a solution is accepted and replaces the initial one, the loudness parameter of the respective solution is decreased and the pulse ration is increased. All the above described processes should be followed for every member of the population. Then, the current best fitness value is retrieved. Subsequently, the best fraction of the current population is selected, denoted by W^*, and the solutions included in this elite population are randomly selected with a probability based on their respective pulse ratio value to undergo a second local search phase. The aforementioned phase is enriched with one more heuristic technique, in which a number of permutations of the nodes included into the solution of interested is tested, aiming to obtain a more efficient node sequence, in terms of distance traveled and emissions minimization. Nevertheless, it is possible that over the evolution of the population, following the local search phases, the algorithmic process could not obtain a more effective solution i.e. smaller fitness value. Thus, in the proposed DIBA, a restart procedure is applied, that introduces to the current population, newly generated solutions, that should replace the worst fraction of the current population and by that avoiding the fast converge of the solution method.

10.7 Computational Experiments

This section presents the experimental results of this study, solving the Green-PCVRP, in order to prove the solution quality of the proposed DIBA. The benchmark instances are drawn form the recent literature (Long et al. 2019), while there is a lack of comparison with other publish algorithms, since the research focuses on a proposed mathematical formulation, as a variant of the PCVRP. Thus, the obtained results of DIBA are compared with the solutions of the Gurobi exact solver on the same instances.

Table 10.1 Parameter setting

Parameter	Description	Expression
NP	Population size	80
L	Number of iterations	200
W^*	Elite population size	$0.2 * NP$
A^0	Initial loudness	$rand[0.7, 0.1]$
r^0	Initial pulse ratio	$rand[0.1, 4]$
γ, α	BA constants	0.98
$itermax$	Local search iterations	100
K	restart parameter	$0.1 * NP$

10.7.1 Benchmark Instances

As the PCVRP has not been studied extensively, previous publications used the benchmark instances of the Capacitated Vehicle Routing Problem (CVRP), incorporating a prize value to each customer and a minimum demand served ratio $ratio_Q$, both generated uniformly from [1, 80] or [1, 100] and [0.6, 0.8], respectively. However, recently, Long et al. publish a set of 120 instances for the PCVRPP, accessible at https://github.com/longjianyuGH/PCVRP.git (2019). In this study, we consider a set that consists in total of 120 benchmark problems, as for each of the 24 CVRP instances (group: A, B, E, M), 5 versions were generated, by changing the ratio $ratio_Q$: {0.60, 0.65, 0.70, 0.75, 0.80}. The different variants include problems with number of nodes from 32 to 200, and number of vehicles from 4 to 17. The parameter setting used for the conducted computational experiments is presented in Table 10.1.

10.7.2 Computational Results

In the following, the conducted experimental results on the benchmark instances are presented in Tables 10.2, 10.3, 10.4 and 10.5. For each of the 120 considered instances, the fitness function value of the best solution obtained by the Gurobi solver, is presented, denoted by g_{min}. In addition, the minimum (w_{min}) and average w_{avg} achieved values of the objective function, over five algorithmic executions of the proposed DIBA can be seen in the aforementioned tables. Moreover, the columns labeled as rpe and rpe_{avg} present the average percentage error of the best and the average solution, from the corresponding g_{min}, for each tested instance.

It is important to highlight that the exact solution method is able to find the optimal results within 10 min, with respect to the small instances, i.e. small number of nodes and routes, while regarding the larger ones the solution deviation from the optimal (MIPgap) is significant, while in some cases the solver could not return a feasible solution within 20 min of execution time, as seen in Table 10.5, when the number of nodes ranges between [101, 200] and the number of routes between [7, 17]. Overall,

Table 10.2 Group A: computational results

Instance	Gurobi solver	DIBA			
	g_{min}	w_{min}	rpe (%)	w_{avg}	rpe_{avg} (%)
A-n32-k5-1	4.357E+03	4.396E+03	−0.89	4.410E+03	−1.20
A-n32-k5-2	4.436E+03	4.459E+03	−0.52	4.473E+03	−0.84
A-n32-k5-3	4.337E+03	4.404E+03	−1.55	4.411E+03	−1.72
A-n32-k5-4	4.367E+03	4.410E+03	−0.98	4.415E+03	−1.09
A-n32-k5-5	4.644E+03	4.703E+03	−1.26	4.713E+03	−1.48
A-n37-k6-1	5.419E+03	5.490E+03	−1.30	5.501E+03	−1.50
A-n37-k6-2	5.450E+03	5.520E+03	−1.28	5.525E+03	−1.38
A-n37-k6-3	5.385E+03	5.454E+03	−1.28	5.459E+03	−1.37
A-n37-k6-4	5.428E+03	5.511E+03	−1.53	5.515E+03	−1.61
A-n37-k6-5	5.181E+03	5.239E+03	−1.11	5.241E+03	−1.16
A-n44-k6-1	5.053E+03	5.115E+03	−1.23	5.117E+03	−1.26
A-n44-k6-2	4.884E+03	4.928E+03	−0.91	4.943E+03	−1.22
A-n44-k6-3	5.249E+03	5.316E+03	−1.26	5.328E+03	−1.50
A-n44-k6-4	4.828E+03	4.887E+03	−1.21	4.892E+03	−1.31
A-n44-k6-5	5.032E+03	5.122E+03	−1.80	5.123E+03	−1.83
A-n48-k7-1	5.941E+03	6.008E+03	−1.13	6.009E+03	−1.16
A-n48-k7-2	6.217E+03	6.277E+03	−0.96	6.282E+03	−1.04
A-n48-k7-3	6.074E+03	6.112E+03	−0.61	6.117E+03	−0.69
A-n48-k7-4	6.056E+03	6.103E+03	−0.77	6.108E+03	−0.85
A-n48-k7-5	6.033E+03	6.125E+03	−1.53	6.128E+03	−1.57
A-n53-k7-1	5.948E+03	6.013E+03	−1.08	6.016E+03	−1.13
A-n53-k7-2	5.704E+03	5.790E+03	−1.50	5.795E+03	−1.59
A-n53-k7-3	5.716E+03	5.811E+03	−1.67	5.826E+03	−1.93
A-n53-k7-4	5.553E+03	5.627E+03	−1.34	5.642E+03	−1.61
A-n53-k7-5	6.008E+03	6.065E+03	−0.94	6.075E+03	−1.11
A-n60-k9-1	7.969E+03	8.083E+03	−1.43	8.093E+03	−1.56
A-n60-k9-2	8.031E+03	7.971E+03	0.75	7.976E+03	0.68
A-n60-k9-3	9.923E+03	8.211E+03	17.25	8.219E+03	17.17
A-n60-k9-4	7.801E+03	7.926E+03	−1.60	7.931E+03	−1.66
A-n60-k9-5	8.069E+03	8.157E+03	−1.10	8.173E+03	−1.30
A-n65-k9-1	7.848E+03	7.661E+03	2.39	7.761E+03	1.11
A-n65-k9-2	9.680E+03	7.599E+03	21.50	7.649E+03	20.98
A-n65-k9-3	8.931E+03	7.448E+03	16.61	7.598E+03	14.93
A-n65-k9-4	9.049E+03	7.692E+03	14.99	7.697E+03	14.94
A-n65-k9-5	7.546E+03	7.355E+03	2.53	7.405E+03	1.87

(continued)

Table 10.2 (continued)

Instance	Gurobi solver	DIBA			
	g_{min}	w_{min}	rpe (%)	w_{avg}	rpe_{avg} (%)
A-n69-k9-1	9.410E+03	7.599E+03	19.25	7.634E+03	18.88
A-n69-k9-2	9.785E+03	7.607E+03	22.26	7.647E+03	21.85
A-n69-k9-3	9.450E+03	7.492E+03	20.72	7.542E+03	20.19
A-n69-k9-4	9.877E+03	7.395E+03	25.13	7.410E+03	24.98
A-n69-k9-5	9.819E+03	7.503E+03	23.58	7.511E+03	23.50
A-n80-k10-1	1.099E+04	9.009E+03	18.05	9.059E+03	17.59
A-n80-k10-2	1.121E+04	8.951E+03	20.16	8.976E+03	19.93
A-n80-k10-3	1.102E+04	8.789E+03	20.27	8.814E+03	20.05
A-n80-k10-4	1.130E+04	9.078E+03	19.64	9.118E+03	19.29
A-n80-k10-5	1.097E+04	8.606E+03	21.57	8.621E+03	21.43

the proposed DIBA approach performs efficiently since, allowing 3 min of max execution time, it obtained 58/120 solutions better than the corresponding of the exact solver, and for 62/120 instances resulted in a worst solution. Nevertheless, the average relative percentage error over these 62 instances does not exceed the 0.98%, which taking into account the different allowed execution time of the two utilized methods, is an effective and competitive result.

With respect to the instance groups A, B and E, for which a comparison among the proposed DIBA and the exact solver can be made, the experimental results are summarized as follows, while the main attribute of the DIBA behaviour is that performs better over the exact solver for instances with more than 60 number of nodes N:

- Group A: with number of nodes $N \in \{32, 37, 44, 48, 53, 60, 65, 69, 80\}$ and number of routes $M \in \{5, 6, 7, 9\}$, the DIBA performed worst with -1.21% and better with 14.94% average deviation from the Gurobi exact solver.
- Group B: with number of nodes $N \in \{39, 41, 50, 56, 63, 78\}$ and number of routes $M \in \{5, 6, 7, 10\}$, the DIBA performed worst with -0.52% and better with 16.81% average deviation from the Gurobi exact solver.
- Group E: with number of nodes $N \in \{23, 33, 51, 76, 101\}$ and number of routes $M \in \{3, 4, 5, 10, 14\}$, the DIBA performed worst with -1.20% and better with 7.14% average deviation from the Gurobi exact solver.

10.8 Conclusions

The presented research introduces the Green-Prize Collecting Vehicle Routing Problem, to optimize the resource of firetrucks, allocation in case of a large fire, where

Table 10.3 Group B: computational results

Instance	Gurobi Solver	DIBA			
	g_{min}	w_{min}	rpe (%)	w_{avg}	rpe_{avg}
B-n39-k5-1	4.015E+03	4.027E+03	−0.30	4.042E+03	−0.67
B-n39-k5-2	4.085E+03	4.112E+03	−0.64	4.114E+03	−0.69
B-n39-k5-3	3.975E+03	4.001E+03	−0.65	4.011E+03	−0.90
B-n39-k5-4	4.058E+03	4.065E+03	−0.17	4.070E+03	−0.29
B-n39-k5-5	3.944E+03	3.969E+03	−0.62	3.984E+03	−1.00
B-n41-k6-1	5.100E+03	5.112E+03	−0.24	5.127E+03	−0.54
B-n41-k6-2	5.090E+03	5.132E+03	−0.83	5.182E+03	−1.81
B-n41-k6-3	4.914E+03	4.919E+03	−0.09	4.924E+03	−0.19
B-n41-k6-4	4.807E+03	4.821E+03	−0.29	4.851E+03	−0.91
B-n41-k6-5	5.009E+03	5.014E+03	−0.11	5.064E+03	−1.10
B-n50-k7-1	6.054E+03	6.060E+03	−0.10	6.079E+03	−0.41
B-n50-k7-2	5.509E+03	5.528E+03	−0.34	5.538E+03	−0.53
B-n50-k7-3	5.718E+03	5.787E+03	−1.20	5.807E+03	−1.55
B-n50-k7-4	5.747E+03	5.780E+03	−0.58	5.790E+03	−0.74
B-n50-k7-5	5.815E+03	5.823E+03	−0.14	5.838E+03	−0.40
B-n56-k7-1	5.311E+03	5.352E+03	−0.76	5.357E+03	−0.86
B-n56-k7-2	5.317E+03	5.350E+03	−0.62	5.395E+03	−1.47
B-n56-k7-3	5.289E+03	5.366E+03	−1.45	5.371E+03	−1.55
B-n56-k7-4	5.478E+03	5.518E+03	−0.73	5.549E+03	−1.31
B-n56-k7-5	5.468E+03	5.500E+03	−0.5	5.570E+03	−1.87
B-n63-k10-1	9.320E+03	9.170E+03	1.61	9.210E+03	1.18
B-n63-k10-2	9.287E+03	9.003E+03	3.06	9.053E+03	2.52
B-n63-k10-3	1.104E+04	9.415E+03	14.70	9.465E+03	14.25
B-n63-k10-4	1.088E+04	9.096E+03	16.36	9.146E+03	15.90
B-n63-k10-5	1.022E+04	9.436E+03	7.65	9.446E+03	7.55
B-n78-k10-1	1.092E+04	7.892E+03	27.72	7.895E+03	27.69
B-n78-k10-2	1.070E+04	8.037E+03	24.90	8.087E+03	24.43
B-n78-k10-3	1.104E+04	8.357E+03	24.31	8.362E+03	24.27
B-n78-k10-4	1.059E+04	8.069E+03	23.84	8.104E+03	23.51
B-n78-k10-5	1.109E+04	8.440E+03	23.92	8.465E+03	23.70

multiple points/assets need to be protected. The problem includes selective attributes, capacity constraints and concerns a predefined number of vehicles. The objective of the Green-PCVRP, is the maximization of the collected prize from the assets protected and the cost-efficiency in terms of fuel-consumption emissions of the operating vehicles, based on the formulated dispatch plan. Considering the optimization of the aforementioned problem, the Discrete Inspired Bat Algorithm has been developed, as

Table 10.4 Group E: computational results

Instance	Gurobi solver	DIBA			
	g_{min}	w_{min}	rpe (%)	w_{avg}	rpe_{avg} (%)
E-n23-k3-1	2.597E+03	2.593E+03	0.15	2.613E+03	−0.62
E-n23-k3-2	2.670E+03	2.693E+03	−0.87	2.713E+03	−1.60
E-n23-k3-3	2.659E+03	2.707E+03	−1.80	2.752E+03	−3.49
E-n23-k3-4	2.490E+03	2.515E+03	−1.00	2.535E+03	−1.81
E-n23-k3-5	2.509E+03	2.544E+03	−1.38	2.547E+03	−1.50
E-n33-k4-1	3.751E+03	3.820E+03	−1.85	3.855E+03	−2.79
E-n33-k4-2	3.491E+03	3.479E+03	0.35	3.489E+03	0.07
E-n33-k4-3	3.377E+03	3.416E+03	−1.14	3.466E+03	−2.62
E-n33-k4-4	3.396E+03	3.443E+03	−1.38	3.493E+03	−2.85
E-n33-k4-5	3.347E+03	3.413E+03	−1.99	3.513E+03	−4.98
E-n51-k5-1	3.354E+03	3.382E+03	−0.84	3.383E+03	−0.88
E-n51-k5-2	3.503E+03	3.541E+03	−1.09	3.541E+03	−1.09
E-n51-k5-3	3.439E+03	3.473E+03	−0.99	3.508E+03	−2.01
E-n51-k5-4	3.416E+03	3.457E+03	−1.20	3.482E+03	−1.93
E-n51-k5-5	3.540E+03	3.589E+03	−1.37	3.596E+03	−1.57
E-n76-k10-1	1.002E+04	8.135E+03	18.84	8.165E+03	18.54
E-n76-k10-2	9.686E+03	7.710E+03	20.40	7.710E+03	20.40
E-n76-k10-3	9.447E+03	7.720E+03	18.28	7.720E+03	18.28
E-n76-k10-4	9.982E+03	7.811E+03	21.75	7.811E+03	21.75
E-n76-k10-5	1.004E+04	7.935E+03	20.93	7.935E+03	20.93
E-n101-k14-1	1.336E+04	1.097E+04	17.92	1.147E+04	14.17
E-n101-k14-2	1.399E+04	1.143E+04	18.33	1.168E+04	16.54
E-n101-k14-3	1.390E+04	1.109E+04	20.21	1.154E+04	16.97
E-n101-k14-4	1.356E+04	1.095E+04	19.21	1.095E+04	19.21
E-n101-k14-5	1.401E+04	1.134E+04	19.00	1.134E+04	19.00

a hybridization of the original BA, omitting only the frequency parameter and altering the original algorithmic scheme by enhancing the local search phase and introducing new solution in the population. To demonstrate the effective performance of the proposed DIBA, computational experiments have been conducted, in comparison with the results of a commercial exact solver.

To further explore the capabilities of DIBA, as future research, we propose the exploration of the Green-PCVRP-NP, where the number of vehicles to be utilized is not a specified value. Finally, in order to enrich the capabilities of the mathematical formulation, by capturing real-life circumstances, time windows and service time for each asset should be taken into consideration.

Table 10.5 Group M: computational results

Instance	Gurobi solver	DIBA			
	g_{min}	w_{min}	rpe	w_{avg}	rpe_{avg}
M-n101-k10-1	–	7.043E+03	–	7.074E+03	–
M-n101-k10-2	–	7.211E+03	–	7.238E+03	–
M-n101-k10-3	–	7.167E+03	–	7.167E+03	–
M-n101-k10-4	–	7.006E+03	–	7.075E+03	–
M-n101-k10-5	–	7.072E+03	–	7.089E+03	–
M-n121-k7-1	–	3.195E+03	–	3.196E+03	–
M-n121-k7-2	–	3.483E+03	–	3.495E+03	–
M-n121-k7-3	–	3.391E+03	–	3.397E+03	–
M-n121-k7-4	–	3.151E+03	–	3.156E+03	–
M-n121-k7-5	–	3.346E+03	–	3.349E+03	–
M-n151-k12-1	–	7.573E+03	–	7.585E+03	–
M-n151-k12-2	–	7.013E+03	–	7.039E+03	–
M-n151-k12-3	–	7.360E+03	–	7.365E+03	–
M-n151-k12-4	–	6.974E+03	–	6.989E+03	–
M-n151-k12-5	–	6.726E+03	–	6.738E+03	–
M-n200-k17-1	–	6.726E+03	–	8.693E+03	–
M-n200-k17-2	–	1.094E+04	–	1.095E+04	–
M-n200-k17-3	–	1.045E+04	–	1.045E+04	–
M-n200-k17-4	–	1.030E+04	–	1.031E+04	–
M-n200-k17-5	–	1.044E+04	–	1.045E+04	–

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Chapter 11
Spatio-Temporal Distribution of Hydrological and Meteorological Droughts in the South Morava Basin

Slaviša Trajković, Milan Gocić, Danilo Misic and Mladen Milanovic

Abstract Over the years, the appropriateness of selection and application of drought indices in a particular climate area have been discussed. A number of drought indicators have been defined for each type of drought (meteorological, hydrological, agricultural) based on different measured data. The Standardized Precipitation Index (SPI) and the Streamflow Drought Index (SDI) were used to establish the association between meteorological and hydrological droughts. Based on the availability, type and accuracy of data, SPI and SDI are the simplest indices to obtain. This paper analyzes the different ways of processing drought data for the South Morava basin in a GIS environment. The largest agricultural drought was recorded in 2007 and because of that this year was selected for the drought analysis. The intensity of the SPI index for the year 2007 was calculated based on monthly precipitation data from eight meteorological stations in the South Morava basin. The SDI data for the year 2007 are provided for 16 hydrological stations. The paper compares the results of meteorological and hydrological droughts in the South Morava basin for the year 2007. The data were processed in the Quantum GIS software package and as a result visualisation of spatial data on meteorological and hydrological droughts was obtained in order to be applied in drought monitoring at the regional level.

Keywords Meteorological drought · Hydrological drought · SPI · SDI · Quantum GIS

11.1 Introduction

Although it has been thought that Serbia could be classified as one of the most promising countries in Europe and the world by water wealth, but due to underdeveloped irrigation systems and lack of water treatment systems, we are witnesses of the devastating effects of droughts on agricultural production. Also, there are frequent

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restrictions in water supply to the population and industry even in low-water periods that do not fall into the category of hydrological droughts.

Drought is caused by changes in climate that have been transmitted through the hydrological cycle, occurring in all climatic zones, but without the clear definition in its occurrence (Nguvava et al. 2019; Lavaysse et al. 2018; Parente et al. 2019). It can be classified as meteorological, hydrological, agricultural, and socio-economic drought (Wilhite and Glantz 1985). The meteorological drought occurs as the first one because of the reduced precipitation compared to the average precipitation in previous years, causing then agricultural and hydrological droughts (Park et al. 2018). The socio-economic consequences of drought depend on the current status in the areas of water resources management and on the use of water and land.

A number of quantitative indicators i.e. drought indicators have been developed in order to determine the intensity, duration and frequency of drought (Svoboda and Fuchs 2016). The determination of drought is especially important in arid and semi-arid regions, where availability of measured data is usually limited. In order to achieve the best selection of drought indicators, the relative low data requirements should exist. Also, an indicator should be applied easily in many regions providing a clear presentation of the results that can be used efficiently in decision making (Hao et al. 2019; Sun et al. 2019).

Considering these criteria, the following indicators have been created for different types of droughts: Reconnaissance Drought Index (RDI), Streamflow Drought Index (SDI), Standardised Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI) and Water Surplus Variability Index (WSVI). RDI, SPI, SPEI and WSVI are used for quantification of meteorological drought, because their main component is precipitation. Also, RDI, SPEI and WSVI can be used for analyzing agricultural drought, because they can describe adequately water balance including reference evapotranspiration in their calculation (Tsakiris and Vangelis 2005; Vicente-Serrano et al. 2010; Gocic and Trajkovic 2014b).

According to the World Meteorological Organisation (WMO), meterological services all over the world should apply SPI index (WMO, 2012). Using the SPI index, it is possible to analyze drought at different intervals such as 1, 3, 6, 9, 12 and 24 months. In Serbia, the Republic Hydrometeorological Service of Serbia (RHMSS) has determined the SPI values based on the amount of precipitation measured in the previous 30, 60 and 90 days since 2010. Also, it presents moisture conditions in the form of map and table per each meteorological station and can be a first step in developing an early warning system. More detailed analyzes of drought based on the SPI index for stations in Serbia can be found in Gocic and Trajkovic (2013a, b, 2014a) and Tosic and Unkasevic (2014).

The main disadvantage of the SPI index is that it cannot detect drought in the case of normal rainfall or due to the increased evapotranspiration or to show increased humidity conditions at high rainfall intensity over a short time interval (Frank et al. 2017). However, the SPI is based on a statistical approach, does not require climate adjustment and allows comparison of its values from region to region.

Hydrological drought is associated with the occurrence of reduced water in rivers and in different reservoirs such as lakes, groundwater, and artificial reservoirs. The intensity of the hydrological drought is most commonly defined at the basin level. It occurs with a significant delay compared to the meteorological and agricultural droughts because it is needed more time to deal with the effects of precipitation shortages in the hydrological system in the form of reduced soil moisture, or reduced water levels in rivers and lakes. Precipitation can cause decreasing in soil moisture, which can be immediately noticeable, but it will affect the runoff in rivers and water management systems in a few weeks or months. In addition to the weather as the primary cause of hydrological drought, the human factor also affects the hydrological characteristics of the basin using land and inappropriate infiltration and runoff intensity. The indicators used for hydrological drought analysis are the Palmer Hydrological Drought Index (PHDI) or Surface Water Supply Index (SWSI), which generally require more data and are more complicated for calculation (Jacobi et al. 2013; Doesken and Garen 1991). The Streamflow Drought Index (SDI) requires minimal input and is simple for the determination (Malik et al. 2018; Tabari et al. 2013).

The key objectives of this research are to calculate drought severity using SPI and SDI at eight meteorological and 16 hydrological stations, respectively, to consider spatial and temporal variability of hydrological and meteorological droughts at South Morava Basin during the year 2007.

11.2 Analysed Study Area and Its Characteristics

Serbia is located in the Balkans, the region of Southeast Europe, but also it is a part of Mediterranean countries considering geographical and climatic characteristics (Fig. 11.1a).

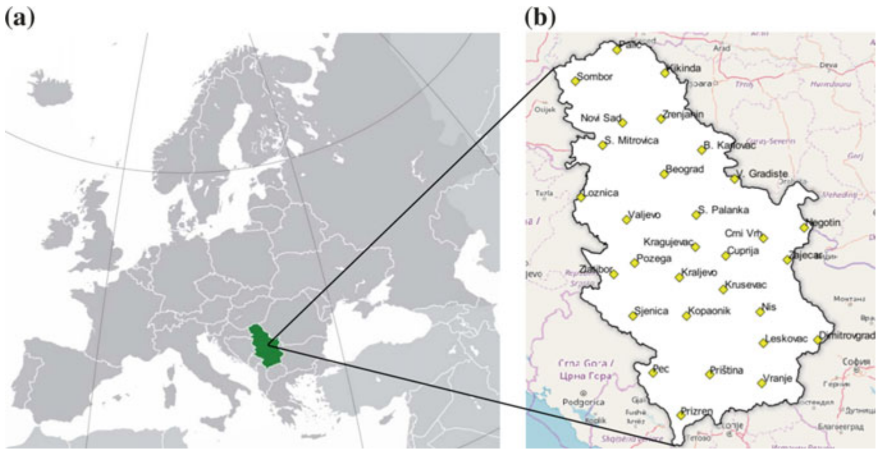

Fig. 11.1 **a** Position of Serbia in Europe, **b** locations of analyzed meteorological stations

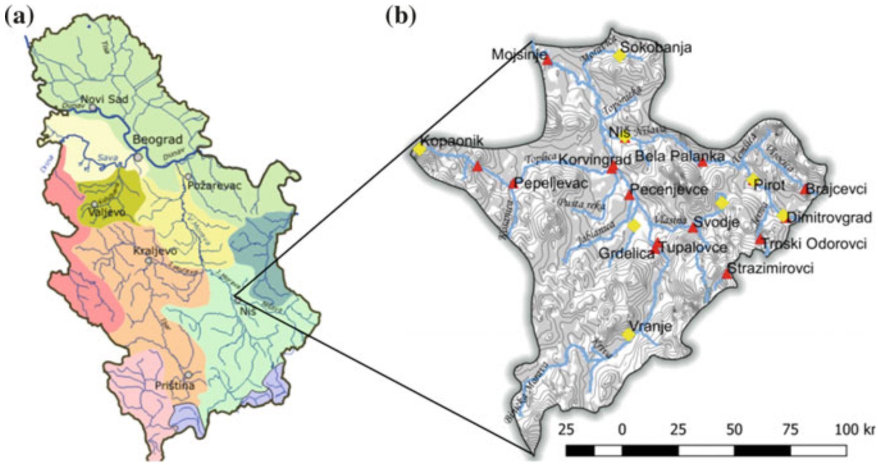

Fig. 11.2 **a** Main river basins in Serbia, **b** South Morava river basin

The climate of Serbia is moderately continental and depends on geographical location, relief and local influence. Two relief parts of Serbia can be identified, the northern part with plains, and the southern part with mountains forming a mountainous region (Trajkovic et al. 2019). The following geographical characteristics directly influence the climate of Serbia: the Alps, the Mediterranean Sea, the Pannonian Plain, the valley of the Morava River, Carpathian and Rhodope mountains (Stojkovic Piperac et al. 2018). The geographical locations of analyzed meteorological stations are presented in Fig. 11.1b.

In Fig. 11.2 the South Morava river basin with the drainage area of 15,696 km^2 is presented. It is located in the south of the Danube river basin connecting Aegean with the Pannonian basin. The South Morava river is 319 km long creating the Great Morava river with the West Morava river. Two most important tributary rivers are the Toplica and the Nisava that springs in western Bulgaria. The temperate-continental climate in this area depends on Vlasina climatic area and the valley of the river Nisava in the north and is characterized by low precipitation, mild winters and very hot summers.

11.3 Applied Drought Indices

11.3.1 Standardized Precipitation Index

In order to quantify precipitation deficit over different time periods i.e. 1, 3, 6, 9, 12 and 24-month periods, the Standardized Precipitation Index (SPI) was developed (McKee, 1993). The SPI index is based on the fact that the typical probability density

Table 11.1 Drought classification based on the SPI index

Drought class	SPI value
Exceptionally wet	SPI ≥ 2.326
Extremely wet	1.645 ≤ SPI < 2.326
Considerably increased moisture	1.282 ≤ SPI < 1.645
Moderately increased moisture	0.935 ≤ SPI < 1.282
Slightly increased moisture	0.524 ≤ SPI < 0.935
Near normal	−0.524 ≤ SPI < 0.524
Minor drought	−0.935 ≤ SPI < −0.524
Moderate drought	−1.282 ≤ SPI < −0.935
Severe drought	−1.645 ≤ SPI < −1.282
Extreme drought	−2.326 ≤ SPI < −1.645
Exceptional drought droughtdrdroughtdrought	SPI ≤ −2.326

distribution of precipitation for a given period of time is not symmetrical, but rather inclines to higher values of precipitation. Abramowitz and Stegun (1964) proposed using approximations for its calculation, transforming the cumulative probability into a standard normal random variable Z:

$$Z = SPI = \begin{cases} -\left(t - \frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right), t = \sqrt{ln\frac{1}{(H(x))^2}} 0 < H(x) \le 0,5 \\ +\left(t - \frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right), t = \sqrt{ln\frac{1}{(1-H(x))^2}} 0,5 < H(x) \le 1,0 \end{cases} \tag{11.1}$$

where $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$. Deviations must be normalized both in time and space in order to obtain a relevant drought assessment. Drought in a time period x is defined as a period in which the value of SPI is continuously negative and SPI takes a value of −1 and less (McKee et al. 1993, 1995). The drought begins when the SPI value is below zero for the first time and ends when the SPI value becomes positive. The drought classification based on the SPI index is presented in Table 11.1.

11.3.2 Streamflow Drought Index

Nalbantis (2008) and Nalbantis and Tsakiris (2009) introduced Streamflow Drought Index (SDI) for the hydrological drought analysis. If a time series of monthly runoff $Q_{i,j}$ is available, in which i denotes the hydrological year, and j is the month within that hydrological year (j = 1 for October and j = 12 for September), then the cumulative runoff volume $V_{i,k}$ can be calculated for the i-th hydrological year of the k-th reference period, k = 1 for the period October–December, k = 2 for October–March, k = 3

Table 11.2 Drought classification based on the SDI index

Drought class	Description	SDI value
0	Non-drought	SDI ≥ 0.0
1	Mild drought	−1.0 ≤ SDI < 0.0
2	Moderate drought	−1.5 ≤ SDI < −1.0
3	Severe drought	−2.0 ≤ SDI < −1.5
4	Extreme drought	SDI < −2.0

for October–June, k = 4 for the period October–September. The SDI is determined for each reference period k and i-th hydrological year as:

$$SDI_{i,k} = \frac{V_{i,k} - \bar{V}_k}{s_k} \quad i = 1, 2, \ldots, \quad k = 1, 2, 3, 4 \tag{11.2}$$

The drought classification based on the SDI index is presented in Table 11.2.

11.4 Drought Analysis

In this paper, the precipitation data from 16 stations of the observed basin for the reference period 1961–2011 were used. Data for the four most significant stations (Vranje, Nis, Dimitrovgrad and Kopaonik) for the year 2007, one of the driest year, are presented in Fig. 11.3.

At all stations except Kopaonik, the highest monthly precipitation occurred in October and November. The highest precipitation at the Kopaonik station was measured in May (Gocic et al. 2016). The SDI values are shown as histograms in Fig. 11.4.

The use of GIS software packages can improve the representation of hydrological processes such as evapotranspiration and droughts (Ramirez-Cuesta et al. 2017; Thenkabail and Rhee 2017). The Quantum GIS 3.0.1 open source software package was used for the spatial presentation of meteorological and hydrological droughts. At the very beginning, the EPSG:4326-WGS 84 was selected as the reference coordinate system. The procedure consists of two separate parts. In the first part, a map of the Earth was loaded and a layer related to the borders of the territory of Serbia and the borders of the South Morava basin was created. In the second part, layers for the locations of meteorological and hydrological stations were created, calculated values of SPI and SDI were loaded, and data for drought representation were interpolated (Fig. 11.5).

The meteorological drought results based on the SPI values and the hydrological drought results based on the SDI values for the 12-month period are presented in Fig. 11.6. The SPI values for the year 2007 were determined using precipitation from eight meteorological stations in the South Morava basin (Vranje, Leskovac, Babusnica, Dimitrovgrad, Pirot, Nis, Sokobanja and Kopaonik). The SDI values for

Fig. 11.3 Precipitation in the South Morava basin in the year 2007

the year 2007 were calculated for the 16 hydrological stations in the South Morava basin. Based on these achieved data, the hydrological drought was compared with the meteorological drought at the basin level.

A rough network of meteorological stations also affects the accuracy of the data as well as the fact that certain hydrological stations are located in sub-basins at the national border. Only the Kopaonik station is at the border of the basin, while the others are concentrated towards the center of gravity of the basin. The hydrological stations, from which the data were used, are also distributed to the interior of the basin, except the Brajcevci, Dimitrovgrad, Trnski Odorovci and Strazimirovci stations.

Due to unavailability of data for precipitation and runoff from neighboring countries, it is not possible to get a more accurate presentation of the drought. As a consequence, there are some deviations in the occurrence of hydrological drought after meteorological e.g. for the period of October–December; SDI-12 values show severe drought although SPI-12 values show normal or increased humidity conditions for the same period (Fig. 11.6).

A comparative analysis of meteorological and hydrological droughts during the year 2007 in the South Morava basin is given respectively in Figs. 11.7 (1-month period), 11.8 (3-month period), 11.9 (6-month period) and 11.10 (12-month period). Moderate drought intensity occurs in the period of March–September, except for the month of April when the hydrological drought reaches the category of severe or extreme drought (Fig. 11.7).

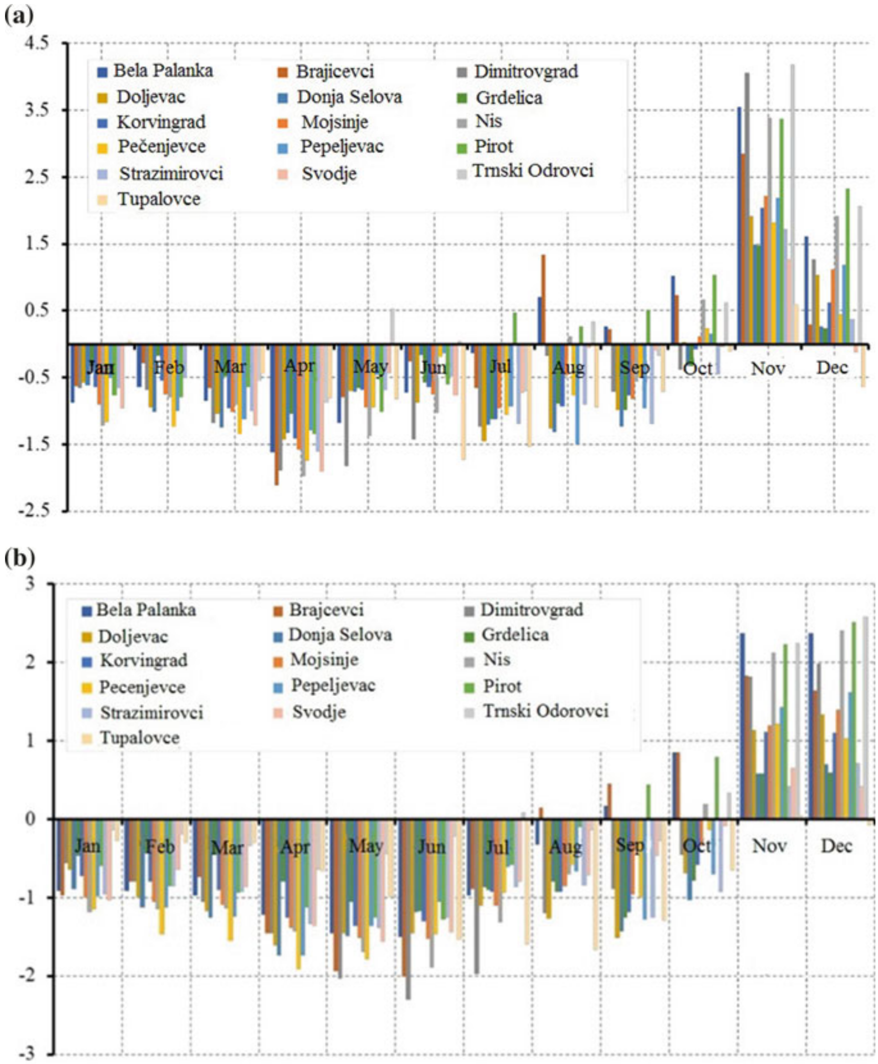

Fig. 11.4 Histogram of SDI values in the South Morava basin for the year 2007: **a** SDI-1, **b** SDI-3, **c** SDI-6 and **d** SDI-12

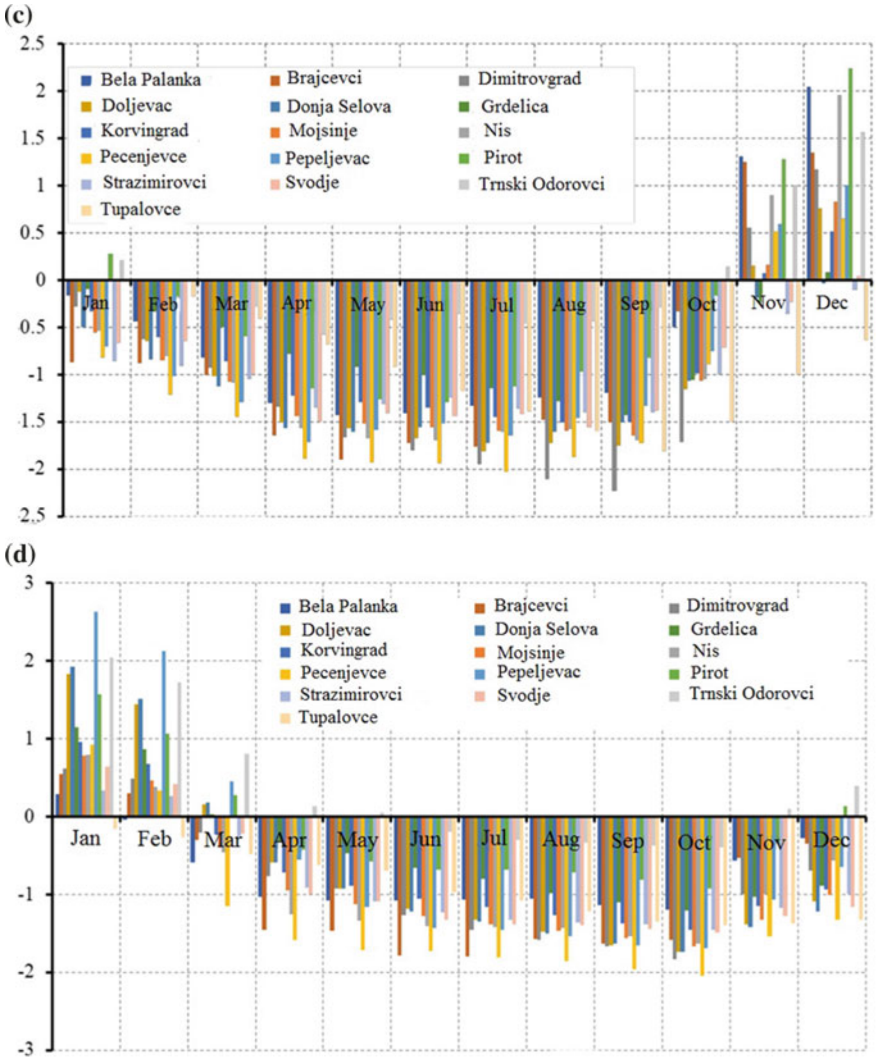

Fig. 11.4 (continued)

It can be seen from Fig. 11.8 that the hydrological drought is more intense than the meteorological one. According to the SPI-3, the humidity conditions are normal or increased throughout the whole year except in April and August when the meteorological drought is of high intensity while the hydrological drought is more intense during the period January–October, but does not exist during November and December.

The meteorological drought during the period of April–September is of high or extreme intensity in April and July (Fig. 11.9). During other months in the vegetation

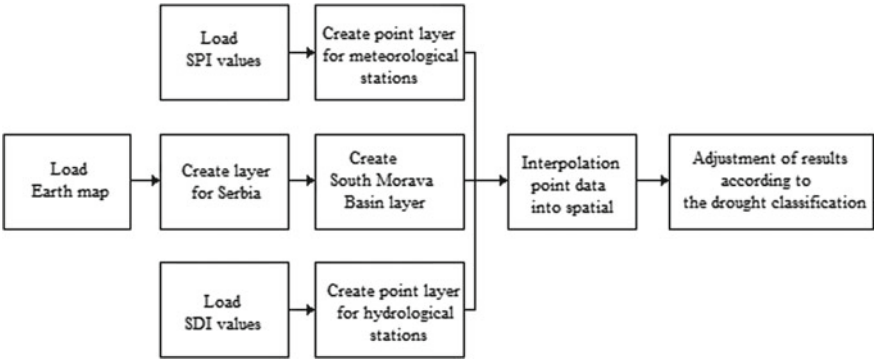

Fig. 11.5 Data processing process in GIS

period, humidity conditions are normal or extremely increased at the Pirot station. Moderate drought occasionally occurs locally in the area of Nis station. Considering the hydrological drought, it has moderate or strong intensity in the period of March–October, except for June when it is not present, as well as in November and December, when the values of the meteorological drought are severely or extremely increased.

According to the SPI-12, the meteorological drought in the basin of the South Morava during the vegetation period of April–September had moderate or strong intensity only during August and September, while it occurs as moderate in the northern part of the basin in July (Fig. 11.10). During other months, the values of meteorological droughts range from normal to severely increased during the winter months in the area of Pirot and Kopaonik stations. There is no hydrological drought from January to March, while in the period of April–December it is uniformly distributed throughout the basin when its intensity ranges from moderate to severe hydrological drought.

It can be further observed from Figs. 11.9 and 11.10 that the occurrence of hydrological drought based on SDI-6 and SDI-12 is mainly oriented around the very course of the South Morava River, and most intensively around the hydrological station Pecenjevce, located upstream of the Toplica and Nisava rivers which are the main tributaries of the South Morava. The reason is that the lack of precipitation in the basin causes a lower amount of flow in the tributary rivers which results in the most pronounced deficit in the main river flow in the basin.

11.5 Conclusions

The aim of this research is to present the spatio-temporal distribution of hydrological and meteorological droughts in the South Morava basin using the capabilities of GIS software. The methodology was based on the use of two drought indicators, Standardized Precipitation Index and Streamflow Drought Index.

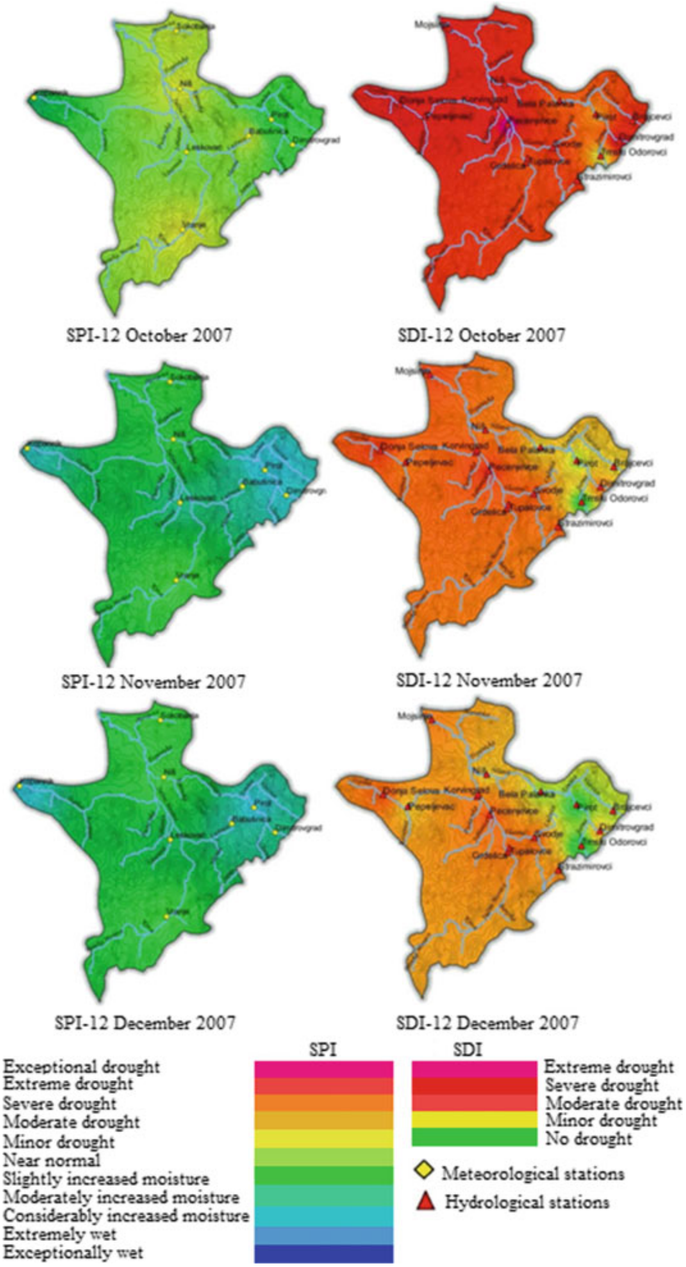

Fig. 11.6 SPI-12 and SDI-12 values for the period October–December 2007 in the South Morava basin

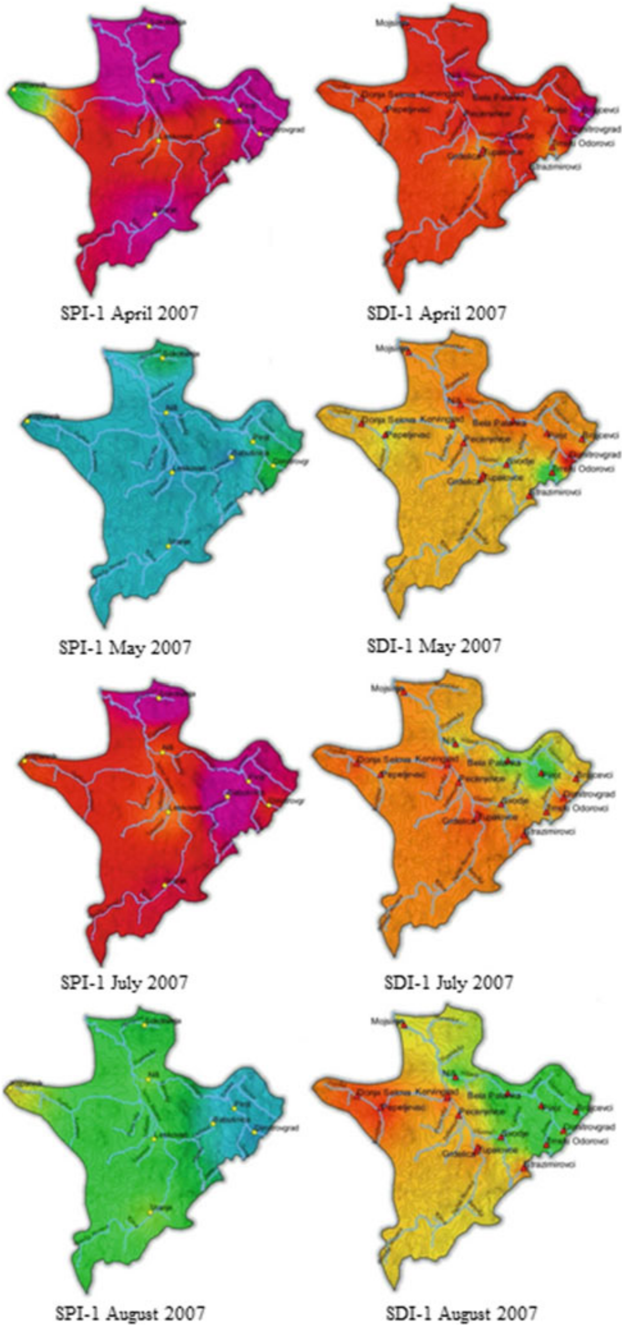

Fig. 11.7 Comparison of meteorological and hydrological droughts in the South Morava basin for the year 2007: SPI-1 and SDI-1 values

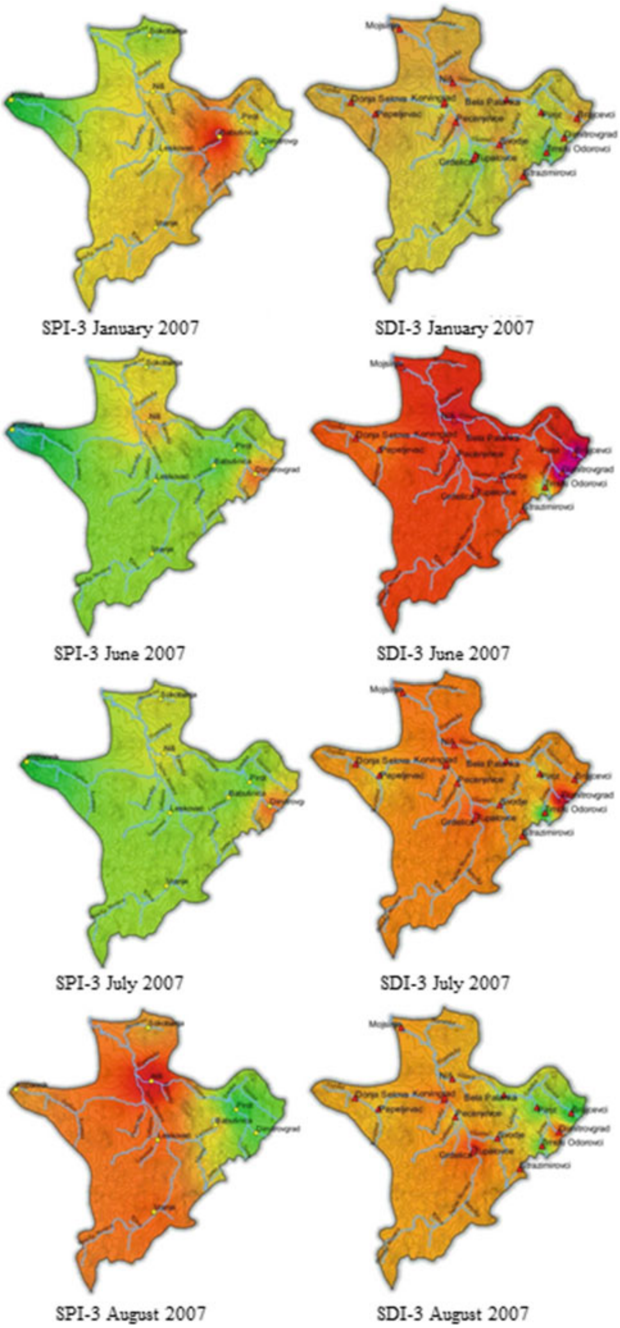

Fig. 11.8 Comparison of meteorological and hydrological droughts in the South Morava basin for the year 2007: SPI-3 and SDI-3 values

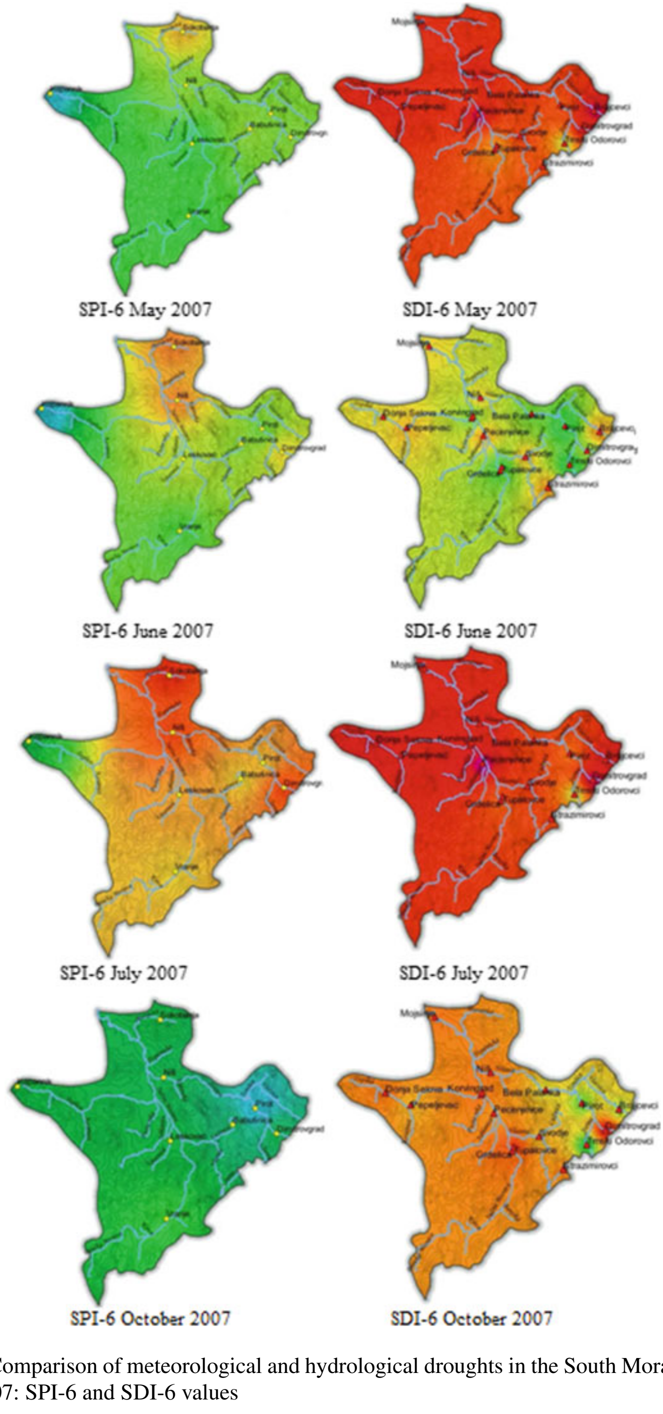

Fig. 11.9 Comparison of meteorological and hydrological droughts in the South Morava basin for the year 2007: SPI-6 and SDI-6 values

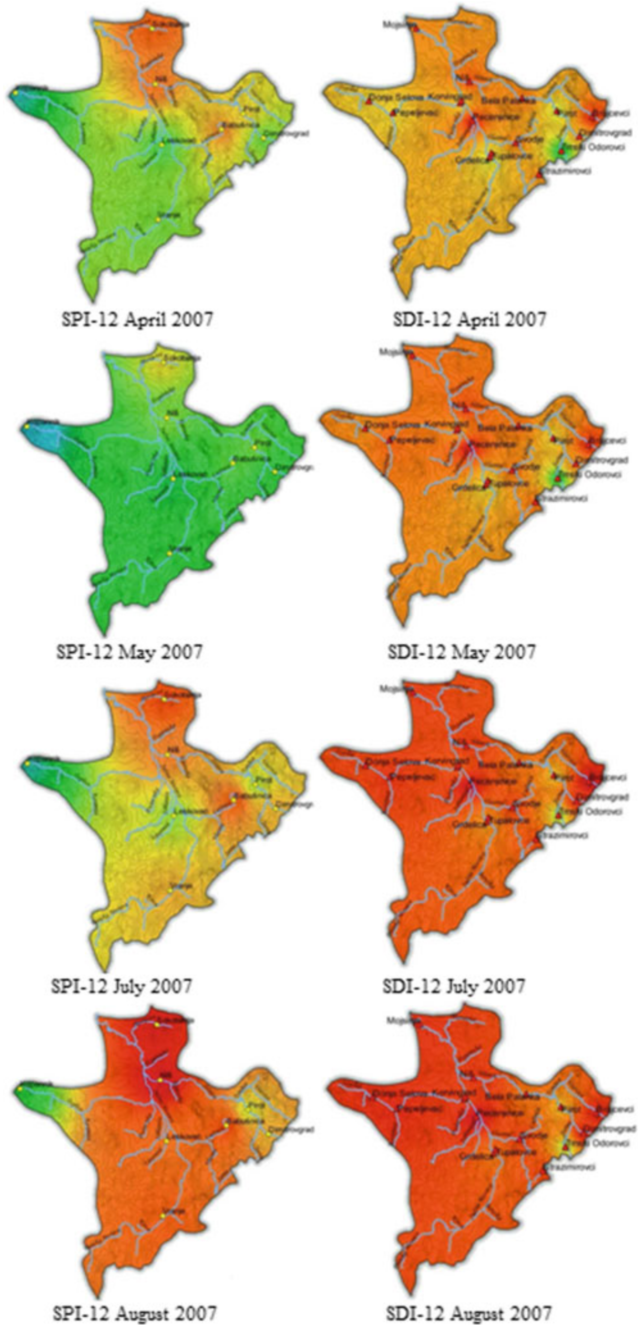

Fig. 11.10 Comparison of meteorological and hydrological droughts in the South Morava basin for the year 2007: SPI-12 and SDI-12 values

In the year 2007, the methodology was implemented to analyze the occurrence of hydrological drought as a consequence of meteorological drought. According to the SPI-3 values, the humidity are normal or increased throughout the year except in April and August. According to the SDI-3 values, the hydrological drought had high intensity while it has more intense during the period of January–October. By analysing the SPI-6 values, it can be concluded that the meteorological drought had high or extreme intensity in April and July, while using the SDI-6 values the hydrological drought had is moderate or heavy intensity in the period of March-October except for June.

According to the SPI-12 values, meteorological drought had moderate or severe intensity only during August and September, while it occurs as moderate in the northern part of the basin in July. Moderate to severe hydrological drought is uniformly distributed throughout the basin between April and December. The occurrence of a hydrological drought based on SDI-6 and SDI-12 is mainly oriented around the very course of the South Morava River, and is most intense around the hydrological station Pecenjevce.

The research also showed that the QGIS can be used adequately for the spatial presentation of drought values. Integration of data involving GIS application can have purpose in spatial planning and in integrating water resources management.

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Conflict of Interest The authors declare that they have no conflict of interest.

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