MASTERTHESIS

Nature-based Solutions (NBS) – current concepts and approaches in the light of Soil and Water Bioengineering implementation

Nature-based Solutions (NBS) - aktuelle Konzepte und Ansätze im Hinblick auf ingenieurbiologische Umsetzungen

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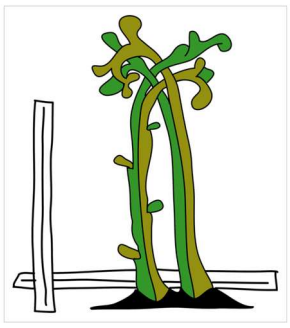

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Affidavit

I hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such. This written work has not yet been submitted in any part.

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Abstract

This master thesis deals with the published concepts and approaches of Nature-based Solutions (NBS) and Soil and Water Bioengineering (SWB) in the current scientific literature.
First, the basics of SWB and the methodical processing of literature analyses were illustrated. By means of a systematic literature search, publications on NBS as well as on NBS in connection with SWB were carried out in three database systems.
With a review selection of 13 publications, a qualitative content analysis was performed for the different research questions.
As an introduction to the topic and a fundamental basis, the definition of Nature-based Solutions was examined. Further on, categorisations and conceptual approaches in relation to Nature-based Solutions were explored.
With a focus on the connection between the current literature of Nature-based solutions and Soil and Water Bioengineering, special measures and detailed concepts were searched for.
The analysis methods were prepared for the review selection from the period 2014-2018, but in order to provide an up-to-date insight into the literature, publications until July 2020 were supplemented.
The results show an increasing interest in the topic, but also a lack of concrete SCI-papers regarding the connection between NBS and SWB. The two main cited definitions of NBS seem to leave a lot of scope for free interpretation. Specific categories and approaches are ambiguous and mostly topic related instead of widely applicable. Links between NBS and specific SWB measures are only apparent to those who already have expertise in SWB, and are rarely discussed directly in the SCI-papers. Thus, there is a clear recommendation for more research and scientific publications to analyse and further disseminate these interlocking topics.

Zusammenfassung

Diese Masterarbeit beschäftigt sich mit den publizierten Konzepten und Ansätzen von Nature-based Solutions (NBS) und Ingenieurbiologie in der aktuellen wissenschaftlichen Literatur.
Zuerst wurden Grundlagen zur Ingenieurbiologie und zur methodischen Bearbeitung von Literaturanalysen veranschaulicht. Durch eine systematische Literaturrecherche wurden in drei Datenbanksystemen Publikationen zu NBS sowie zu NBS in Verbindung mit IB durchgeführt.
Mit einer Review Auswahl von 13 Publikationen wurde zu den unterschiedlichen Forschungsfragen eine qualitative Inhaltsanalyse ausgeführt.
Als Einstieg in die Thematik und grundlegende Basis wurde die Definition von Nature-based Solutions untersucht. Ebenso wurden Kategorisierungen und Konzeptansätze in Bezug auf Nature-based Solutions erforscht.
Mit Fokus auf den in der aktuellen Literatur abgebildeten Zusammenhang zwischen Nature-based Solutions und Ingenieurbiologie wurden spezielle Maßnahmen und detaillierte Konzepte gesucht.
Die Analysemethoden wurden für die Review Auswahl aus dem Zeitraum 2014-2018 aufgearbeitet, um jedoch einen aktuellen Einblick in die Fachliteratur geben zu können, wurden die Publikationen bis Juli 2020 ergänzt.
Die Ergebnisse weisen ein ansteigendes Interesse am Thema, jedoch auch ein Defizit an konkreten SCI-Papers bezüglich der Verbindung von NBS und Ingenieurbiologie auf. Die zwei hauptsächlich zitierten Definitionen zu NBS lassen noch viel Spielraum für freie Interpretation. Speziell Kategorien und Ansätze sind uneindeutig und meist themenbezogen anstatt übergreifend anwendbar. Verknüpfungen von NBS und speziellen ingenieurbiologische Maßnahmen sind nur für jene erkennbar, die bereits über Fachwissen bezüglich Ingenieurbiologie verfügen, und werden in den SCI-Papers kaum direkt diskutiert. Somit gibt es eine klare Empfehlung für mehr Forschung und wissenschaftliche Publikationen, um diese ineinander greifenden Themen zu analysieren und weiter zu verbreiten.

Table of contents

1 Introduction

1.1 Problem definition and Motivation

In the context of increasing worldwide problems raised by climate change and different kinds of pollution, many scientific papers, and concepts regarding Nature-based Solutions (hereafter as well referred to as NBS) have been published. Working in the field of Soil and Water Bioengineering (hereafter as well referred to as SWB), a deep connection between NBS and SWB became obvious.

In order to identify the connection between the above-mentioned terms, the field and definition of Soil and Water Bioengineering are summarised at the beginning. Following this clarification, publications concerning the trendy term Nature-based Solutions were studied. This provides an insight into the increasing interest and importance of NBS. Working with the publications of the last six years a quantitative overview is presented as well as a summary of the appearance and development of NBS. The main focus is here on the closer definition of Nature-based Solutions. To provide a better understanding of the definitions, categorisations of the concepts or approaches were also taken into account. To focus on the connection of NBS to Soil and Water Bioengineering concepts with specific measures, these were searched and examples of written connections to SWB were discussed.

In a nutshell, the motivation of this thesis was to clarify the definition of suggested strategies and actions of NBS in general and in relation to Soil and Water Bioengineering.

1.2 Research Questions

At the beginning of the working process research questions and goals of the thesis were defined. The questions led to a specific focus, and the range of these extensive concepts were limited and aligned to a detailed aim. In this case, the questions emphasised the connection between concepts on NBS and SWB. The research questions are:

1. How many scientific publications were released considering both Nature-based Solutions and Soil and Water Bioengineering? (RQ 1)
2. What common definitions of Nature-based Solutions can be found in the present literature? (RQ 2)
3. Are there different categories and approaching types towards Nature-based Solutions concepts? (RQ 3)
4. What kind of specific measures can be identified pertaining to Nature-based Solutions and Soil and Water Bioengineering? (RQ 4)
5. Are there specific publications connecting Nature-based Solutions and Soil and Water Bioengineering? (RQ 5)
6. Are there significant developments after the main analysis timeframe? (RQ 6)

1.3 Aimed results and expectations of knowledge profit

Related to the research questions three goals give an impression of what is expected of this thesis.

Goal 1: To give an overview impression on released scientific publications regarding NBS and SWB and to present a review selection for further analysis.

Goal 2: To clarify the definitions and actions of Nature-based Solutions, specifically in the context of Soil and Water Bioengineering.

Goal 3: To highlight measures regarding Soil and Water Bioengineering and their correlation towards NBS in the present literature.

2 Soil and Water Bioengineering

This chapter is providing an overview of Soil and Water Bioengineering (SWB) principles in order to clarify terms and definitions of this field of expertise. Consequently, the linkage between SWB and the term Nature-based Solutions (NBS) is later presented in a more comprehensive way.

SWB belongs to the field of civil engineering with emphasis on vegetation based engineering and similarities to ecological engineering. Ecological engineering is described as a sustainable system, where engineering builds on ecological principles connecting human society and natural environment in a way to get the most out of it for both (Mitsch and Jørgensen, 2003; Mitsch, 2012 in Rey et al., 2019).

Relating published manuals and specialised books are dominated by some pioneers and organisations of SWB, such as Arthur von Kruedener, Hugo Meinhard Schiechtl, Florin Florineth, to name a few experts in this field. Since its foundation, EFIB (European Federation of Soil Bioengineering), the umbrella organisation of different European SWB organisations as well published various specialised books and guidelines including definitions, basic principles, and constructional types (EFIB, 2015).

2.1 History and development of Soil and Water Bioengineering

The use of plants to shape, design and stabilise the environment is not a new approach but follows a long tradition. Examples of wine bowers, roof gardens, hanging gardens, tree spurs, wattle fences and willow bush mattresses can be dated back to times before Christ (Florineth, 2012; Zeh, 2007).

Regarding these early roots, Soil and Water Bioengineering can be described as a complex and user-oriented science, which is connected to very old knowledge. It basically evolved from manual work (EFIB, 2015). The increasing importance of securing slopes and shores of rivers and lakes is associated with the growing population and the protection of human infrastructure. Therefore constructions in the environment have grown as well (Florineth, 2012). The closer concept of Soil and Water Bioengineering originated centuries ago in Europe, probably because of the need for land. The growing density of population and the history of land use, such as agriculture as well as human settlements were reason for the increasing need for land and probably the reason for securing and stabilising this land.

Hence from long known stabilisation methods using living plants and parts of plants in hydraulic and earthwork engineering, the science of Soil and Water Bioengineering was developed (EFIB, 2015). In the late nineteen forties, the occurrence of this field of science seemed to be justified as there was a rapid increase of written publications about this topic around 1950 (e.g. Kruedener, 1951). But not just literature but also planning documents and evidence of performing the discussed methods are proofing this assertion (Schlüter, 1986). Arthur von

Kruedener, one of the early pioneers focussing on the term Soil Bioengineering, pointed out that using biological methods not only improves security, durability, and sometimes cost-benefit comparison of technical structures but also benefits for the good of rural economy (Kruedener, 1951). Therefore, SWB was established as an interdisciplinary field of science through all kinds of knowledge enhancement, findings, evaluations, and different applications. For example, using knowledge of landscape ecology regarding regional observations, working with indicator information of plants, process-specific site and habitat findings connected to different materials and plants. There could be a long list added, unnecessary to point out that it's a living science and therefore a developing process, for instance, related to research and development regarding modern environmentally friendly materials (EFIB, 2015).

2.2 Definitions of Soil and Water Bioengineering

Regarding the definition of Soil and Water Bioengineering it is stressed that most of the above elucidated historic development, as well as the following given definitions of SWB are publications in German language (e.g. Kruedener, 1951; Schlüter, 1986; Begemann and Schiechtl, 1994; Hacker and Johannsen, 2012; Florineth, 2012). Therefore, the expression *"Ingenieurbiologie"* first was translated to Soil Bioengineering, only with the foundation of EFIB and new publications and unifications the term was refined to Soil and Water Bioengineering. Although it seems that even in the field of experts, probably out of convenience sometimes the shorter and simple expression "bioengineering" is used (Rey et al., 2019). Thereby the English term bioengineering is covering other disciplines and techniques of medical-biochemical origin, as the Merriam-Webster definition implies (Anon, n.d.). As in many scientific disciplines and designations, there is not only one true definition of Soil and Water Bioengineering, but there are some aspects in focus, which can be seen as specific facts of the field. Therefore, statements and explanations of the main pioneers and organisations as well as aims regarding Soil and Water Bioengineering, are leading to a discussion of the different definitions, listed as follows by source and definition.

One of the first combining engineering and botanical work documented can be traced back to Arthur von Kruedener (1951). He defined SWB as following:

> *"Soil and Water Bioengineering is a construction discipline, which uses biological findings for earth construction and water engineering as well as to secure unstable slopes and banks. It is characterised by the use of living plants and part of plants, that are applied in order to achieve a secure existence of technical constructions, as living construction material as well as in combination with*

inanimate materials. " (Kruedener, 1951 in Schiechtl and Stern, 1992, p.14; own translation)[1]

Because of this definition, Soil and Water Bioengineering, according to Schiechtl and Stern (1992), should be handled as a necessary and useful addition to simple technical engineering. Uwe Schlüter (1986) is referring to Kruedener's definition, but mentioning scientific development of biological or ecological planning and technical basics, therefore giving himself a new definition:

"Soil Bioengineering is a field of work in landscape planning with the objective of promoting applications through construction methods using living or living and dead building materials." (Schlüter, 1986, p.11; own translation)[2]

To counteract the impoverishment of the landscape the aim of Soil and Water Bioengineering is to reuse and include the strengths of landscapes. This can be attained through biotechnological suitable plants, which thereby improve soils and hydraulic structures to reduce the force of water (Begemann and Schiechtl, 1994).

"These resulting plant structures provide new living spaces, which leads up to an ecological-mechanical impact complex." (Begemann and Schiechtl, 1994, p.11 own translation)[3]

This effect achieves and conserves a dynamic state of equilibrium, as much as the striven stabilisation. Basis for the performance of bioengineering methods are inheritable biotechnical characteristics and biotechnical benefits of plants (Begemann and Schiechtl, 1994).

Treating the problems of using concrete instead of renewable building materials after the Second World War, Florin Florineth points out the consequences for slopes and rivers. Considering himself a student of Schiechtl, he admired his work and improvements for the field of Soil and Water Bioengineering in developing old and new methods as well as its dissemination and organisation. Therefore, it seems appropriate to understand the technique and application of plants for support work as the definition of Soil and Water Bioengineering by Florineth. (Florineth, 2012).

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[1] *„Die Ingenieurbiologie ist eine Bautechnik, die sich biologischer Erkenntnisse bei der Errichtung von Erd- und Wasserbauten und bei der Sicherung instabiler Hänge und Ufer bedient. Kennzeichnend dafür sind Pflanzen und Pflanzenteile, die so eingesetzt werden, dass sie als lebende Baustoffe im Laufe ihrer Entwicklung für sich, aber auch in Verbindung mit unbelebten Baustoffen eine dauerhafte Sicherung der Bauwerke erreichen."* (Kruedener, 1951 in Schiechtl and Stern, 1992, p.14)

[2] *„Die Ingenieurbiologie ist ein Arbeitsgebiet der Landschaftsplanung mit der Zielsetzung, durch Bauverfahren mit lebenden bzw. lebenden und toten Baustoffen Nutzungen zu fördern."* (Schlüter, 1986, p.11)

[3] *„Die so entstehenden Pflanzenbauwerke schaffen neue Lebensräume, deren Summe sich in einem ökologisch-mechanischen Wirkungskomplex niederschlägt."* (Begemann and Schiechtl, 1994, p.11)

Another definition of SWB expresses it as "*a biological-technological field of science, which deals with the protection of constructions and applications through plants and plant populations",* according to Hacker and Johannsen (2012, p.14, own translation)[4]
In various publications of the EFIB the definition of the designation 'Soil and Water Bioengineering' is explained as follows:

> *"Soil and Water Bioengineering is a discipline that combines technology and biology, making use of plants and plant communities to help protect land uses and infrastructures, and contribute to landscape development."* (EFIB, 2015, p.28)

It builds on technological methods, which use natural and living material like seeds, plants and parts of plants to fit constructions and land use techniques as well for human needs as to support natural conditions. Therefore manuals, technological know-how and mechanical and biological knowledge of plants and used materials are requisite skills (Zeh, 2007).

All the definitions and statements regarding Soil and Water Bioengineering have in common is the usage of plants and parts of them. The most important specific and important aspects of the definitions were collected and therefore used in the frame of this thesis: The definition and measures of Soil Bioengineering are understood as living technological methods, which differ in aims and fields of applications but have in common (1) relying on organic parts and their biological properties, (2) trying to support technical constructions through (3) sustainable structures made of renewable materials.

2.3 Aims and functions of Soil and Water Bioengineering

To give an impression of the state of the art of SWB, three aspects – aims, functions, and construction methods – are described as follows. This serves for the understanding of approaches and reasons for Soil and Water Bioengineering use, carrying on to their connection to the NBS concepts.

2.3.1 Aims

From the beginning of the development of SWB, the main aim was to create constructions, which combine technological constructions with their natural surrounding environment. The basis, therefore, according to Hacker and Johannsen (2012), is built by knowledge and interactions of plants in their environment as well of the structure and properties of the plants themselves. In focus nowadays are solutions, which are close to nature, restoring ecosystems,

[4] *"Ingenieurbiologie ist ein biologisch-technisches Fachgebiet, das sich mit der Sicherung von Bauwerken und Nutzungen mittels Pflanzen und Pflanzen- beständen befasst."* (Hacker and Johannsen, 2012, p.14)

e.g. renaturation, and conserving landscapes and establishing vegetation related to improving site and climate conditions. Adapted measures and suitable plant selections must be coordinated to ensure erosion control, sustainability and biodiversity (Hacker and Johannsen, 2012).

Kruedener already emphasised the call for sustainability of SWB:

> *"The generations that will grow into the engineered land will thank him* [the engineer] *if he did not act according to the point of view "After me the deluge", but think biologically, i.e. with the living nature. I understand such an extension of the daily work to biological aspects as agricultural Soil and Water Bioengineering."* (Kruedener, 1951, p.12; own translation)[5]

EFIB (2015) is defining the aim of Soil Bioengineering as creating alive and near-nature surroundings through constructions. For SWB constructions living and naturally grown material is used and combined with technical auxiliary and complementary substances. Thus, the constructions match up with the natural environment ecologically and aesthetically. Furthermore, fulfilling functions can be understood as the aim of Soil and Water Bioengineering (Zeh, 2007).

2.3.2 Functions

All kinds of engineering techniques provide a long list of functions and effects. The main functions - technological, ecological, aesthetic, and economic - are explained briefly.

One of the central functions for constructions is obviously technical concerns. These can be understood as the protection of soil areas against damages by different kind of erosion, for instance, due to strong wind or rain, severe frost or water flows. Further-more the elimination of mechanical forces, improvement of stabilisation and cohesion characteristics at the surface and in the deep soil is strived for. Functions as drainage, reducing flow velocity and aiding the deposition of snow, drift sand and sediments and many other operations are being fulfilled.

Ecological functions as the development of plant communities and biotope structures, improvement of soil properties like living conditions for microorganisms and formation of nutrients, habitat for fauna, filtering, absorbing, and reduction functions can contribute to improving the environmental quality (Zeh, 2007).

Aesthetic or landscaping functions are provided through recovering and rehabilitating measures as creating new features, structure shapes and colours of vegetation. The

[5] *"Die Generationen, die in das technisierte Land hineinwachsen, werden es im danken, wenn er nicht nach dem Standpunkt "Nach mir die Sintflut" gehandelt, sondern biologisch, d.h. mit der lebendigen Nature gedacht hat. Eine solche Erweiterung des täglichen Schaffens auf biologische Gesichtspunkte verstehe ich unter landwirtschaftlicher Ingenieurbiologie."* (Kruedener, 1951, p.12)

integration of new constructions into the landscape or replacing conventional engineering structures are also classified under aesthetic functions (Zeh, 2007).

Regarding economic functions of Soil and Water Bioengineering, the research method of life cycle assessments is an important and interesting newer approach (e.g. von der Thannen et al., 2020). But without discussing the topic of cost efficiency, there are a lot of functions contributing to a sustainable and economic way of engineering and the reduction of material and energy usage. Less material use is a given fact since vegetation and living components reproduce and develop themselves already in the construction process as well as through self-regeneration in cases after damaging events. Working with site-specific and regional plants, soil, and stones, transportation and material costs can be reduced. Socio-economic factors as the local recreation in urban areas or tourism in high mountain regions should also be considered (EFIB, 2015; Zeh, 2007).

Based on these widespread functions and application fields, the interdisciplinary nature of Soil and Water Bioengineering becomes obvious. Methods and knowledge of Soil and Water Bioengineering are used in areas of fundamental stabilisation work as well as basic knowledge in geotechnics, hydraulic or structural engineering. The following disciplines are implementing Soil and Water Bioengineering methods (EFIB, 2015, p.31):

- Landscape management
- Agro-hydraulic engineering
- Agricultural and landscape planning
- River engineering, hydraulic engineering
- Coastal protection
- Torrent and avalanche control
- Industrial hydraulic engineering
- Mining and reclamation
- Quarrying
- Sanitary engineering
- Waste management
- Construction of sports and leisure facilities
- Road, railway, and airport constructions
- Construction of country and forest roads
- Construction of footpaths and cycle paths
- other areas of civil engineering

Consequently, due to many different functions and fields of application, Soil and Water Bioengineering prevents or moderates effects of natural hazards, retrieving and relaunching plants and animal species in surroundings and environments which have been disturbed or degraded and improving the quality of soil, air and water (Rey et al., 2019).

2.4 Categories and methods of Soil and Water Bioengineering

Most published literature about Soil and Water Bioengineering is distinguishing construction methods according to their field of application. The main distribution, already obvious due to its designation, is split between soil and hydraulic engineering (Begemann and Schiechtl, 1994). Many classifications approaches separate SWB applications towards more detailed

scopes. A classification of application fields derived from different publications is shown in the following **Table 1**.

Table 1 Categorisation of Soil and Water Bioengineering applications (according to Schlüter, 1986; Florineth, 2012; Hacker and Johannsen, 2012 modified)

Categories	**Fields of application**
Soil	Hillsides
	Slopes
	Ditches
	Along traffic routes
	Along settlement areas
Hydraulic	At standing water bodies (e.g. Lakes)
	At running water bodies (e.g. rivers, fumes etc.)
	Coastal areas
Others / transferable	Wind and erosion influences
	Mountainous and alpine regions
	High risk or vulnerable areas regarding fire
	Urban areas (design with trees and shrubs)

With the objective of a standardisation in order to simplify communication and distribution of knowledge regarding specific methods of Soil and Water Bioengineering, EFIB published a book on construction types in 2007. Although it may not include some newer technologies, since it was published in 2007, it serves as a good basis for an overview of construction methods. These construction methods or types build the smallest unit regarding Soil and Water Bioengineering terms. They describe the actual process to build working Soil and Water Bioengineering measures.

It does not follow the goal of this thesis to discuss and explain all kinds of construction methods in detail, but in order to provide a basis for category possibilities, an excerpt of different measures is listed. This approach of a categorisation of measures is divided in preliminary work, as this regards mainly working with non-living materials, and the methods working with living materials, i.e. plants. The extract of the construction methods (Table 2) is structured into categories named as generic terms of methods, as existing subcategories, according to materials, and titles of the specific methods.

Table 2 Excerpt of different planting and construction methods in a classification option (derived from Zeh, 2007, pp.156–342)

Generic term of methods	Title of specific methods
Seeds	Hayseed sowing
	Seeding with hay mulch
	Mulch seeding with long straw or long hay
	Sowing of wild flowers
	Hydroseeding of woody plants
Planting of woody species	Planting (planting of seedlings)
	Bare root planting
	Large-tree transplantation
	Pioneer planting
	Afforestation
Working with herbaceous plant parts	Container and pot planting of grasses and herbs
	Rhizome planting
	Dividing of tufts
	Stem planting
	Brush mattress constructions with reeds
Working with shoot-forming woody plants and woody plant parts	Dormant cuttings and live stakes
	Fascines along the toe of embankments
	Fascine with brushlayers
	Living brush mattress
	Hedge brush layers
Working with plant communities	Spontaneous vegetation (succession zone)
	Transplantation
	Turves/ sods (sod slab)
	Turve/ sod rolls
	Turve/ sod waterway
Combined construction methods (with living and non-living materials)	Vegetated log cribwall
	Bank pile wall
	Planted or greened dry stone walls and rip raps
	Vegetated bank protection mattress
	Vegetated reinforced soil

This excerpt of construction methods only shows a small selection out of many different opportunities of procedures and construction types, which belong to the applications of Soil and Water Bioengineering. With the advent of the term NBS, the present thesis explores further the connection of NBS concepts and Soil and Water Bioengineering in the present literature.

3 Material and Methods

This chapter enlarges on the theory of literature research and analysis process. In the first part research methods, review selections and analysis types are provided. The second part explains the research design, this includes the methodology and the documentation description throughout the processes.

3.1 Theory of Literary analysis

To provide a comprehensible literature review and analysis, theoretical approaches and methods are discussed. The present chapter gives a short overview of selection and analysis possibilities and closes with an insight in the chosen type of literature analysis – a qualitative content analysis. Providing an understanding of its development and procedure steps.

3.1.1 Literature research and review selection

Theoretical basics for the research and selection process are listed.

3.1.1.1 Research basics

When working with literature one of the most important aims is to provide decent research. Starting a thesis usually involves literature when preparing and delimiting the subject area, but – as the aim of the present thesis is to build a basis for new scientific work - extensive research of already existing literature about the topic had to be conducted. This chapter implies the first part of the literature research. That means finding relevant literature to get information about theory and working models to build up the theoretical part of the thesis (Brauner and Vollmer, 2004).

3.1.1.2 Search strategies

To conduct literature research there are two main strategies, the systematic, and the cumulative research.

Systematic research (see **Figure 1**) means to search systematically through specialist literature via electronic databases, library catalogues as well as journals lists (Becker, 2012). To find appropriate publications in these huge pools of literature, it is necessary to define keywords or search strings. For this purpose, a certain prior knowledge regarding the topic is necessary to choose certain keywords, which are related to methods, research area or other aspects of the subject field. To limit the results of a search, it can be helpful to build a keyword chain, including or excluding certain information (Becker, 2012).

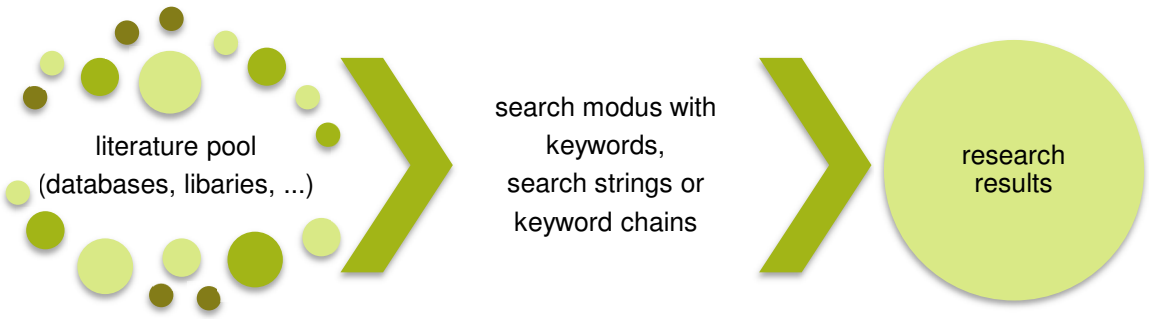

Figure 1 Systematic research process (according to Becker, 2012; Kornmeier, 2016 modified)

The second strategy is the cumulative research, which means working around citations and statements of authors and publications. This method can be divided into two subcategories.

The first is the so-called snowballing or backward method (see **Figure 2**) (Webster and Watson, 2002; Kornmeier, 2016). For this method, no prior knowledge surrounding the topic is required, but different, ideally central, literature publications have to be chosen. The backward search is starting from one or more chosen sources, the reference list is searched backwards for earlier publications. Obviously, using this strategy only previous literature can be collected and there is a risk to get caught up in a fellowship of researchers if they tend to mainly cite like-minded colleagues.

The second subcategory of cumulative research is representing the forward-searching process (shown in **Figure 3**). Thus, it works similar to the snowballing method only in the contrary direction. The aim is to follow the citations of one or more main publications. For example, using Web of Science database will identify articles, which have been cited regarding keywords, this as well gives a specific impression of the importance of publications (Webster and Watson, 2002, p.xvi; Kornmeier, 2016, pp.84–85).

Positive effects of cumulative methods are that there is a rather fast summation of connected literature as the searching process will soon come to a point where the search is circling back to the same sources, and an impression of the most frequent or important publications is generated automatically (Becker, 2012; Kornmeier, 2011).

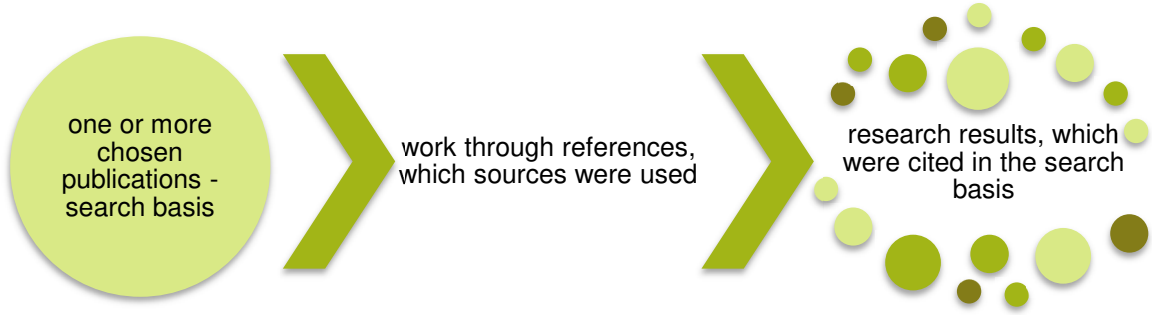

Figure 2 Cumulative research processes - backwards search (i.e. snowballing method) (according to Webster and Watson, 2002; Kornmeier, 2016 modified)

Figure 3 Cumulative research processes - forward search (according to Becker, 2012; Kornmeier, 2016 modified)

3.1.1.3 Research process

The following illustration (**Figure 4**) shows the different sections of research and selection processes according to Becker (2012). Starting with the available literature pool, different search modi, systematic or cumulative, are leading to the research results, which build the basis for the review selection. Further on it is a common and usually necessary method to limit processed literature by declaring the selection criteria, those need to be explained in the documentary process, and in conclusion reveal the review selection as a result of the research process.

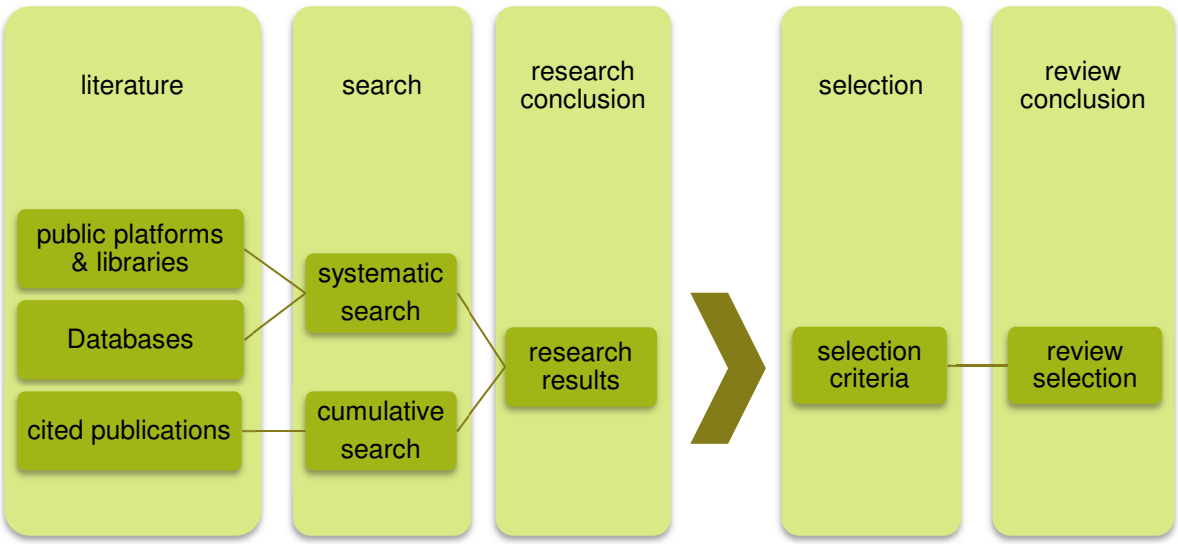

Figure 4 Illustration of the basic research and selection process (according to Becker, 2012 modified)

Under consideration of working with a lot of publications, the importance of the documentation of the literature research is apparent. No matter if the detected information is managed on index cards or manual excel sheets, it is recommended to note additional to bibliographic information, keywords, abstracts as well as copies or excerpt (Becker, 2012). Nowadays these index cards can as well be managed with text or excel sheets or even special literature administration programmes. Various programmes (e.g. Citavi, Endnote or Zotero) are available

on different price levels, some are freeware or with student licences available for free, some of them may even be used for citations in the writing process, which may be a simplification on more angles (Becker, 2012).

3.1.1.4 Selection process

As illustrated in **Figure 4**, the final part of the literature research leads to the basis of the review selection (according to Kornmeier, 2016). The research results are passed through a selection process to evaluate the publications regarding their content-related suitability and to restrict the literature to a feasible effort. This selection process can be divided into different steps, i.e. screening and testing on eligibility, and is leading to a selection of relevant publications, as shown in **Figure 5** below.

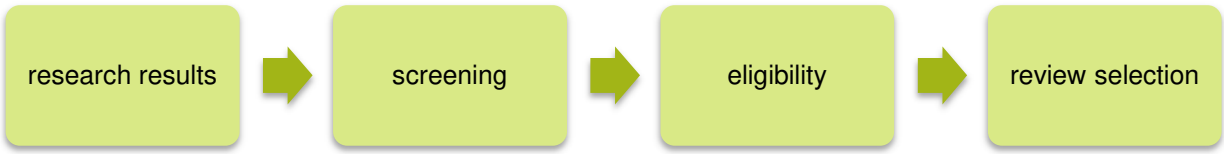

Figure 5 Steps of the selection process (according to Kornmeier, 2016 modified)

Although the research results – no matter which strategy was chosen – all include related content towards the processed topic, not all results are necessarily meaningful or in-depth of the research questions.

Screening

A recommended start is to perform a screening of these publications before working ahead on a more detailed level. This means to scan through the most informative parts of the publications such as title, abstract, or blurb, searching for direct connection towards the thesis' topic and research questions (Becker, 2012). Only the publications with a direct connection to research subjects or questions get ahead in the selection process.

Eligibility

After this first reduction of results, their eligibility has to be proven. So, the intermediate results are skimmed along with a list of criteria, which are connected to the research questions. In this step of the process, the whole paper or publication is scanned, methods and results are noted as well as upcoming questions and further annotations for research. As Kornmeier (2016) recommends, when working through literature it is useful to write short excerpts and add this to the literature overview.

The final result of the selection process is the review selection, i.e. the chosen publications, which also build the basic material for further analysis.

3.1.2 Principles and concepts

To answer the defined research questions, there are many different options for analysis methods. This chapter gives an overview of theoretical possibilities followed by a description of the chosen method.

3.1.2.1 Quantitative analysis

Researchers of quantitative studies work objectively and disjoined from the subject and examination (Erlingsson and Brysiewicz, 2013). Quantitative analysis briefly summarises results, which are measured and reported as numbers. It looks at attributes of similar parameters and works with majorities and distributions.

3.1.2.2 Qualitative analysis

Qualitative analysis, on the other hand, searches for a maximum of variation, human realities, and relations to objects (Erlingsson and Brysiewicz, 2013). Results often tend to be in rich literature style instead of countable results. They try to understand patterns, similarities, and differences in research goals.

3.1.2.3 Mixed analysis

Out of current developments of analysis trends, as there are growing studies not only using quantitative or qualitative methods, a third type has emerged. Grown out of the previous two analysis types, and in order to gain more completeness towards specific research goals, the mixed analysis was progressed (Erlingsson and Brysiewicz, 2013).

The following illustration (**Figure 6**) gives an overview of common existing research methods according to Erlingsson and Brysiewicz (2013).

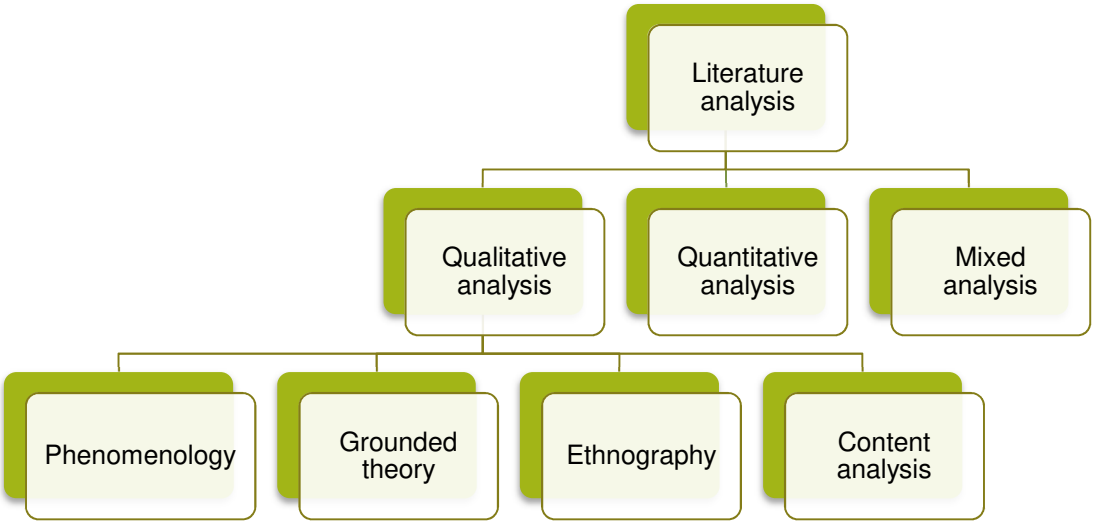

Figure 6 Typology of research analysis (elaborated from Erlingsson and Brysiewicz, 2013; own illustration)

3.1.3 Approaches of qualitative analysis concepts

Neglecting a quantitative overview, the focus of this thesis was set on qualitative research. As the main research questions are aiming to find information relating to the content and detailed published information, the amount is not as important as the expressed information

As a consequence and to lead this overview of analysis types towards a decision-making process, these four qualitative methods according to Erlingsson and Brysiewicz (2013) as well shown in **Figure 6**, will be shortly explained and advantages or disadvantages are listed:

[1] **Phenomenology:** working with essence descriptions, main interpretations, and comprehensive understandings. Results are mainly in descriptive forms favoured reclining towards experiences rather than simple statements.

[2] **Grounded theory:** aims for a theoretical or conceptual understanding through inductive methods. The focus lies on the data collection, as the theories assume to be grounded in data, this has to be continued until a saturation point.

[3] **Ethnography** – forms a study about people and their surroundings and everyday attitudes. While aiming for social significance and regular activities the researcher is actively participating.

[4] **Content analysis** – focuses on the subject matter of data and deals with relational connections, investigating the purpose of the text.

3.1.4 Development and procedure of qualitative content analysis

There is a historical development from comparisons of texts to structured content analysis, along this process definitions of the expressions are changing (Merten 1983; Krippendorff 1980; Mayring 1994a in Mayring, 2000). It is challenging to phrase a simple expression, as the description is rather often directly connected to the field of work and therefore many different specific definitions mirror various working areas. However, summarising content analysis can be explained *as 1) analysis of any kind of communication 2) fixed communications analysis* 3) *systematic,* 4) *rule-guided and* 5) *theory-based approach and* 6) *providing conclusions about aspects of communication* (Mayring, 2015, pp.11–13).

A declaration of various techniques to do a qualitative content analysis should be given. There are three fundamental forms of interpretation listed by Mayring (2014), which are largely compatible with three approaches of Hsieh and Shannon (2005), all of these belonging to the rather large and still evolving pool of methods and techniques regarding qualitative content analysis. So, therefore, the following three main forms or analysis types will be shortly described (Mayring, 2014; Hsieh and Shannon, 2005):

- **Summary or conventional content analysis:** The aim is to reduce data to the essential content to draw an image of the basic information.

This analysis starts with observations, the categories are built during data analysis, and therefore they are received from the data.

- **Explication or directed content analysis:** The analysis aims to provide supplementary information to raise understanding of text passages.
  Beginning with theory, different categories can be compiled before as well as during the data analysis signifying that these derive as well from theory as out of research findings.
- **Structuring or summative content analysis**: The object of the analysis is to focus on certain aspects of the data and present an overview of the material and sort this information according to defined criteria.
  The keywords are identified before or during the analysis process and are deduced from the interest of researchers or review of the literature.

Following these fundamental forms of analysing methods, there are further differentiations as well as it is mentioned, that there is no certain regulation and always an ongoing development and different theoretical considerations. In the table below (**Table 3**) an approach of nine distinct forms of analysis is shown, devoted from the three main forms – listed above – supplemented with a fourth, so-called mixed form (Mayring, 2014, pp.64–65; Hsieh and Shannon, 2005).

Table 3 Catalogue approach of distinct analysis forms (according to Mayring, 2014, pp.64–65; Hsieh and Shannon, 2005, p.1285 et seq. modified)

Reduction (Conventional content analysis)	1	summarising
	2	inductive category formation
Explication (Directed content analysis)	3	narrow contextual analysis
	4	broad contextual analysis
Structuring (Summative content analysis)	5	nominal deductive category assignment
	6	ordinal deductive category assignment
Mixed	7	Content structuring/ theme analysis
	8	Type analysis
	9	Parallel forms

3.1.4.1 Procedure steps of qualitative content analysis

Although there are these different forms and approaches to qualitative content analysis, the operational analysis process is always described additionally. According to Hsieh and Shannon (2005, p.1285), any content analysis always demands a similar sequence of seven classic steps, as shown in **Figure 7**.

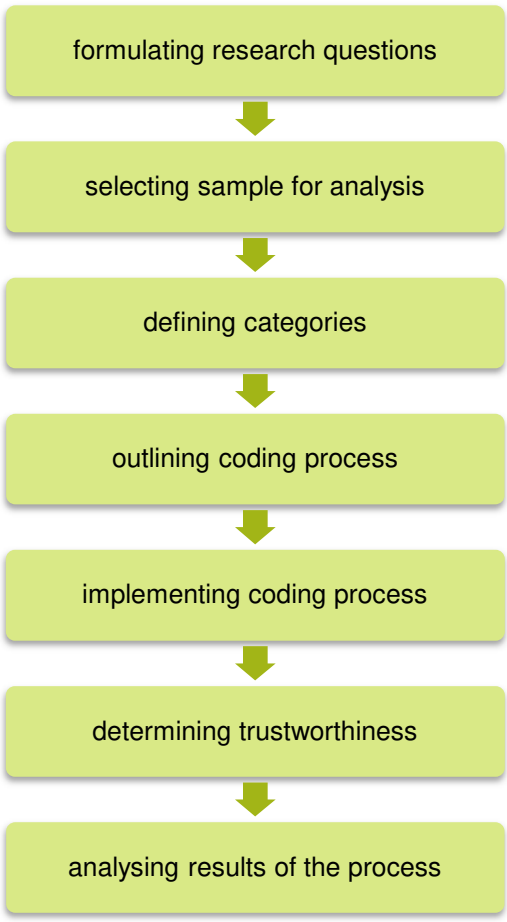

Figure 7 Seven steps of a qualitative content analysis (according to Hsieh and Shannon, 2005, p.1285 modified)

1) Formulation of research questions

The formulation of research questions depends more on the defined goals of the analysis by the researcher than on the analysis method itself (Mayring, 2000, 2015). Though, the manner of the questions and their details are as important for the output as the selection of a specific method is as well. It needs to be decided in which direction the questions should lead whether certain subjects or measures are in the centre of attention, or emotional conditions of survey participants are of interest. Another option to formulate research questions is the socio-cultural background of the context, the intentions of publishers or the focus group of mass media. Regarding the formulation of research questions, it is of importance that the characteristic of a content analysis is conducted systematically and theory-based, so the questions are connecting experience with research progress (Mayring, 2000, 2015).

2) Sample selection

The second step, sample selection, sets the frame for the analysis (Kuckartz, 2016). Various terms for a sample are leading to different definitions and their understanding. Therefore, the main two terms – ‘sampling unit’ and ‘recording unit’ – are briefly explained.

A ‘sampling unit’ sets the basic unit, e.g. an article in a newspaper. A ‘recording unit’ can exist out of numerous ‘sampling units’, e.g. the newspaper including different articles. It depends on the assessment of the researcher to choose the number of samples (Kuckartz, 2016).

3) Category system

There are two paths to create a category system (Kuckartz, 2016). On the one hand, there is deductive category creation, which is also called a-priori-category formation. The categories will be developed before working through the analysing material. On the other hand, inductive categorising is also called ‘open coding’ and means to work out the categories directly from the texts, this means, reading through and marking the main keywords, and afterwards working with coding sheets, organising keywords into category groups (Mayring, 2000; Kuckartz, 2016; Elo and Kyngäs, 2008)**.**

Although the creation of this category system is such an important part of the analysis process, there is only little description in the theoretical literature regarding how to create or define these categories. As this categorising has a major effect on which information is used or lost during the process, it is important to follow the focus of the research questions and goals of the assignment. To properly work with the created category system each category has to be explicitly defined and easily selected towards each other.

To give the wide spectrum of categories a little bit more structure, different types of categories were noted. Consequently, the four main coding frames are briefly explained according to Kuckartz (2016):

- **Fact codes:** Categories, which focus on a specific condition. For instance, a location or a profession.
- **Theme codes:** Categories referencing a certain topic such as political involvement or environmental knowledge.
- **Evaluation codes:** This type is more complex and usually includes an assessment standard. For example, the code helper syndrome is extended with further characteristics as strong, mediate or low expression.
- **Analytical codes:** Categories, which are developed during an extensive dispute with the data. As an example, working with finances and benefits, a code as cost-benefit assessment could be created.

To create a clear, well-structured and easy pursuable analysis, it is important to provide a precise methodology and clear explanations of the steps (e.g. the creation of the category system).

4) Outlining coding process

These next two steps – outlining coding process and implementation coding process – are of special importance to the success of the content analysis (Hsieh and Shannon, 2005). The coding process is closely connected to the category system because the better the categories are chosen and determined the easier the coding process will work.

The outlining means to work out a way to match the samples towards the category systems, if these can be whole text passages or code phrases. In a testing or trial period, the categories and coding process itself will be exercised and new categories can be established if necessary (Kuckartz, 2016; 2005).

5) Implementing coding process

If the trial results of the outlining coding process are reliable, the coding process will be implemented for the full sample units (Kuckartz, 2016; 2005).

6) Trustworthiness

Certain quality criteria can hardly be separated from qualitative content analysis and a general discussion of the topic (Kuckartz, 2016).To determine satisfying trustworthiness the sixth step of the analysis procedure is carried out. Classic criteria as reliability and validity are often criticised in connection with qualitative content analyses, therefore specific content analytical criteria have been developed and have to be included in the analysis process (Mayring, 2015).

7) Discussion of results

And last but not least the seventh and final step of qualitative content analysis is to analyse and discuss the results of the coding process.

3.2 Research design and process documentation

This chapter provides a detailed insight into the elaborated methodology and documented description of the performed processes.

The methodology of this thesis mainly followed the schemes from Hsieh and Shannon (2005), Elo and Kyngäs (2008) and Mayring (2015) which are illustrated in Figure 8 below.

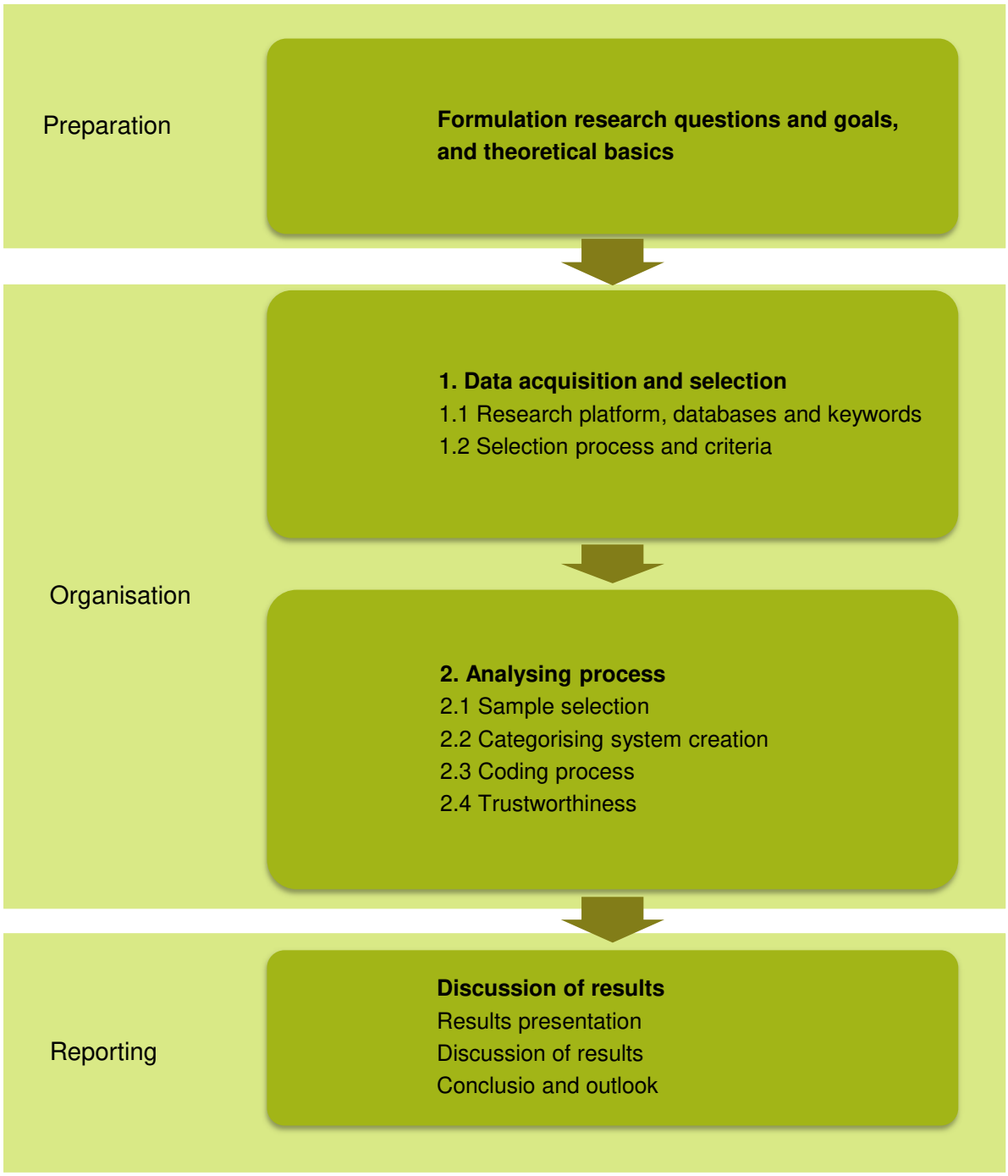

Figure 8 Research design scheme for this thesis (established from Elo and Kyngäs, 2008; Hsieh and Shannon, 2005; Mayring, 2015)

The whole working process was divided into three main phases: preparation, organisation and reporting according to Elo and Kyngäs (2008), illustrated on the left side of the scheme in **Figure 8**.

These phases were split into four stages, whereby the first phase 'preparation' corresponds to the first stage 'Formulation of research questions and goals, and theoretical basics'. This stage was already implemented in the chapters 1.2 - Research Questions, 1.3 - Aimed results and

expectations of knowledge profit, 2 - Soil and Water Bioengineering and 3.1 - Theory of Literary analysis.

The phase ‘organisation’ persisted out of two stages – ‘data acquisition and selection’ and ‘content analysis’. The third phase ‘reporting’ equals the stage ‘discussion of results’ stage.

According to a structured documentary of this review, these four stages were further divided into determined steps. Some of them were redefined for the working process (e.g. data acquisition) others appeared as steps of theoretical process descriptions (e.g. analysis process steps see Hsieh and Shannon (2005)).

Especially for the documentation of the analysis process and their result presentation and discussion, the coverage was further divided into the main research questions.

3.2.1 Data acquisition and selection

As main research method, a systematic research was chosen (Becker, 2012; Kornmeier, 2016).

To handle the number of publications and organise more detailed information, at the beginning, an excel sheet was used, but as the extent of literature became obvious, a literature management programme was applied to handle the search data administration. Out of software considerations (i.e. Macintosh User) and financial reasons (e.g. free software) the literature management programme Zotero (Version 5.0.70, Roy Rosenzweig Center for History and New Media at George Mason University and the Corporation for Digital Scholarship) was chosen.

The stage of ‘data acquisition and selection’ was named after its two steps (see **Figure 8**). The data acquisition itself was divided into two parts as well. The first part – research overview – was designed as a general insight into the topic and to get an impression of the size of interest towards this topic. This overview was pursued as a quantitative presentation of search hits. The time frame was restricted on a five-year time period from 2014 until 2018.

The second part – database research – was conducted as a database search with different search strings and search parameters towards Nature-based Solutions (NBS) and Soil and Water Bioengineering (SWB). These search hits were evaluated, and a defined assortment was further used for the selection process. For the database search modi the time frame was set with the end of the year 2018.

Beforehand the actual search was started a short research trail about the capitalisation and spelling of the term “Nature-based Solutions” was done. Regarding the capitalisation there was no differentiation in search hits notable, but the use of “Solution” or “Solutions” led to a slight but negligible difference in search hits. Concerning this thesis, the spelling “Nature-based Solutions” was determined as it displayed minimally larger results.

3.2.1.1 Research platforms, databases and keywords

Research overview

For the general overview a search on Google Scholar was performed. To enable a comparison of search hits as a second platform the online search platform of the University Library and University Archive of BOKU – "BOKU:LITsearch" – was used. To compare the expected results using the library platform with the online web search on Google Scholar the inquiry of BOKU:LITsearch was extended, using the offered function called "Add results beyond your library's collection", providing a wide online search. For this search modality the expression "BOKU:LITsearch (extended)" is used in further processing.

To process questions about NBS in general, a search string "Nature-based Solutions" was used. To focus on the implementation of Soil and Water Bioengineering the keyword chains "Nature-based Solutions" AND "Soil and Water Bioengineering" as well as "Nature-based Solutions" AND "Soil Bioengineering" were chosen in the search.

Originating from the expectation of a large number of results the search was processed for a five-year time frame (2014-2018). This time frame was set out of prior knowledge regarding the appearance of the topic and its raising significance.

The results of this research overview are presented as search hits in chapter 4.1.1.

Database research

Throughout previous research on this topic, a high number of results was expected. For this research, the selection and review process was restricted. Looking for scientific concepts and approaches the literature search was confined to two databases and the BOKU:LITsearch platform. The availability of publications – either through open access or the possibility through the Database of the University Library and University Archive of BOKU – built the argument for the preselection.

ScienceDirect Database is a large platform for peer-reviewed literature and is used by academic institutions, governments, and research teams. Additional to indices and abstracts it often supplies full-text downloads. As a second database, Scopus was chosen. The database as well includes peer-reviewed scientific papers, books, and conference papers. Both databases relate to science as a discipline and can be divided into four main subject fields: life sciences, social science, physical sciences, and health sciences.

For the research through the databases, different keyword chains and search frame definitions were chosen. For all search requests, the timeframe was set until the end of the year 2018. First, an overall search with the keyword "Nature-based Solutions" without any further parameters was conducted. As it is a quite trendy term, it was presumed that only the appearance of the term does not necessarily signify a focus on the topic. Through the search mode limitation on "article title, abstract, keywords" the importance of the term was pushed and similarly a preselection for the work frame was made.

To guide the research request towards the connection to Soil and Water Bioengineering the keyword chain “Nature-based Solutions” AND “Soil and Water Bioengineering” was added. This search string request was, such as the single keyword search before, performed as an overall search without limitation as well as the restricted search towards “article title, abstracts and keywords”.

These intermediate results were provided as search hits in the result section (see chapter 4.1.2, Table 6).

Depending on the quantity of search hits and the extent of a qualitative work frame the results of these search series were examined. The publications on this search list – providing the basis for the selection process and further the qualitative analysis – were downloaded in the literature program Zotero. While all bibliographic information, keywords, and abstracts of these publications were organised, the search results were tested and proofed if there were any duplicates or other citation errors left to correct. This cleared search list was chosen for post-processing (see chapter 4.1.2, Table 7) further on referred to identified publications.

3.2.1.2 Selection process and criteria

The selection process – as shortly introduced in chapter 3.1.1 – was divided into two steps. Starting from the results of the research process, the identified publications were screened and in the next step, the eligibility of the publications was proofed.

Identified publications

The results of the database search built the foundation for the selection process. In the literature program a merge of these identified publications of the two databases and the BOKU:LITsearch platform were assembled, leading to the sum of identified publications (n= 205) for the screening process.

Screening

As displayed in **Figure 5**, the first step was a screening of the research results. Working through the material showed that many publications were focusing on a certain topic, either emphasising a specific goal or following a particular purpose regarding NBS. Out of this reason the research question 2 - about categorisation and approaches - was adapted towards topics of NBS. This analysis was not prepared systematically for all 205 publications but for a list of these topics in order of the most appearance that was established. As part of the content related information this was included in the analysis process for the third research question (see chapter 3.2.2).

As a second discovery during the screening process other topic related sources showed up, either cited or mentioned in processed literature. Although they weren’t part of the database search results, some of those appear as substantial publications for this thesis (e.g. framework

reports of the European Commission and the IUCN) and where therefore included in the selection process.
Equally to the different approach directions, it became obvious that some of the publications only mention the importance and the existence of the NBS concepts without any closer information or discussion in more detail. So, therefore, the next step of the selection process needed to be choosing eligible publications for the review and analysis process.

Eligibility

Following on the information content of the respective publication, a list of criteria was prepared to scan the literature towards information answering the research questions. The elaborated criteria were ranked in order of their importance and search sequence resulting in the following list:

1. Discussing definitions of NBS
2. Examples for categorisation of concepts or approaches of NBS
3. Concepts with specific measures concerning SWB
4. (Written) connection between NBS and SWB

Working further to eligible sources, the publications were skimmed more closely and divided into sections regarding the criteria.

To provide a feasible dose of publications to go ahead with qualitative content analysis, the selection process also includes a determination of the selection set. Therefore, 13 publications were chosen to continue with in the analysis processes. For each research question respectively, analysis type a sample unit out of this review selection was chosen and presented beforehand the results.

3.2.2 Documentation of content analysis process

In chapter 3.1.2 an overview of the theory of possible analysis methods was provided. Focusing on the attempt to achieve content related answers and research statements, as well as to work with published scientific material and framework concepts, qualitative content analysis was chosen to proceed with. Therefore, this chapter equals the third stage of the research design scheme (see **Figure 8**) – i.e. 2. Analysis process.
Considering the various analysis forms (see Table 3) for different research questions various analysis types were used. The research questions reflect a different level of details and various aims, therefore different content analysis types were chosen.

Research Question 1 (RQ 1): How many scientific publications were released considering both NBS and SWB?

As the basis for all the following research questions, a review selection was performed. Within this research and selection process, the first research question (RQ 1) about the amount of

published literature already was answered (see **Figure 9**). As these quantitative results were compiled during previous steps and do not equal a content analysis, RQ 1 won't be further mentioned in the following analysis steps.

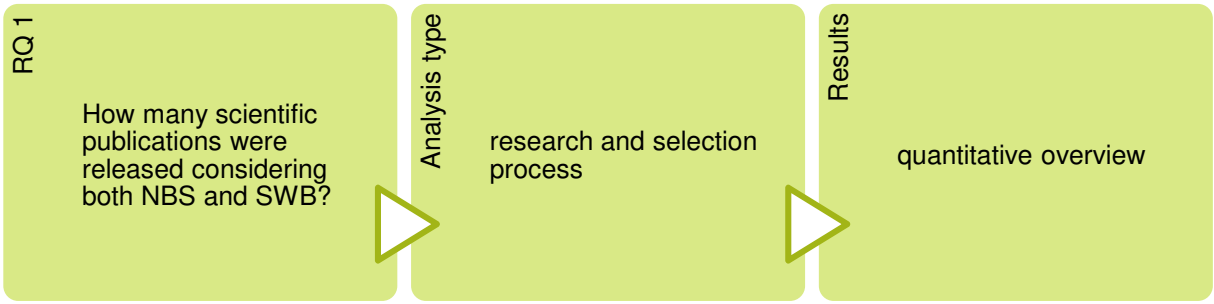

Figure 9 Overview of all process steps for Research Question 1

Research Question 2 (RQ 2): What common definitions of NBS can be found in the present literature? – Analysis A

This research question was approached with a directed content analysis, as shown in **Figure 10**. The focus was on certain information included in these publications and to discuss this specific information in greater depth of detail. The narrow context analysis focuses on the direct text environment (Mayring, 2014).

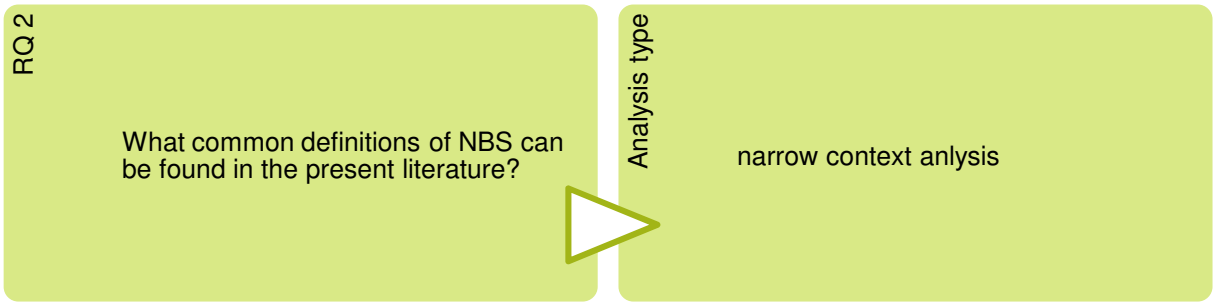

Figure 10 Analysis type for Research Question 2

Research Question 3 (RQ 3): Are there different categories and approaching types towards NBS concepts? – Analysis B

During the selection process, it became obvious that there are various systems of categories, approaches, and publications as these topics were analysed using inductive content analysis; this means working through the publications and thereby choosing and generating categories out of the present material.

Regarding the approach of NBS, a content structuring also referred to as theme analysis was processed (see **Figure 11**). This provided a general overview on which aims or pursues are presented and important in the actual scientific literature pool. These findings were presented as a list of topics. For detailed information concerning categories and approaches, the publications of the review selection were presented as summaries.

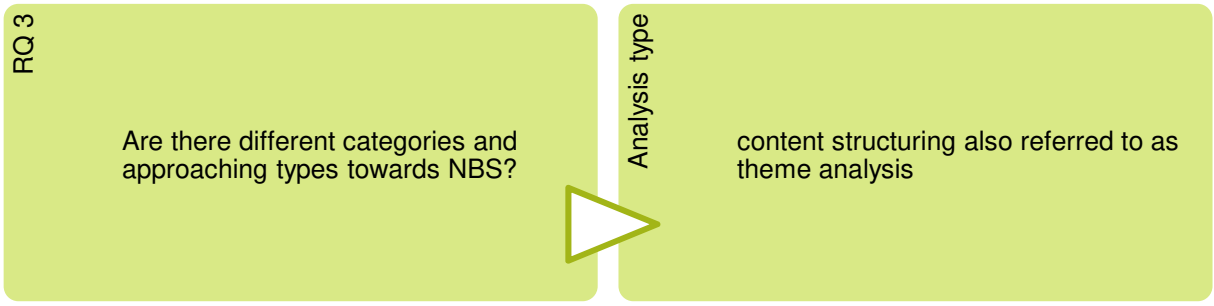

Figure 11 Analysis type for Research Question 3

Research Question 4 (RQ 4): What kind of specific measures can be identified pertaining to NBS and SWB? – Analysis C

To provide an overview as well as to discuss different specific measures of NBS and SWB a structuring analysis was prepared (see **Figure 12**). To pursue this method, the category building process is deductive. Therefore, the information on Soil and Water Bioengineering (see chapter 2) builds the foundation of the analysis (Mayring, 2014).

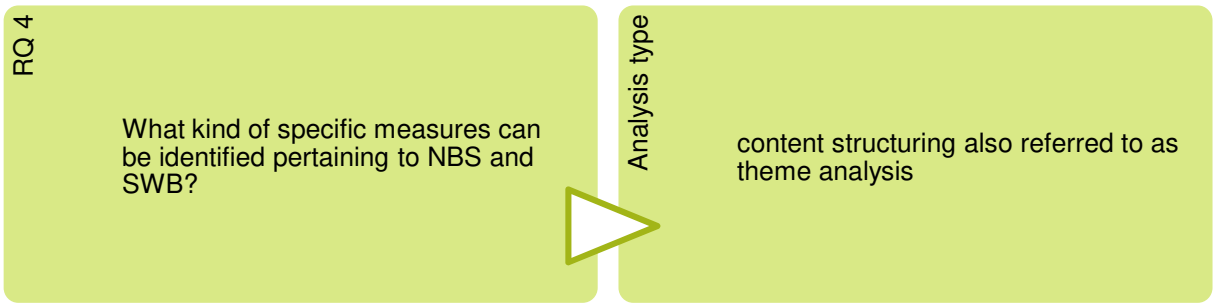

Figure 12 Analysis type for Research Question 4

Research Question 5 (RQ 5): Are there specific publications connecting SWB and NBS? – Analysis D

This question leads to examples and summaries of their content, followed by a reduction or summary of the content analysis, as shown in **Figure 13**. Also known as the conventional content analysis it may be the most common used type (Mayring, 2014).

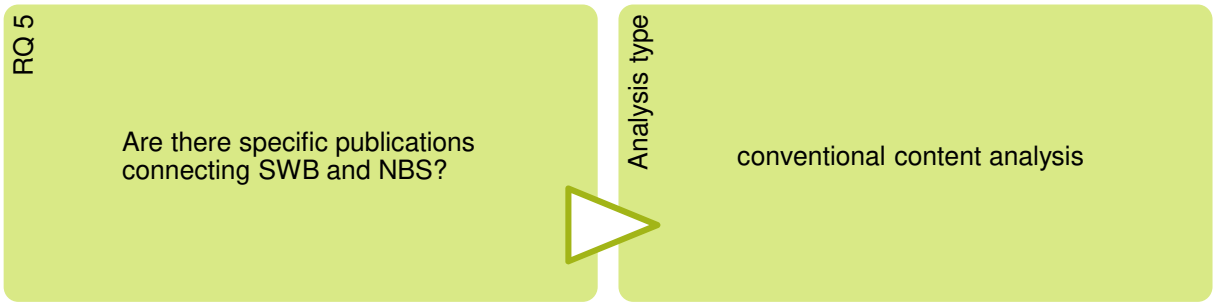

Figure 13 Analysis type for Research Question 5

3.2.2.1 Sample selection

Analysis A

Regarding the second research question (RQ 2) about a closer definition of Nature-based Solutions, the review selection was scanned for definitions as well as executive discussions. This led to nine publications used as sampling units.

Analysis B

The manifold approaches of NBS resulted in a huge amount of search hits (n= 205). Focusing on different category systems and approaches, seven publications out of the review selection were chosen. These were presented in a short summary focusing on the scheme of the classification and categorisations.

Analysis C

According to the fourth research question (RQ 4) regarding specific measures of Nature-based Solutions, the scale of specific measures is the key issue. Through the screening process it was established, that there were neither publications with the main focus on one or more case studies or one chosen method. The connection of NBS and different SWB measures was not present in the analysed scientific literature. Nevertheless, the decision was made to look for a list of specific measures or actions which correspond to the level of the generic term of SWB methods (see chapter 2.3, **Table 2**). There were hardly any publications about a larger amount of specific constructions methods to be compared, but a lot of measures in the scale of conceptual work.

Therefore, a recording unit, the topic of natural water retention measures (further also referred to as NWRM) was chosen including numerous sampling units, as a derived form of theme-based coding process.

As the second recording unit, the report of a climate change adaptation concept of the Basque Country was chosen, as a derived form of a fact-based coding process. The sampling units build each of the listed measures.

Analysis D

As a result of the low number of search hits of the direct written connection between NBS and Soil and Water Bioengineering, two journal articles, resulting from the database search, were serving as two sample units.

3.2.2.2 Categorising system creation

Analysis A

The single and main category for this analysis is called ‘definition’.

Analysis B

The category system regarding categorisation and approaches was created as an inductive creation process.

Regarding the overview of approaches, the systems of categories were established during the working process. A clear division and claim to completeness cannot be given, due to the amount of the recording unit as well as the close connection of topic themes.

Analysis C

Following the concept of direct content analysis, the categories were created through a deductive approach. Creating the categories in advance needs a focus on the research question and its goals, as well as some basic information according to the topic of the thesis. Consequently, the chapter about the basic information towards, SWB (see chapter 2) generates the foundation to list criteria’ and differentiates the categories.

Therefore, the main categorisation was simply SWB measures. These were understood as measures, which include characteristics and aims like:

1. biological measures
2. use of living plants
3. protect land uses and/or infrastructures
4. contribute to landscape development and biodiversity

As discussed in chapter 2.4, SWB is rather often divided into fields of applications. The main categories – obviously including areas of soil and water – sometimes seem to be too loose, and their absorption towards hillsides, running and standing water bodies seem to hinder development towards Nature-based Solutions in urban areas.

Therefore, the examples connecting NBS and SWB measures will be analysed according to a categorisation system derived from the collection of construction methods.

Table 4 Category system for analysis 2 (derived from Zeh, 2007)

Categorisation title	Description
Seeds	Measures using different seeding techniques, methods and tools
Woody plants	Measures forming out of the use of woody plants

Herbaceous plants	Measures forming out of the use of herbaceous plant parts
Shoot-forming woody plants and woody plant parts	Measures securing areas and reproducing vegetation using shoot-forming woody plants and woody plant parts
Plant communities	Measures building on the existence and positive aspects of plant communities
Combined construction methods	Measures which partly have a historic background as well as the ones using new materials to combine living and non-living materials to secure areas and reproduce the positive effects of vegetation.

Working out this category system, it became obvious that specific measures of Soil and Water Bioengineering are often used in overlapping combinations, therefore, it seems not possible to provide a category system which is as strictly separated as for example the use of qualitative content analysis for interview questions in social sciences. This problem will be further addressed in the discussion.

Analysis D

The category system was based on measures of NBS and SWB overlapping and displaying connections.

3.2.2.3 Coding process

Analysis A

According to the limited categorisation of Analysis 1, there was no specific coding developed. The process was to work through the review selection and look for specific statements regarding the definition of Nature-based Solutions. To work through the information without certain statement declarations towards missing definitions or mentioning already listed definitions is included.

Analysis B

Two different processes were executed. The first already happened during the screening process where the general number of publications (n=205) was connected to main topics. The second process working within the review selection provides short summaries of the selected publications leading to a discussion of the approaches in the discussion chapter.

Analysis C

After choosing the sampling units and creating a deductive category system, the publications were scanned for distinctions of these specific measures. According to the literature of content analysis methods the categories had to be clearly defined and multiple allocations were not allowed (Kuckartz, 2016). Nevertheless, in this specific analysis it seems not realistic to divide certain measures only towards one generic Soil and Water Bioengineering method – as already mentioned at the category systems this will be discussed in the closing chapters.

Analysis D

Focusing on the information of Soil and Water Bioengineering short summaries of the chosen sample units are given.

4 Results

This chapter displays the results of the research and selection process. A general impression about the existence and inquiry regarding this topic will be given in numbers before presenting the results of the selection and analysing processes partly as citation accumulation and excerpt summaries.

4.1 Search hits and review selection (RQ 1)

The first part of the results presentation focuses on the number of publications. The process was started with a general search, therefore a quantitative overview is displayed. This provides an answer to the question regarding the amount of released publications.
The second part presents the database search and the selection process as well in numbers leading to the final review selection as a basis for the analysis processes.

4.1.1 Quantitative topic distribution overview

RQ 1 asks for a quantitative insight into the current scientific publications regarding NBS and NBS combined with SWB. This first impression of the topic and publications around the term “Nature-based Solutions” (see **Table 5**) were listed as search hits for three search strings for the annual search frame from 2014 till 2018 as well as the sum of the five-year frame. The development is visualised in **Figure 14**.

Table 5 Quantitative search results - Outcome of the general search

Keywords	Search frame	Search hits on Google Scholar	Search hits on BOKU:LITsearch (extended)	Search hits on BOKU:LITsearch
“Nature-based Solutions”	2014	132	149	14
	2015	221	250	23
	2016	444	668	96
	2017	694	941	162
	2018	1.204	2.406	283
	Sum for 2014 - 2018	**2.730**	**4.414**	**578**
“Nature-based Solutions” AND “Soil and Water Bioengineering”	2014	---	---	---
	2015	1	---	---
	2016	2	---	---
	2017	---	---	---
	2018	4	3	1
	Sum for 2014 - 2018	**7**	**3**	**1**

"Nature-based Solutions" AND "Soil Bioengineering"	2014	---	---	---
	2015	---	---	---
	2016	5	---	---
	2017	3	---	---
	2018	7	5	3
	Sum for 2014 - 2018	**14**	**5**	**3**

This overview of search results merely mirrors the number of hits without further content proof, this means that the same publication may be counting for several search hits. This may contribute to the surprisingly high number of search hits and was examined in the discussion chapter (see chapter 5.1).

The sum of publications of the extended search modus of BOKU:LITsearch platform (n= 4.414), which includes an advanced web search – detailed explanation see Methodology page 23, was more than 7 times higher as the search modus limited to the library platform itself (n= 578) and 1,6 times higher as the search hits on Google Scholar (n= 2.730). Combining NBS with SWB, both keyword chains revealed significant smaller number of results. Other than in the search on NBS the highest hit number occurred on the Google Scholar platform and was in both search strings (n= 7 and 14) more than twice as high as the hits of the BOKU:LITsearch (extended) quest (n= 3 and 5).

To illustrate the increasing number of publications surrounding the topic NBS the quantitative results of the keyword search "Nature-based Solutions" were processed and shown in **Figure 14**. The quantitative results only give a first impression and were not fully checked regarding content-related overlaps and publications.

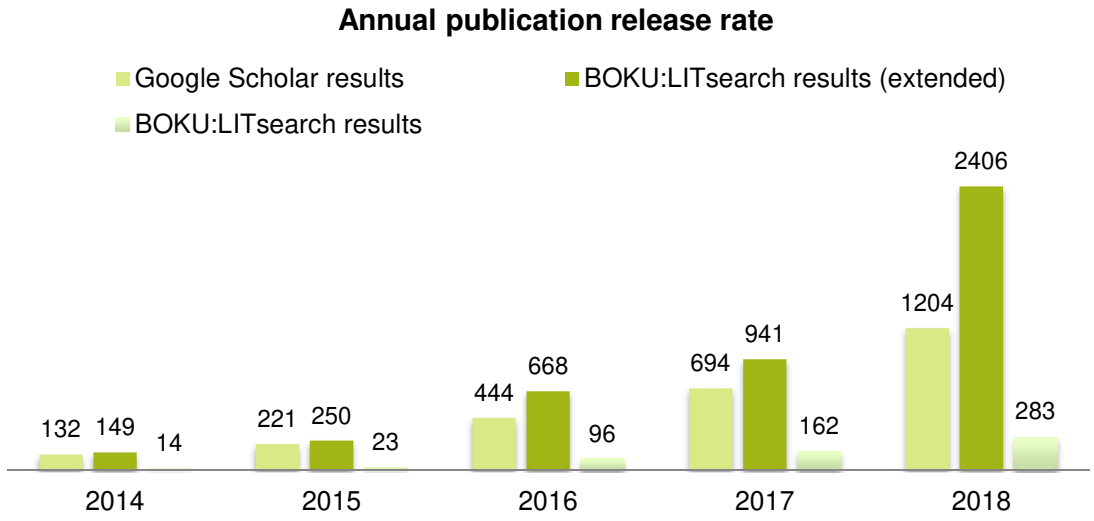

Figure 14 Development of the publication numbers corresponding to the search term "Nature-based Solutions"

The graphic shows a significant increase of annually published publications. The curve develops for all searches linearly up to exponentially. The most increasing factor provides the search results of BOKU:LITsearch with an average increase with the factor of 2,3 over the five year period. The extended BOKU:LITsearch presents the results out of the offered function to find results beyond the Boku library's collection. The curve, in this case, shows an especially great increase from the year 2017 towards 2018. Additionally, to the exponential increase of all search results, it's noteworthy that they all share a particularly high rise from the year 2015 to 2016. In both periods the number of related publications doubled compared to the year before.

4.1.2 Database search results

Pursuing a systematic literature research the results of ScienceDirect Database and Scopus Database as well as the search on the BOKU:LITsearch platform are presented in the following chart. The keyword chains and two search modi are noted and lead up to six search series. Their results are given in search hits (see **Table 6**).

Table 6 Search hits listed of ScienceDirect and Scopus Databases, and BOKU:LITsearch platform with various keywords and search modi – six search series

	Keywords	Search mode	Search hits on ScienceDirect	Search hits on Scopus	Search hits on BOKULIT:search
1	"Nature-based Solutions"	Full text search	325	676	766
2		Article title, abstract, keywords	92	218	182
3	"Nature-based Solutions" AND "Soil and Water Bioengineering"	Full text search	1	2	1
4		Article title, abstract, keywords	---	1	1
5	"Nature-based Solutions" AND "Soil Bioengineering"	Full text search	---	2	3
6		Article title, abstract, keywords	---	1	3

The search series 1 and 2 were covering the main term "Nature-based Solutions" and show the highest number of hits. Especially obvious was a high difference between Science Direct (n= 325) and Scopus Database (n= 675). Scopus scored in both modi with more than twice as much search hits as Science Direct did. The limitation of the search mode towards "Article, abstract and keywords" reduced the search hits for all databases to approximately a quarter of the full text search series. As described in the methodology section (see chapter 3.2.1.1) depending on the occurring search hits and for a manageable working frame, the decision to proceed with search series 2 was made.

For the search series 3 to 6, which highlight the connection to Soil and Water Bioengineering, a very low number of hits was displayed (n= 1 up to n= 3). To keep a focus of NBS connecting to SWB the search series 3 and 6 were merged and added to the search list for post-processing.

Due to the refinement process to import the information to the literature programme it became apparent that the result numbers of the searches in BOKULIT:search still contain multiple occurrences of publications. Therefore, these numbers were corrected and the following **Table 7**, presents the cleared search list that was used for post-processing further on referred to identified publications.

Table 7 Identified publications from ScienceDirect and Scopus Databases, and BOKU:LITsearch platform cleared form multiple occurrences and processed towards the selection process

Keywords	Search mode	Search hits on ScienceDirect	Search hits on Scopus	Search hits on BOKULIT:search
"Nature-based Solutions"	Article title, abstract, keywords	91	217	155
"Nature-based Solutions" AND "Soil Bioengineering" OR "Nature-based Solutions" AND "Soil and Water Bioengineering"	Full text search	1	2	3

These search hits indicate a considerable high occurrence of the topic Nature-based Solutions in the scientific databases (n= 91, 217 and 155), but a low existence of written connections between publications dealing with Nature-based Solutions and Soil and Water Bioengineering (n= 1, 2 and 3).

4.1.3 Selected publications for the review selection

The selection process according to Becker (2012) and Kornmeier (2016) included screening of the identified publications, testing their eligibility and selecting samples according to previously defined criteria focusing on the research questions. This process and the relating search hits are presented as a quantitative flow chart in **Figure 15**.

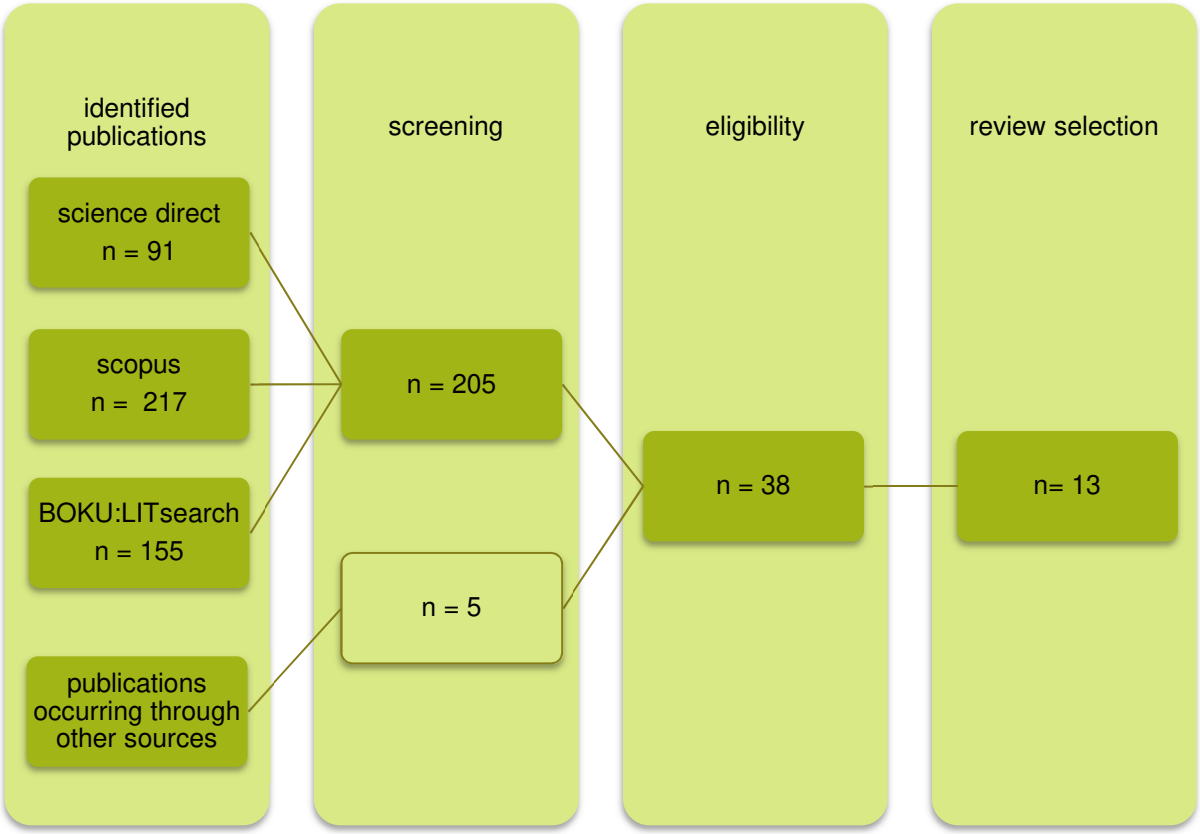

Figure 15 Quantitative overview of data base research hits and the selection process

The identified publications were collected, and the duplicates were removed, which led to a screened number of 205 publications. In the screening process publications were added, which occurred out of obvious citations. Therefore five additional publications, the EC Horizon 2020 report (European Commission, 2015), the IUCN Guideline towards societal challenges (Cohen-Shacham et al., 2016) and three exemplary reports (Strosser et al., 2014; European Commission, s.a.; Ihobe, Environmental Management Agency, 2017) were included.

Focusing on concepts and main questions towards the thesis topic, 38 publications were assessed as useful and relevant. In the next step the eligibility by means of the criteria was proven in more detail. Due to the working frame and time resources, 13 papers were chosen for the review selection.

All publications with the search connection to SWB occurred in the overall search results and were included in the selection process above (see **Figure 15**). However, in order to highlight the significantly lower number of publications on NBS relating to SWB, the results are displayed separately in **Figure 16**.

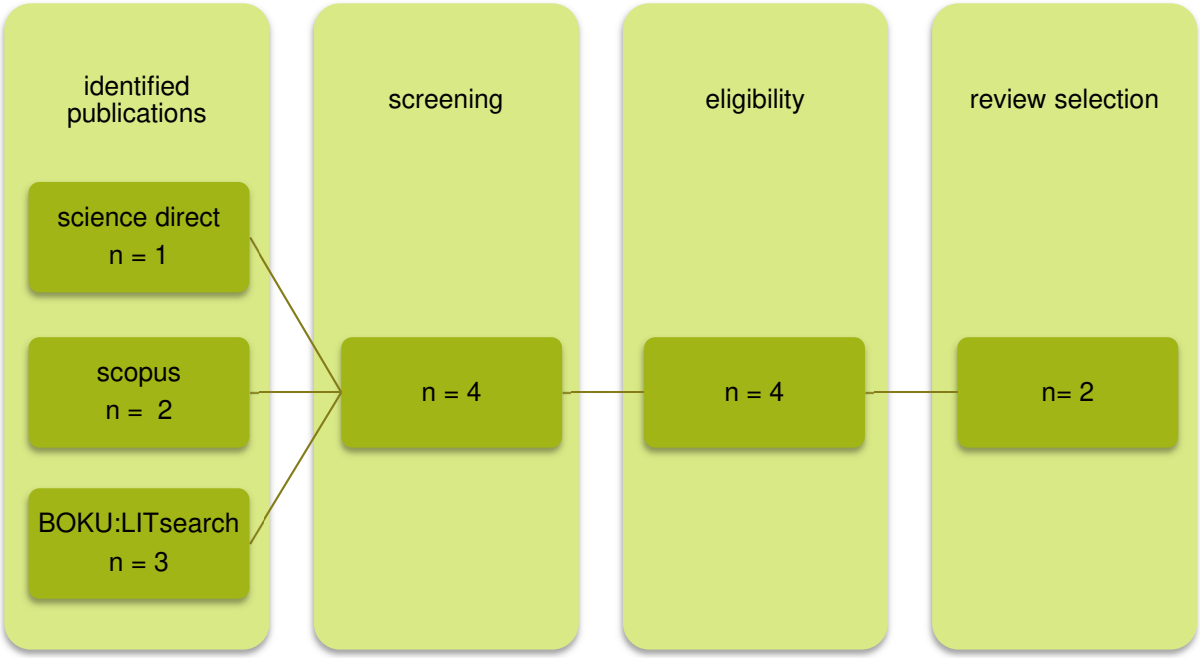

Figure 16 Quantitative overview of the database results and the selection process connection NBS and SWB

Review selection

The final results of this displayed selection procedure built the review selection. Therefore, answering RQ 1, provided a review selection that proceeded further research questions. The collection, presented in **Table 8**, delivers the basic information of the publications like title, author(s) and year of publication as well as the criteria as the reason for their selection. The selected publications are code-numbered, for all further analysis processes.

Therefore, the selection criteria (listed in the columns of **Table 8**) were: (1) discussing definitions of NBS, (2) examples for categorisation of concepts or approaches of NBS, (3) concepts with specific measures concerning SWB, and (4) published (written) connection between NBS and SWB.

Table 8 Review selection - publication selection basis for all analysis procedures combined

No	Title of publication	Author(s)	Year	Selection criteria met			
				Definition	Categorisation/ Approaches	Specific Measures	Published written connection
[1]	*A guide to support the selection, design and implementation of natural water retention measures in Europe: capturing the multiple benefits of Nature-based Solutions.*	Strosser, P. et al.	2014		■		
[2]	*Natural Water Retention Measures - 53 NWRM illustrated.*	European Commission	s.a.			■	
[3]	*Towards an EU research and innovation policy agenda for Nature-based Solutions & re-naturing cities: Final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities' (full version).*	European Commission	2015	■	■		
[4]	*Nature-based Solutions: New Influence for Environmental Management and Research in Europe*	Eggermont, H. et al.	2015	■	■		
[5]	*Nature-based solutions to address global societal challenges.*	Cohen-Shacham, E. et al.	2016	■	■		
[6]	*Nature-based solutions for local climate adaptation in the Basque Country.*	Ihobe, Environmental Management Agency	2017	■	■	■	
[7]	*Nature-based solutions: criteria.*	Albert, C. et al.	2017	■	■		
[8]	*Nature-Based Solutions for Europe's sustainable development.*	Maes, J. and Jacobs, S.	2017	■			
[9]	*The science, policy and practice of Nature-based Solutions: An interdisciplinary perspective.*	Nesshöver et al.	2017	■			
[10]	*Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges.*	Faivre et al.	2017	■			

No	Title of publication	Author(s)	Year	Selection criteria met			
				Definition	Categorisation/ Approaches	Specific Measures	Published written connection
[11]	*Urban forests, ecosystem services, green infrastructure and Nature-based Solutions: Nexus or evolving metaphors?*	Escobedo et al.	2018				
[12]	*Nature-based solutions: The need to increase the knowledge on their potentialities and limits.*	Fernandes, J.P. and Guiomar, N.	2018				
[13]	*How vegetation can aid in coping with river management challenges: A brief review*	Rowiński et al.	2018				

4.2 Qualitative content analysis results

This chapter presents the results of the analysing processes and is divided into five sections each relating to a research question. To provide a sufficient understanding of the processed data, the selected publications are listed at the beginning of each implemented analysis.

4.2.1 Definitions of NBS (RQ 2)

According to the detected information the publications [3] – [13] (see **Table 9**) were processed in relation to the definition of NBS.

Table 9 Selected publications towards definition analysis

No	Title	Author	Year
[3]	*Towards an EU research and innovation policy agenda for Nature-based Solutions & re-naturing cities: Final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities' (full version).*	European Commission	2015
[4]	*Nature-based Solutions: New Influence for Environmental Management and Research in Europe*	Eggermont, H. et al.	2015
[5]	*Nature-based solutions to address global societal challenges.*	Cohen-Shacham, E. et al.	2016
[6]	*Nature-based solutions for local climate adaptation in the Basque Country.*	Ihobe, Environmental Management Agency	2017
[7]	*Nature-based solutions: criteria.*	Albert, C. et al.	2017
[8]	*Nature-Based Solutions for Europe's sustainable development.*	Maes, J. and Jacobs, S.	2017
[9]	*The science, policy and practice of Nature-based Solutions: An interdisciplinary perspective.*	Nesshöver, C. et al.	2017
[10]	*Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges.*	Faivre, N. et al.	2017
[11]	*Urban forests, ecosystem services, green infrastructure and Nature-based Solutions: Nexus or evolving metaphors?*	Escobedo, F.J., et al.	2018
[12]	*Nature-based solutions: The need to increase the knowledge on their potentialities and limits.*	Fernandes, J.P. and Guiomar, N.	2018
[13]	*How vegetation can aid in coping with river management challenges: A brief review*	Rowiński et al.	2018

In the coding process the publications were searched towards clearly stated definitions of NBS - or if no explicit declaration could be detected - similar statements or links towards other definitions were collected. These results are displayed either as direct citations or a short description in **Table 10** below.

Table 10 Variation of definitions of NBS

No	Definition
[3]	*"Nature-based solutions aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions, for example, mimicking how non-human organisms and communities cope with environmental extremes*." (European Commission, 2015, p.24)
[4]	There is no certain definition given, rather more the goals of the concept were important. The approach was described as an umbrella concept, giving a typology to produce a better understanding of the term and the respectful application of other concepts (Eggermont et al., 2015). This typology was presented and discussed according to the categorisation and approach (RQ 3, see chapter 4.2.2).
[5]	A concurrent and similar development of a definition of NBS alongside the definition of the EC [3] was mentioned. The IUCN defined NBS as: *"Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*." (Cohen-Shacham et al., 2016, p.2)
[6]	The guide points out that there is no single definition and refers towards the expert report of the EC [3] highlighting the following description: Innovations that *"*[…] *are inspired by nature and use the characteristics and processes of its complex systems* […] *in order to help societies address a variety of the economic, social and environmental challenges* […]*"* (Ihobe, Environmental Management Agency, 2017, p.5)
[7]	The author shortly refers to the missing precise definition and instead suggests three criteria for the concept of NBS suggested (Albert et al., 2017). These criteria were presented and discussed according to the categorisation and approach (RQ 3, see chapter 4.2.2).
[8]	After citing the *definition* of the EC [3], it was mentioned that for specific applications in research and innovation a sharper definition, benefiting from the research knowledge of ecosystem services, had to be made. Defining NBS as "[…] *any transition to a use of ecosystem services with decreased input of non-renewable natural capital and increased investment in renewable natural processes."* (Maes and Jacobs, 2017, p.123)
[9]	This paper did not present an own definition but performed a comparison of the two NBS concept definitions of the EC [3] and the IUCN [5]. Furthermore, six relating concepts were analysed (Nesshöver et al., 2017).
[10]	The paper cites the EC definition of NBS [3] and points out the promotion of a joint tale of science, practice, and policy communities and further the numerous challenges NBS can apply to. *"In the implementation of Nature-Based Solutions, the conservation of biodiversity is an objective, but it is also a prerequisite: functioning ecosystems are necessary to ensure the delivery of ecosystem services."* (Faivre et al., 2017, p.510)
[11]	As the paper evolves around different metaphors the authors based the discussion regarding definitions on national-level policy documents and did not further discuss local-level or urban specific definitions. According to the comparison of the definitions in the papers' appendix, they give following version of the EC definition [3], listed as NBS- Government: *"Living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits."* (Escobedo et al., 2018, p.11)

[12]	The authors point out the growing interest and importance of NBS, e.g. in the IUCN Programme 2013-2016, but no certain definition of NBS is given. Remarking that information about NBS approaches about practice effectiveness and monitoring is still rare, the definition and concept of NBS is better elucidated listing the criteria of Albert [7] and the typology of Eggermont [4] (Fernandes and Guiomar, 2018).
[13]	The existence of different NBS concept approaches were stated and followed by the citation of the EC definition [3] and the IUCN definition [5]. NBS built an alternative towards technological strategies and were presented as managing system of ecosystem services, as expressed in Eggermont's [4] Type 2 approach. For a closer discussion on NBS for water related topics it was referred to WWAP (2018) (Rowiński et al., 2018).

Out of the 11 findings towards a definition or statement relating to NBS, eight publications give a clear definition. But out of these publications four authors (Ihobe, Environmental Management Agency (2017) [6], Maes and Jacobs (2017) [8], Faivre et al. (2017) [10] and Escobedo et al. (2018) [11]) had either cited the EC definition [3] directly or gave slightly adapted or supplemented versions. Two papers (Nesshöver et al. (2017) [9] and Rowiński et al. (2018) [13]) cited and compared the EC definition [3] and the IUCN definition [5]. Which led to the final result of only two basic definitions by the European Commission (2015) [3] and from the IUCN, Cohen-Shacham et al. (2016) [5].
The identified definitions (shown in **Table 10**), especially those with the clear definitions will be discussed regarding their similarities and differences in chapter 5.2.

The three remaining publications ([4], [7] and [12]) gave similar statements, that the approach or categorisations are more important than a certain definition. These possible categorisation types presented by Eggermont et al. (2015) [4] as well as the criteria set from Albert et al (2017) [7] were used as category approaches in the next analysis. For the publication of Fernandes and Guiomar (2018) [12], it is noted that they are referring to the types and criteria of Eggermont et al. (2015) and Albert et al. (2017) ([4] and [7]).

4.2.2 Categorisation and approaches of NBS (RQ 3)

There are different kinds of approaches, applications, and their categorisation to be found in the here analysed literature. There is not a single universal category system, therefore the chosen publications are given as summaries, including the various most significant categorisations. Possible overlaps, similarities, or connections within these categories are elaborated in the discussion in chapter 5.2.
During the selection process (see chapter 4.1.3) 205 publications were screened, and differing main topics of the papers and books became evident. Therefore, the research question regarding categorisation and approaches (RQ 3) focuses on topics related towards NBS. The variety of motivations for NBS research and publications divided into these various topics could

partly be understood as a reason for different approaches of NBS. The following list (**Table 11**) presents the most commonly addressed topics and their number of hits.

Table 11 Identified topics of NBS publications

Topics	Occurrence
Green infrastructure, urban forests, urban parks, urban gardens	49
Disaster risk management, flood protection, stormwater run off	44
Biodiversity	44
Ecosystem-based services	31
Human health and social connections	23
Climate change	18
Water pollution (surface and marine waters as well as fresh water/drinking water)	16
Coastal protection	12
Air pollution (air in general and Co2-Emissions)	11

Firstly, similar topics, e.g. urban forests and urban parks as well as flood protection and stormwater runoff were compiled for the counting of occurring topics. In order to give a perspective, those which higher frequencies were listed, leading up to nine topics respectively topic groups, which displayed more than ten hits.

The top of the list, with 49 hits, was led by green infrastructure, urban forest, urban parks and urban gardens. Second with 44 hits were, ex aequo, the topic group disaster risk management, flood protection, and stormwater runoff as well as the topic biodiversity. Followed by ecosystem-based services with 31 and human health and social connections with 23 hits. The topic climate change counted 18 hits, while water pollutions (compiled several types of water bodies as well as drinking water) score 16 hits. Coastal protection with 12 and air pollution with 11 hits built the end of the topic list.

Regarding the review selection, the following publications dealing with category systems were selected for the analysis.

Table 12 Selected publications towards category systems analysis

No	Title	Author	Year
[1]	*A guide to support the selection, design and implementation of natural water retention measures in Europe: capturing the multiple benefits of Nature-based Solutions.*	Strosser, P. et al.	2014
[3]	*Towards an EU research and innovation policy agenda for Nature-based Solutions & re-naturing cities: Final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities' (full version).*	European Commission	2015

[4]	*Nature-based solutions: New Influence for Environmental Management and Research in Europe*	Eggermont, H. et al.	2015
[5]	*Nature-based solutions to address global societal challenges.*	Cohen-Shacham, E. et al.	2016
[6]	*Nature-based solutions for local climate adaptation in the Basque Country.*	Ihobe, Environmental Management Agency	2017
[7]	*Nature-based solutions: criteria.*	Albert, C. et al.	2017

[1] Strosser et al. (2014): *"A guide to support the selection, design and implementation of natural water retention measures in Europe: capturing the multiple benefits of Nature-based Solutions."*

The European Commission has launched different initiatives regarding Natural Water Retention Measures (NWRM) including the NWRM Pilot Project, including the production of this report.

Digression: The DG ENV (Directorate-General for Environment), the European Commission's department responsible for the Environment, launched a study called *"Pilot Project - Atmospheric Precipitation - Protection and efficient use of Fresh Water: Integration of Natural Water Retention Measures in River basin management (2013-2014)."* The main goals of this pilot project were the development of easily accessible knowledge about NWRM and support of the progression of an association around NWRM-specialists. The project was funded by the EC for one year. Different guides, case studies and illustration are available on the Online-Platform http://nwrm.eu. (Strosser et al., 2014).

Out of the connection to the NBS and Green Infrastructure concept of the EU, the guide can be used as an example of categorisation and overview of approaches of Nature-based Solutions measures.

This guide was developed as part of the project to show the multiple-benefits, which NWRM can provide and the importance of policy coordination and correlation to make the most out of NWRM. Although this guide is only an overview of the project, the information on the NWRM Website (www.nwrm.eu) is extensive and well structured.

The first chapter clarifies the definition of NWRM and explains which conditions and factors define any measure as a Natural Water Retention Measure. The second chapter shows some reasons, why somebody - in this case skilled workers - shall choose and expand NWRM. These could as well be understood as an aim of the guide. However, it is noted that different professional backgrounds of the reader will lead to various reasons to use NWRM. Similarly, it is stressed that these NWRM are no universal remedy in case of hydrological and biodiversity measures, but they should build a guideline to apply Green Infrastructure and concepts of Nature-based Solutions.

The following chapter is dealing with the planning process and the question of which steps are needed to make the best out of NWRM through policy coordination. Therefore, four key principles are mentioned to change the management and planning processes not only choosing a different measure (Strosser et al., 2014, p.21):

- Giving priority to Nature-based Solutions.
- Joint accounting for the potential multiple benefits of measures.
- Capturing all opportunities favouring policy integration and simultaneous contributions to the objectives of different policies.
- Thinking of a bundle of measures from the outset, which can include both NWRM and grey infrastructure measures.

The fourth chapter treats the selection, design, and implementation of NWRM. As there are many different factors, which are not closer discussed in this guide but probably originating from changing with countries, areas and varying cultural backgrounds, the main goal is to give the right incentives for different policies and strategies. Because of that, this chapter gives five pre-conditions to secure the efficiency of NWRM (Strosser et al., 2014, p.40):

- Ensure knowledge is truly 'multidimensional'
- Make the function and the scale of the hydrological cycle explicit in your measure selection process
- Mobilise stakeholders who represent the expected multiple benefits in your planning processes
- Find the right incentives
- Widen the scope of monitoring and evaluation

The last chapter gives an insight into the practice of NWRM. Five case studies are illuminated in their contexts, such as management issues, objectives, measures, finances, main impacts and benefits.

[3] European Commission (2015): *"Towards an EU research and innovation policy agenda for Nature-based Solutions & re-naturing cities"*

This report produced by a Horizon 2020 Expert Group, gives comprehensive information for the research and innovation agenda for the European Commission. It discusses the definitions of Nature-based Solutions and gives recommendations about goals and therefore required research and innovations actions.

The four goals listed are 1) *enhancing sustainable urbanisation,* 2) *restoring degraded ecosystems,* 3) *developing climate change adaptation and mitigation* and 4) *improving risk management and resilience.* (European Commission, 2015, pp.8–14) To meet these goals seven priority nature-based actions were identified and listed according to European Commission (2015, pp.16–19):

- Urban regeneration through Nature-based Solutions
- Nature-based solutions for improving well-being in urban areas
- Establishing Nature-based Solutions for coastal resilience
- Multi-functional nature-based watershed management and ecosystem restoration
- Nature-based solutions for increasing the sustainable use of matter and energy
- Nature-based solutions and the insurance value of ecosystems
- Increasing carbon sequestration through Nature-based Solutions

To reach the overall aim – greening the economy and making development sustainable – the Expert Group gives the following main recommendations for the EU Research and Innovation agenda on NBS and Re-naturing Cities (European Commission, 2015, p.21):

> *"The development and deployment of Nature-based Solutions that maximise cost-effectiveness and co-benefits* […]
>
> *The scaling-up of Nature-based Solutions across Europe, through a better evidence base* […]
>
> *The development of new business and investment models and legal and institutional frameworks for Nature-based Solutions* […]
>
> *The empowerment, involvement and reconnection of citizens with nature to enhance their well-being" (European Commission, 2015, p.21)*

Although it is difficult to show examples, which can quantify social, economic and environmental benefits, they included a list in the appendix that aims to promote Nature-based Solutions. (European Commission, 2015, p.38 et seq.)

Some examples are explained in a short description and give details to theme, measures, costs and benefits as well as their location and partners (e.g. "*The Big Tree Plant*", "*Sustainable Urban Drainage Systems (SuDS)*", "The Green City Initiative")

[4] Eggermont et al. (2015): "*Nature-based Solutions: New Influence for Environmental Management and Research in Europe"*

Stating the difficulties regarding the definition of the term nature-based this publication sets its aim to sharpen the term due to suggesting a typology, considering existing terminology and concepts, potential negative effects and expected challenges. Through this typology, the expectations should lead to a better understanding of the use and real potential of the term.

The suggested typology is based along two parameters 1) *How much engineering of biodiversity and ecosystems is involved in NBS?* and 2) *How many ecosystem services and stakeholder groups are targeted by a given NBS? (Eggermont et al., 2015, p.244)*

In this relation, the hypothesis was stated, that a higher number of targeted services and stakeholders most often leads to a lower number of met expectations regarding maximising the services and meeting the stakeholders' needs (Eggermont et al., 2015).

Eggermont et al. (2015) described three types of NBS:

> *"Type 1 consists of no or minimal intervention in ecosystems, with the objectives of maintaining or improving the delivery of a range of Ecosystem services both inside and outside of these preserved ecosystems.* […]
>
> *Type 2 corresponds to the definition and implementation of management approaches that develop sustainable and multifunctional ecosystems and landscapes (extensively or intensively managed), which improves the delivery of selected Ecosystem services compared to what would be obtained with a more conventional intervention.* […]
>
> *Type 3 consists of managing ecosystems in very intrusive ways or even creating new ecosystems (e. g., artificial ecosystems with new assemblages of organisms for green roofs and walls to mitigate city warming and clean polluted air)."* (Eggermont et al., 2015, pp.244–245)

The authors mentioned that there is no clear boundary leading to hybrid solutions regarding time and space. For example, an ecosystem service can be newly developed, falling into category type 3. After establishment, they might be judged as type 1 later (Eggermont et al., 2015).

[5] Cohen-Shacham et al. (2016): *"Nature-based solutions to address global societal challenges"*

In this report, various categorisations and structuring principles were provided. After stating multiple definitions of NBS several principles were proposed to build a definitional framework. Provisionally existing frameworks were analysed leading to the following eight proposed principles, essential for an adequate insight of the NBS for IUCN according to Cohen-Shacham et al. (2016):

> *"1. embrace nature consecration norms (and principles);*
> *2. can be implemented alone or in an integrated manner with other solutions to societal challenges (e.g. technological and engineering solutions);*
> *3. are determined by site-specific natural and cultural contexts that include traditional. local and scientific knowledge;*
> *4. produce societal benefits in a fair and equitable way, in a manner that promotes transparency and broad participation;*
> *5. maintain biological and cultural diversity and the ability of ecosystems to evolve over time;*
> *6. are applied at a landscape scale;*

7. *recognise and address the trade-offs between the production of a few immediate economic benefits for development, and future options for the production of the full range of ecosystems series;*
8. *are an integral part of the overall design of policies, and measure or actions, to address a specific challenge."* (Cohen-Shacham et al., 2016, p.6)

After this first categorisation of NBS adding proposed principles to specify the definition, the next classification was focused on the application of NBS. The typology of NBS applications match the three types presented by Eggermont et al. (2015, pp.244–245), here recalled: 1) *used of natural ecosystems,* 2) *managed or restored ecosystems and* 3) *creation of new ecosystems.* (Cohen-Shacham et al., 2016, p.9)

As a final categorisation, the matter of approaches was addressed. According to the IUCN *"Nature-based Solutions (NBS) use ecosystems and the services they provide to address societal challenges such as climate change, food security or natural disasters." (Cohen-Shacham et al., 2016, p.2)* Therefore NBS is used as an umbrella term for ecosystem-related approaches and related challenges and goals illustrated in **Figure 17**.

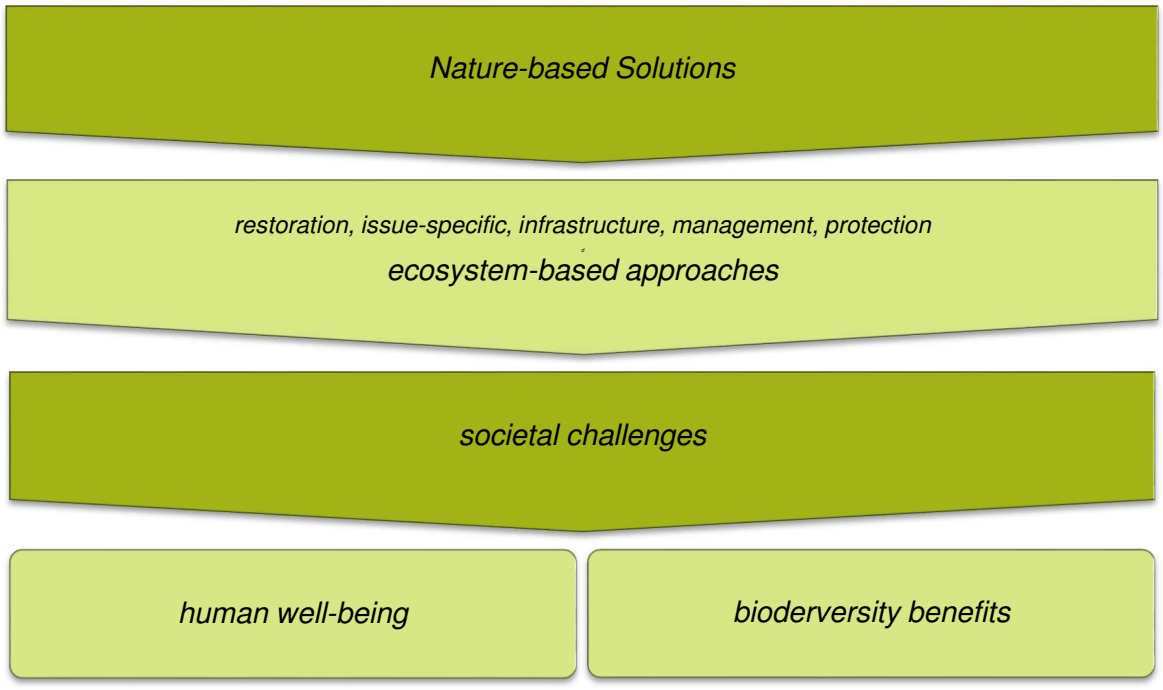

Figure 17 NBS as an umbrella concept (taken from and listed according to Cohen-Shacham et al., 2016, p.11)

As seen in **Figure 17** above, the umbrella concept of NBS considers human well-being and biodiversity benefits as downstream aims of meeting societal challenges. The IUCN discussed NBS as an activity to address specific societal challenges as water security, food security, disaster risk reduction, and climate change (Cohen-Shacham et al., 2016).

To address these challenges different ecosystem-based approaches were defined, leading to five categories for Nature-based Solutions. These five categories and relating concept examples are provided in **Table 13** (Cohen-Shacham et al., 2016, p.10).

Table 13 Categories and examples of NBS approaches defined by the IUCN (taken from and listed according to Cohen-Shacham et al., 2016, p.10)

Main category approaches	Concept examples
Ecosystem restoration approaches	Ecological restoration Ecological engineering Forest landscape restoration
Issue-specific ecosystem-related approaches	Ecosystem-based adaptation Ecosystem-based mitigation Climate adaptation services Ecosystem-based disaster risk reduction
Infrastructure-related approaches	Natural Infrastructure Green Infrastructure
Ecosystem-based management approaches	Integrated coastal zone management Integrated water resources management
Ecosystem protection approaches	Area-based conservation approaches including protected area management

[6] Ihobe, Environmental Management Agency (2017): *"Nature-based Solutions for local climate adaptation in the Basque Country"*

This report presents a methodology for local authorities, which intend to be easily reproducible, connected, and explicit to show existing Nature-based Solutions and their potential and development as climate change adaptions.

It is split into seven chapters and further on includes a useful glossary of terms and a vast annex consisting of Nature-based Solutions factsheets.

The first chapter builds the introduction, therefore discusses 1) *nature-based adaptation to climate change;* 2) *what's understood by Nature-based Solutions;* 3) *efficient and effective NBS; and* 4) *Advances regarding Climate Change Adaption in the Basque Country* (Ihobe, Environmental Management Agency, 2017, pp.5–7). Adaption is explained as adjustment of the human or natural system as a reaction to climate changes, therefore different types are listed (Ihobe, Environmental Management Agency, 2017, p.5):

- Anticipatory adaption – proactive measures
- Reactive adaption – response to impacts
- Adaption driven by the private sector
- Adaption guided by authorities and public bodies
- Autonomous adaption – evolution of human or natural systems

- Planned adaption – aiming specific risks or objectives

Summarising, it is stated that anticipatory adaption, which is coordinated from private and public characters tends to be most effective, efficient during minimising damage and maximising gained opportunities from global change.

Regarding the definition of NBS, it leans on the explanations published in the report of the Horizon 2020 export group of the EC. Then it is emphasised that multi-functionality is one of the main aspects of NBS and therefore verified by studies that NBS is more efficient against climate change than engineering and technical solutions regarding costs, performance and resource use and considering their provided benefit range.

Among efficient and effective NBS the discussion highlights, as already mentioned in the previous part about adaption that now is the time to act and reduce rehabilitation costs for private and public assets.

The Basque Country can list initiatives regarding climate change and adaptions starting from the 2000s. Most important the Basque Plan to Combat Climate Change 2008-2012 includes mitigation and adaption as priority arrangements.

The second chapter is titled scope and deals with the objective and the target audience of the guide. The objective is already expressed in the beginning, the target audience can be listed as follows (Ihobe, Environmental Management Agency, 2017, p.10):

- Local authorities
- Academia, professionals, and consultants
- Ecology groups and educational institutions
- Private initiatives
- General public

Furthermore, the report discusses the approach on different local levels of intervention: 1) *Building – site level,* 2) *neighbourhood – district level* and 3) *municipality level including its periurban areas.* And as for the last part, there is an overview of how mapping of NBS can be utilised (Ihobe, Environmental Management Agency, 2017, p.10).

In chapter number three, recommendations for using the guide are made. For this purpose, a short outline of the structure and the using options of the guide are given. It closes with general recommendations for the usage divided into various types of municipalities and dominate surrounding land use (Ihobe, Environmental Management Agency, 2017, pp.14–17):

- High density urban areas
- Low density urban areas
- Urban community amenities
- New development/planning areas
- Industrial areas
- Rural areas

- Coastal zones
- Blue solutions (i.e. NBS associated with water bodies)

Chapter four provides classifications and characterisations of NBS linked to the Basque Country. The classification of NBS has been partitioned in the following six different levels (Ihobe, Environmental Management Agency, 2017, p.19):

- Building-scale interventions
- Interventions in the public space
- Interventions in water bodies and drainage systems
- Interventions in transport linear infrastructures
- Interventions in natural areas and management of the rural land
- Coastline/coastal interventions

The characterisation of NBS was split in 1) *climate threats,* 2) *social, economic environmental co-benefits and* 3) *implementation criteria.* With the aid of these classifications and characterisation, NBS has been processed and illustrated as factsheets, which are included in the annex. (Ihobe, Environmental Management Agency, 2017, p.22)

The fifth part five of the guide presents information, their sources and tools on different scales to perform an inventory as formulated in the previous chapter. Therefore, Nature-based Solutions are listed regarding different interventions, types and their single names to explain information availability and data sources. Further on, methods and tools to assemble and handle the information are registered.

The methodology to consider Nature-based Solutions in urban planning is summarised in part five. This shows how to address a nature-based adaption strategy in seven phases (Ihobe, Environmental Management Agency, 2017, pp.36–44):

1. Defining objectives
1. Selection the analysis level
2. Gathering the available information and data processing
3. Characterisation of the municipality/ units of analysis by their (urban) typology
4. Diagnoses of the natural capital using land cover
5. Analysis of the NBS: availability and potential
6. Selecting and assessing the measures

Chapter seven demonstrate a case study about climate change adaption via NBS in Donostia/San Sebastián.

[7] Albert et al. (2017): *"Nature-based solutions: criteria"*

The short publication of Albert et al. (2017) was dedicated to a categorisation of NBS. Referring to an article in the editorial "nature" stating that there is still an absence of a definite definition of the expression "nature-based solution", three criteria were suggested (Anon, 2017 in Albert

et al., 2017, p.315). They aimed to provide a better understanding of the concept and adaptation of policies regarding societal challenges and provided the following criteria according to Albert et al. (2017):

1. *"[…] Nature-based solutions need to provide simultaneous benefits for society, the economy and nature."* (Albert et al., 2017, p.315)
2. *"[…] the term should be understood to represent a transdisciplinary umbrella that encompasses experience form existing concepts such as 'blue-green infrastructure' in engineering, 'natural capital' and 'ecosystem services' and 'landscape functions' in environmental planning."* (Albert et al., 2017, p.315)
3. *"[…] Nature-based Solutions need to be introduced gradually to allow time for careful assessments of its application in real-life settings and further refinement."* (Albert et al., 2017, p.315)

The authors further suggested that such actions could turn on collaborations between stakeholders of science, policy markers, and practice.

4.2.3 Specific measures analysis (RQ 4)

Due to the lack of suggestions or discussions about different specific measures of SWB in the publication identified, two of the additional publications were included in the review selection and will be displayed in this certain context. They both provide a list of nature-based solution measures in a rather detailed description, so it seemed acceptable to match them with the previously classified generic categories of Soil and Water Bioengineering measures.

[2] European Commission (s.a.): *"Natural Water Retention Measures - 53 NWRM illustrated"*

This publication builds the illustrated catalogue of Natural Water Retention Measures according to the official guide of NWRM (Strosser et al., 2014). Therefore, this is a very good example of the connection of specific Nature-based Solutions measures and Soil and Water Bioengineering measures.

Table 14 Coding implementation regarding specific measures of the EC publication on NWRM measures (summarised from European Commission, s.a.)

Measure designation	Short description	Categories
Forest riparian buffers	Treed spaces by the side of rivers and other water bodies. These buffers are found in urban, agricultural and wetland areas. They provide different functions such as improvement of water quality and flow moderation.	Combined construction methods

Afforestation of reservoir catchments	Setting plants around reservoir catchments. This afforestation can control soil erosion and improve water quality, but also reduces water yield during the forest life cycle as well as intensive forest management can have negative impacts.	Woody plants
Urban forest parks	Forested areas in urban sectors. Urban forests provide many ecosystem services as improvement of air quality, urban biodiversity, and climate change mitigation.	Woody plants
Trees in urban areas	Woody plants in urban sectors. Urban areas gain numerous advantages as in aesthetics, microclimate and biodiversity resorts from trees, precipitation and air pollution are positively influenced.	Woody plants
Floodplain restoration and management	Floodplain restoration signifies afforestation, riparian buffer development, planting of native grasses, scrubs and in swales. These restoration areas work as retention spaces and provide various ecosystems services shall be restored and reconnected with the river.	Shoot-forming woody plants and woody plant parts, Combined construction methods
Re-meandering	Regression from straightened rivers. Re-meandering positively affects biodiversity, water velocity, and sedimentation.	Combined construction methods
Stream bed re-naturalisation	Breaking up modifications of rivers concerning the floor and riverbanks. Stream bed re-naturalisation influences erosions processes and improve flood prevention, fauna habitats and vegetation diversity.	Combined construction methods, Shoot-forming woody plants and woody plant parts
Restoration and reconnection of seasonal streams	Rebuilt connections of seasonal streams. Seasonal streams are important for flood control, irrigation and other societal ecosystem services.	Combined construction methods, Shoot-forming woody plants and woody plant parts
Natural bank stabilisation	Recovering riverbanks from concrete or other types of wall constructions and restore with ecological components. Bank stabilisation influences the natural movement of a river, water flow and erosion and biodiversity on the stream banks.	Combined construction methods, Shoot-forming woody plants
Permeable surfaces	Pavements, which permeate water through its surfaces, e.g. reinforced grass. Permeable surfaces can mitigate effects of precipitation and limit runoff to other areas.	Plant communities

Swales	Straight vegetated pathways. Swales can replace or support drainage systems. They reduce runoff rates and provide retention space and can deal with polluted runoff before recycling to the water circulation.	Plant communities
Channels and rills	Open trenches and little streams. They collect runoff at the start of drainage systems. These channels and rills provide aesthetic supply lines, sedimentation space and water treatment towards drainage systems.	Plant communities

[6] Ihobe, Environmental Management Agency (2017): *Nature-based solutions for local climate adaptation in the Basque Country.*

The guide towards climate change adaption includes a part of implementation measures. Working through these specific measures some show relations towards the definition of SWB leading to an overlap and fulfilling the requirements of NBS and SWB at the same time.

Table 15 Coding implementation regarding specific measures of the Ihobe publication on climate adaption measures (summarised from Ihobe, Environmental Management Agency, 2017)

Measure designation	Short description	Categories
Sustainable urban drainage systems	Measures as […] *pervious pavements, the restoration of streams and gutters, wetlands plant roofs and so on build the network of sustainable urban drainage systems." (Ihobe, Environmental Management Agency, 2017, p.76)*	Plant communities
Renaturing rivers and streams	*"*[…] *the majority of the rivers and streams of the cities are either underground or channelled, and the riparian ecosystems have therefore disappeared.* […] Renaturing […] *allows better regulation of the natural water cycle, by catching the residual rain water and thus helping to reduce the impact from flooding." (Ihobe, Environmental Management Agency, 2017, p.79)*	Woody plants, Plant communities, combined construction methods
Greening streets	Linear vegetation alongside streets. Sealed areas in streets shall be surrogated with pervious surfaces, wooded areas, and flower spaces	Woody plants, Plant communities
Green linear infrastructures	Woody plants and greening areas alongside infrastructure. Vegetation alongside linear infrastructure provides habitats for flora and fauna and promotes necessary ecological connectivity between urban green areas.	Woody plants, Plant communities, combined construction methods

4.2.4 Examples for written connections for NBS and SWB (RQ 5)

During the research, screening, and skimming process there were some papers relating to the strategies and methods of Soil and Water Bioengineering, but only a few definitely mention and connect the specific terms and methods of Soil and Water Bioengineering and Nature-based Solutions.

In order to focus on the connection between NBS and SWB, two papers actually deal with both issues in written form. To present such examples as a result these two papers are subsequently reflected in the form of a paper review to give an insight for the discussion.

[12] Fernandes and Guiomar (2018): "*Nature-based solutions: The need to increase the knowledge on their potentialities and limits*

This reviewed SCI-paper addresses different areas of Nature-based Solutions and deals with various emerging issues regarding NBS concepts. Therefore, Fernandes and Guiomar (2018) choose three different fields of NBS applications, summarised as:

- *„[...] techniques that use predominantly living organisms (plants, bacteria, and other microorganisms) as construction materials and that build the interdisciplinary science of Soil and Water Bioengineering." (Fernandes and Guiomar, 2018, p.1926)*
- *„[...] use of living communities and habitats in building and renaturing urban environments, improving functions like storm water and runoff retention, allowing more areas for recreation and leisure, or promoting services to climate change adaptation." (Fernandes and Guiomar, 2018, p.1926)*
- *"*[…] *application living organisms are used in the frame of technical systems to perform critical tasks of environmental management where biological wastewater treatment and soil and water decontamination* [...]*"*
  (Fernandes and Guiomar, 2018, p.1926)

In five divided sections the paper discusses at first the basic concept of NBS. Here it is mentioned that there are not necessarily new methods and measures emerging but that there was a change in history when the communities started to trust artificial methods using concrete, steel and similar materials compared to natural processes and technics. In this context, the term "nature-based" and "naturalness" and the importance of NBS in correlation with the concept of ecosystem services was marked. The second section focuses on Soil and Water Bioengineering, different application areas, advantages which engineering with vegetation and bio-systems can bring, but also limitations related to SWB application. Limitations due to lack of knowledge are currently counteracted through increased research efforts. Different researchers show promising results for different applications but also demonstrate the need for new approaches.

The next section treats the topic of reintroducing nature in cultural landscapes. Although it is mentioned that nature reintroductions can be achieved in urban areas in different ways the main focus points to the importance of the cooperation and conviction of all stakeholders. The fourth section describes NBS for environmental quality and land degradation remediation. The fifth section is about different implementation issues at the practical societal level. As NBS is dealing with dynamic and evolving living systems, it is obvious that these are changing and for certain characteristics they need to be maintained. Secondly and probably the most important issue regarding societal needs is to gain trust in plants and living organisms and their use in a technical context as it is common understanding to trust artificial technics and materials. The third critical issue is the fact that NBS leads to many positive impacts of ecosystem services, from which most of them are neither appreciated nor paid. So, it is important to treat the matter of remuneration for ecosystem services and the regulation of different plant usage (allochthonous varieties, etc.) very carefully. Probably the implementation of NBS is most efficient if it evolves from a bottom-up approach.
In the conclusion, it is pointed out that perhaps the main issue of NBS is the lack of knowledge of systems and components since nature can provide a basis for other technical solutions in a humanised environment. However, it has to be mentioned that NBS definitely offers many options, which are short and long-term more economically, and tendentially more profitable than conventional technical solutions and shows all parties of society a way of sustainable and nature-friendly development.

[13] Rowiński et al. (2018): "*How vegetation can aid in coping with river management challenges"*

This reviewed SCI-paper discussed the necessity of new sustainable and cost-effective solutions for river management with a special emphasis on vegetation.
In the introduction, the authors connected the use of vegetation with the developing concept of Nature-based Solutions (NBS). In this context, the definitions of the EC and IUCN were explained. Further on, the connection to ecosystem services for humans was discussed and is following Type 2 of Eggermont et al. (2015), described as management approach that develops sustainable and multifunctional ecosystems and landscapes, with the goal of the improvement of ecosystem service delivery compared to conventional practices. It was stressed that these are equally important for agricultural as urban areas.
The dispute between ecological issues and human demands on river systems was further discussed and the increasing challenges occurring through climate change were emphasised. In this context, the high costs and possibilities of implementation of restoration projects were questioned.

In the section "*Challenges of conventional river management practices*" the historic development of channelisation was explained. Man-maid drainage systems had a big influence on the hydrological regimes in large areas of Northern America and North-West Europe. In this matter, agricultural security always was an overall goal in the area of water and river management. This importance led to a high number of water bodies which drain contaminant, nutrient and sediment loaded water out of agricultural areas. Following the research question of hydrodynamic complexity in connection with vegetation potential conflicts as ecological benefits versus reduced water flow capacity appeared, leading to the challenge how to best use and manage vegetation.

In the third section, the statement of a new paradigm in assessing hydrodynamics implications of riverine vegetation was found, and literature and study methods were listed. According to literature based on the geomorphological influence of vegetation within fluvial systems, the complementary field of flume and theoretical or modelling investigation supported the understanding of the influence of plants on fluvial systems.

The next section dealt with the potential of vegetation for reducing pollution concentrations in watercourses. The contamination of rivers and channels is dominated by water flow, channel shape, sediment transport and – especially focused on in this paper – vegetation and its connection with the previously listed. Studies of these correlations working with different models, e.g. transient storage models as well as 2D and 3D mass transport models, should determine where to apply Soil and Water Bioengineering (SWB) methods. The authors mentioned that further investigations of SWB methods are necessary. To evaluate the influence of applied vegetation methods studies about channel systems need to be treated as an integrated system. The obstacles, in this case, were identified in the complexity of different effects of vegetation.

In the last section two-stage channels as an exemplary problem solution were discussed. A reconnection to floodplains leads to benefits of ecosystem services of the riparian zones. Further advantages were seen in the improving ecological as agricultural resilience on basis of narrower channels. These systems not only showed lower construction costs, measured on finished investigation sites, but were improved threefold if the longer lifetime cycle is taken into account: In pilot studies a decrease in flooding and channel erosion, as well as an improvement of water quality, was found.

The authors concluded that the performance of NBS to water management was proven to be working by observations. They stated that there are numerous research gaps regarding the holistic processes, controls, and interconnections, even within explored examples. As climate change lets expect increasing problems regarding nutrients and sediment substances and transport as well as extreme events, NBS seem to be needed more urgently than ever. The

authors state that even if there is no guarantee of the success of NBS, it is better to try to find a sustainable way in learning from nature than to wonder if it would have brought benefits.

4.2.5 Search update and development of publications after the main analysis (timeframe 2014-2018), 2019 - July 2020 (RQ 6)

This section provides a short insight in a number of publications and contents discussed in the 1.5 years following the here presented analysis timeframe, which was set as a five year period ending with the year 2018.

To proof if and how many publications were released since the end of 2018, the data acquisition was repeated for the time frame from January 2019 till July 2020. The earlier processed search modi (see chapter 4.1.2, **Table 7**) for the selection process were applied. The search hits from this added search were not part of the content analysis.

Working through the data research a rather increasing number of recent publications (see **Table 16**) became obvious.

Table 16 Research results update for the timeframe 2019 till July 2020, repeating the selected search modi as applied for the processed review selection

Keywords	Search mode	Number of results on ScienceDirect	Number of results on Scopus	Number of results on BOKULIT:search
"Nature-based Solutions"	Article title, abstract, keywords	157	351	368
"Nature-based Solutions" AND "Soil Bioengineering" OR "Nature-based Solutions" AND "Soil and Water Bioengineering"	Full text search	6	8	1

After reducing the multiple occurring publications (viewed in **Figure 18**) the number of results (n= 414) still doubled the processed publications (n= 205) of the original search results during the main analysis from 2014 till 2018.

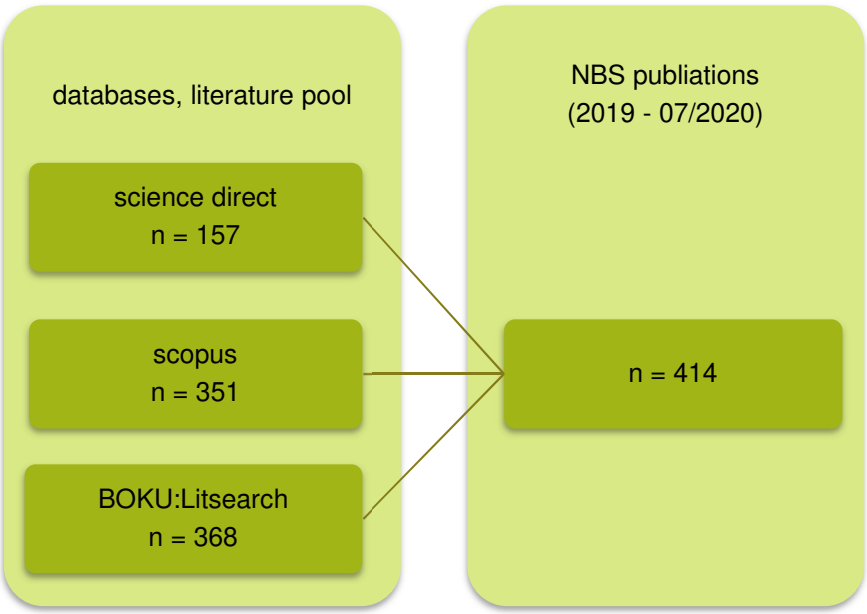

Figure 18 Research results – 2019 till July 2020 of selected search term number 2

In order to provide a more complete picture of the NBS-SWB related discourse following the main analysis of this theses, it was decided to work out an overview of the collected data related to Soil and Water Bioengineering issues. These papers (n= 12) were edited as in the selection process (see **Figure 19**) and led up to two papers, which will be shortly discussed subsequently.

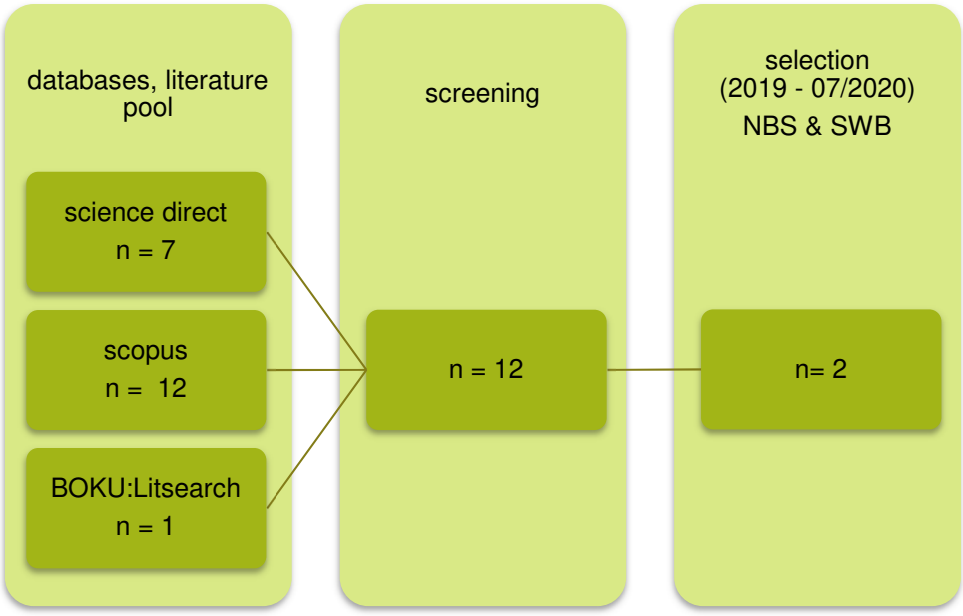

Figure 19 Selection process – NBS and SWB 2019 till July 2020

[A] Arce-Mojica et al. (2019): *"Nature-based solutions (NBS) for reducing the risk of shallow landslide: Where do we stand?"*

The publication of Arce-Mojica et al. (2019) provides a systematic literature review of the present situation surrounding disaster risk reduction and NBS.

In the introduction section, the occurrence of NBS and their definition was discussed, referencing above all the publications of the IUCN (Cohen-Shacham et al., 2016) and the EC (European Commission, 2015). After presenting a list of ecosystem-based approaches combined in the name of NBS, the scientific publications of landslide risk reduction and shallow landslides, in particular, were reflected. The above named authors implemented an extensive systematic literature review method, similar to the here applied approach, using Scopus and Science Direct Databases, aiming to identify papers for shallow landslides connecting towards vegetation and/or NBS.

Their result section displays search hits that connect to vegetation and to NBS for example regarding the scientific type of paper, applied research methods as well as a list of numbered main topics.

The discussion of the results reveals that there is an extensive number of publications dealing with landslides, primarily treading the geomorphological aspects. Out of the smaller extent of papers dealing with vegetation, an even minor part directly refers to NBS. In those, the often close or overlapping concepts and approaches of NBS lead to confusion.

The authors note an important increase of publications towards NBS and shallow landslides, they state that it seems scientific publications are hold back compared towards international and policy areas of NBS. The complexity of this field is emphasised, and confusion is due to overlapping and similar NBS concepts. The authors recommend further research to be necessary to launch NBS in forest ecosystems and biogeographical areas as well as to explore potential negative effects of vegetation as causing aspect towards shallow landslides.

[B] Rey et al. (2019): *"Soil and Water Bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration"*

This publication reviews definitions and improvement of SWB (referred to "bioengineering" by the authors) typologies and presents practices and research questions to clarify the connection between natural endangerment control and ecological rehabilitation.

The first chapter presents the development and issues in Soil and Water Bioengineering. After presenting a definition, applications and benefits of Soil and Water Bioengineering (SWB) the connection towards natural hazard was brought up. The rising importance of SWB is connected or even more promoted by frameworks, e.g. European Green Infrastructure, and other publications of the European Commission (EC), and the International Union of the Conservation of Nature (IUCN).

The second chapter discusses the connection between natural hazard control and ecological restoration. The challenge is seen in providing practicable measures, which as well fulfil functions and benefits of ecological restorations as meet the characteristics of natural hazard control.

In the third chapter, the course from SWB practice towards research needs was discussed. The start of this discussion built the topic selection of plant species. There are studies and databases about certain species for different hazards in certain climate, environmental or topographic areas. But there is a research gap concerning the question if species suitable for hazard protection are used for ecological restoration, too. Equally, it is not sure, according to the authors, if biodiverse planting systems, as recommended for ecological restorations, are more or less efficient toward hazard control. About the selection of SWB structures, it is mentioned that most of them have not been adequately studied. On the level of individual plants, the breaking point for topographical and hydrological forces are not known as well as which parts are important for mechanical resistance. Furthermore, according to the authors, the correlation between inactive and living materials in SWB structures needs to be researched. To enhance the application for SWB methods for natural hazard control new implementations must be evolved. This design of SWB structures must connect new frameworks, methods, and guidelines for projects on all levels and scales. To proof these solutions, several attempts and different study methods are listed as necessary research requirements. Another point for practice and research needs is seen in the coordination of quantitative engineering and – sometimes better – qualitative SWB experience. In addition to the technical view, the financial component can be an issue. Further, more research needs are listed regarding catchment and landscape scales. Therefore, the concepts and measures of Green and Blue Infrastructure are discussed. A long list of examples elucidates the closer cooperation and consideration between scientists and practitioners and a clearer determination of existing expertise.

In the conclusion by Rey et al. (2019), six key considerations to accomplish bioengineering actions - which equals SWB measures as discussed in chapter 2.2 - are listed:

> *"(i) considering a multidisciplinary approach for Soil and Water Bioengineering projects, (ii) establishing practical guidelines and tools for designing bioengineering structures, (iii) implementing monitoring stages in bioengineering projects, (iv) transmitting knowledge and know-how on Soil and Water Bioengineering, (v) analysing existing bio- engineering works in terms of their performance, successes and failures, and (vi) continuing to identify the needs of the bioengineering professional sector."* (Rey et al., 2019, p.1217)

5 Discussion

The following chapters provide a discussion of the presented results connecting them towards the elaborated research questions (see chapter 1.2).

5.1 Review of published data (RQ 1)

The first part of the thesis deals with current scientific publications, quantitative search presentation, selection processes, and consequential review outcomes.

5.1.1 Quantitative overview (see chapter 4.1.1)

Towards the quantitative overview (see **Table 5**) and the surprisingly high number of search hits for the search string “Nature-based Solutions” two main reasons can be deduced:

1. Although it seems like a rather specific expression and the high number of search hits may appear as the resulting display hits for single words out of the search string, it turned out that the search hits only follow the exact word combination. But quite a lot of publications only showed one or two hits of the word combination, not really pursuing a discussion of its approaches or functions.
2. NBS concepts are strongly promoted – especially in Europe – including financial funding programs, which raise a high interest out of many different subject areas or specialist fields leading to frequent usage of the term NBS.
3. The quantitative overview search was not investigated in more depth in this thesis. In the course of the further research and selection processes, i.e. the screening process, it appeared that the search hits might not always account for singularities of publications.

Therefore, the quantitative search results should only be taken as an approximated value on the real working range on NBS.

There was only a very limited number of search hits for the used keyword chains building the connection towards Soil and Water Bioengineering topics. Deducing from subsequent work and analysis steps in this thesis, it is stressed that quite some publications contain relations towards SWB although the specific term “Soil Bioengineering” or “Soil and Water Bioengineering” were not used and, therefore, these publications are not captured in the search. For clearer search results the process could be enhanced with related keywords as *ecological engineering, soft or green engineering* (Rowiński et al., 2018, p.349). This suggests that, in order to find publications connecting NBS and SWB, the definition and use of certain wording for SWB might be even more significant than the definition of NBS.

5.1.2 Quality of the database search results (see chapter 4.1.2)

The database research was the basis for qualitatively processed publications. However, the search hits regarding general NBS search and the focused search on publications connecting

NBS and SWB displayed the same striking gaps as the quantitative overview, which only confirmed the first impression.

On basis of the low number of publications during the main analysis (timeframe set for 2014-2018) and occurring for the search series focusing on SWB, the decision to follow through the NBS search limited towards “article title, abstract and keywords” seemed comprehensible.

When the chosen data was transformed into the literature analysis programme the process displayed multiple occurrences of the same publications in the search hits. Especially on the BOKU:LITsearch platform these numbers were corrected and the reason was questioned. Sometimes articles linked or released in different books were not identified as the same publication. Additionally, publications compiled by multiple authors occurred, where the bibliographic information cited different authors as the first, which resulted in more search hits for the same publications.

Due to this working process and the significant reduction of search hits on the BOKU:LITsearch platform on basis of multiple occurrences, the high number of search hits in the overview research had lost some credibility. But regarding the database search results were not as important as the content, so the corrected data was pursued.

5.1.3 Selection Process and review selection

The selection process on basis of the widespread topic and application of NBS turned out to be very complicated. The focus was laid on criteria trying to focus on the research questions, however, in the end it was only the top of an eligible list, which was picked.

The following **Figure 20** shows the complete process chain of RQ 1. A summarising statement will be provided in the conclusion (see chapter 6.1).

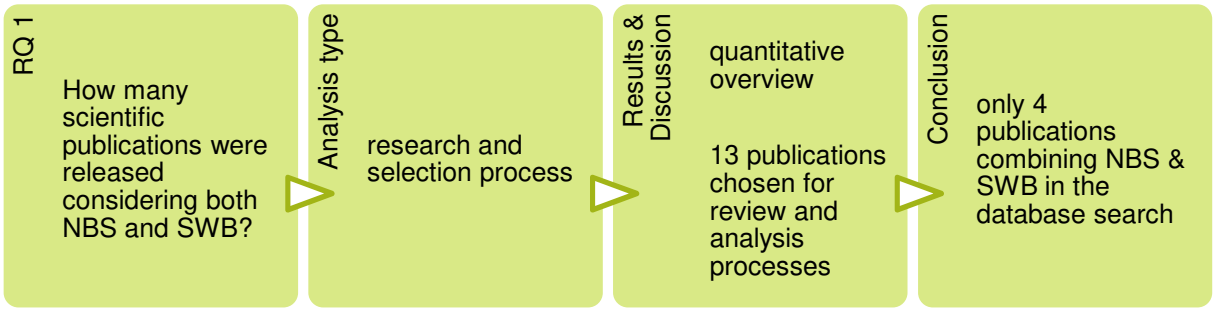

Figure 20 Process chain for Research questions 1

5.2 Definition on NBS in the present literature (RQ 2)

Although the composition of the phrase Nature-based Solutions could easily be taken as somehow self-explanatory, the analysis brought to light that many authors determine a closer description.

Figure 21 shows the complete process chain of RQ 2. This overview with keywords is followed by a detailed discussion and a short answer for RQ 2 in the conclusion (6.1).

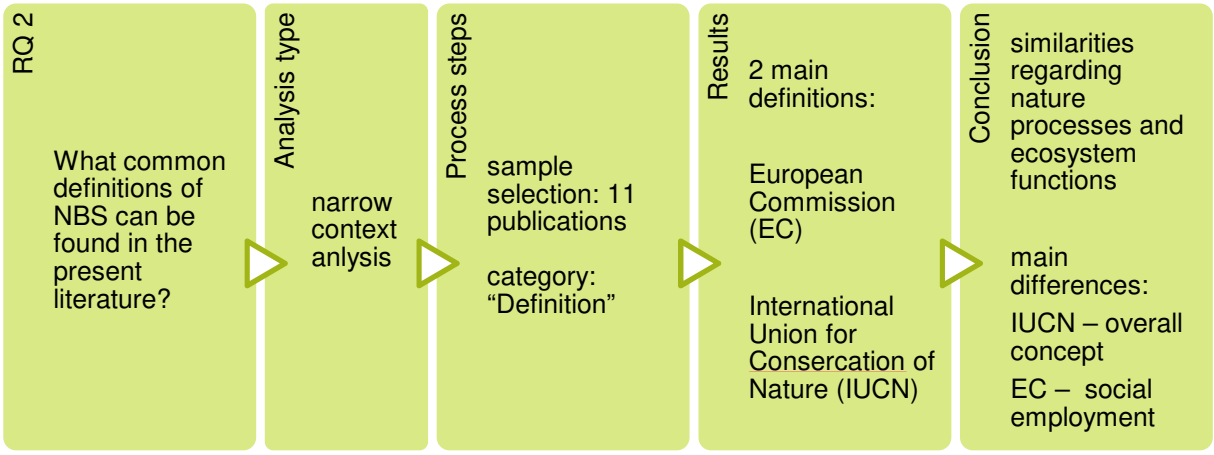

Figure 21 Process chain for Research Question 2

Working through literature and publications it became obvious, even though there were different definitions as listed in **Table 10** (see chapter 4.2.1), many of them were referencing or expanding each other.

The conclusion, therefore, led towards two main definitions, one from the European Commission (EC), (2015) [3] and another one from the International Union for Conservation of Nature (IUCN), (Cohen-Shacham et al., 2016) [5]. Therefore, these two will be discussed regarding their similarities as well as their differences.

> *“Nature-based solutions aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions, for example, mimicking how non-human organisms and communities cope with environmental extremes.“* (European Commission, 2015, p.24)

> *“Nature-based Solutions are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.“ (Cohen-Shacham et al., 2016, p.5)*

These two main definitions seem very similar, that one might even think IUCN (published 2016) is created due to the other one (EC, published 2015). But IUCN states that the concept of NBS was developed to a greater extent from organisations as the EC and themselves. The focus of their definition clearly lies on the natural processes and ecosystem functions, both connecting

NBS to human well-being and social challenges or aiming towards benefits or as eponymous solutions.
The definition and topic specifications in the report published by the EC leans more towards social impacts to connect the use of nature imitating constructions to labour and interactive processes in the community.
The description and processes in the IUCN, on the other hand, relate more in direction of overall concepts to promote different kind of near-nature approaches.

Four of the selected publications ([6], [8], [10] and [11]) used the EC definition (2015) directly or gave slightly adapted or supplemented versions. Selected publication number [6], published by Ihobe, Environmental Management Agency (2017) deals with the definition as basic information with the rest of the guide focusing on the influence of NBS towards climate change and specific measures. Publication number [8], published by Maes and Jacobs (2017), focused on the influence of NBS for sustainable development and its influence on the economy, which relates to the report of the EC. Publication number [10], presented by Faivre et al. (2017), not only discusses the definition but moreover relates to the whole Horizon 2020 project and the Research and Innovation agenda and actions of the EC. The last one citing the EC definition, publication number [11] published by Escobedo et al. (2018), is thematically dealing with different metaphors as well as their coexisting or connecting developments.
The selected publications number [9], published by Nesshöver et al. (2017), dealing with interdisciplinary approaches as well as publication number [13], published by Rowiński et al. (2018), covering the topic of river management, both include a discussion about both definitions of NBS - the EC definition [3] and the IUCN definition [5].
Therefore, out of this analysis process, it appears that the definition of NBS most used in the present literature is the one that the EC published in the Horizon 2020 report [3]. However, it is noted that in discussions regarding the definition of NBS a sharper definition is demanded, and it is highlighted that none of the above-mentioned publications clearly provides an own characterising definition. All of the publications in the review are tightly connected to the two main definitions of European Commission (2015) and Cohen-Shacham et al. (2016).

I agree with the three remaining publications ([4], [7] and [12]) which all provide statements, that the approach or categorisations are by far more important than a certain definition. More details about that are provided in the discussion of RQ 3 (see chapter 5.3), but it seems important to notice that the details of the definitions are connected towards the approach or moreover the scale factor of the NBS concept. The chosen publications of this review discussing definitions but referring towards categorisations provide the three possible categorisation types presented by Eggermont et al. (2015) in paper number [4], which covers

changes and influences on environmental management and research in Europe. The publication number [7], written by Albert et al (2017), that present a set of criteria for NBS, is basically a short publication solely presenting these criteria. The discussion regarding definition and categorisations in publication number [12] of Fernandes and Guiomar (2018), who are only referring to the types and criteria of the other two publications ([4] and [7]), is an analysation of NBS concepts and their potentials.

5.3 Variation of categories and approaches towards NBS (RQ 3)

Working through the publications dealing with different categories and approaching systems towards NBS it was unambiguous that there is not only one clear structure or system.

The following **Figure 22** shows the complete process chain of RQ 3. This overview with keywords is followed by a detailed discussion and a short answer of RQ 3 in the conclusion (see chapter 6.1.)

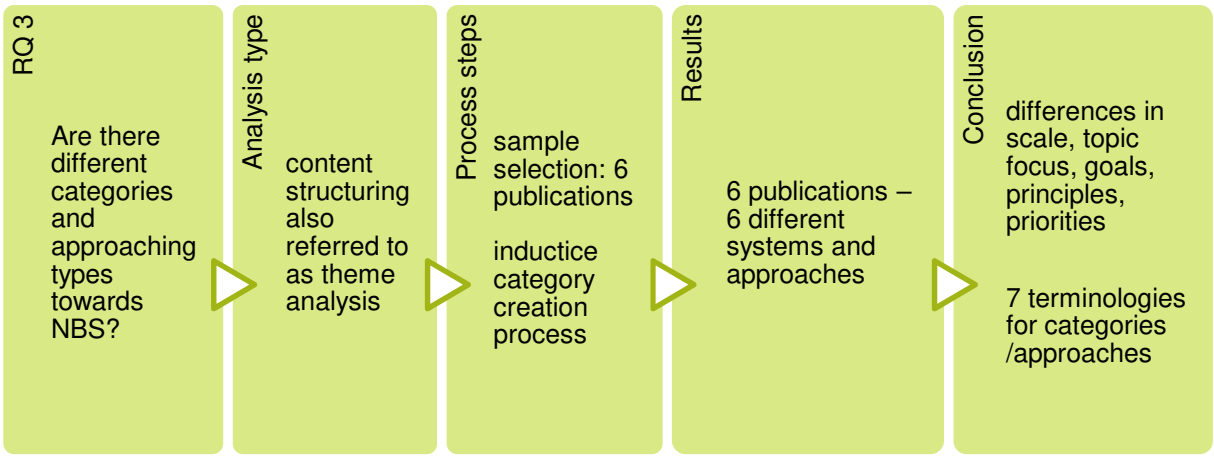

Figure 22 Process chain for Research Question 3

The answer to this research question is quite unsatisfactory due to different uses of the terms, categories and approaches in the selected publications. The main findings are compared to each other to show the “wild and numerous” allocation of categories and approaches. It became not clear yet, when to correctly use the term category and when approach, as each publication uses them but in different ways.

The following **Table 17** shows the attempt to give an overview of the variation of categories and approaches out of the identified publications.

Table 17 List of possible NBS categories and approaches

No	Publications	Categories and approaches						
		Goals/aims	Principles/ criteria	Types	Conditions/ phases/ levels	Actions / measure	Connected / related concepts	Case studies / promoting examples
[1]	(Strosser et al., 2014)		■		■			■
[3]	(European Commission, 2015)	■			■	■		■
[4]	(Eggermont et al., 2015)			■				
[5]	(Cohen-Shacham et al., 2016)		■	■			■	■
[6]	(Ihobe, Environmental Management Agency, 2017)	■		■	■	■		■
[7]	(Albert et al., 2017)		■					

As first of the six chosen publications towards categorisations and approaches towards NBS Strosser et al. (2014)'s *"A guide to support the selection, design and implementation of natural water retention measures in Europe: capturing the multiple benefits of Nature-based Solutions."* [4] was chosen. With the aim of making knowledge on Natural Water Retention Measures (NWRM) more attainable the report of this pilot project provides three approaches. All of them are very specifically formed regarding NWRM, so therefore a comparison with others only seems to make sense in the notion of the category or approach term.

As analysed in RQ 1 the European Commission (2015) publication "*Towards an EU research and innovation policy agenda for Nature-based Solutions & re-naturing cities."* [3] builds one of the main publication towards the NBS definition. Therefore, it is an important guideline for categories and approaches as well. In this publication, three categories and connecting approaches could be deducted. The first categories build general NBS goals. In order to meet these goals, they provide seven priority actions. And as final category the publication is indicating future approaches, naming recommendations for research and innovation.
All in all, the categories of the EC report are dealing with NBS on a very general level, so therefore the scale of goals and actions is rather large.

The publications of Eggermont et al. (2015) "*Nature-based Solutions: New Influence for Environmental Management and Research in Europe."* [4] creates a category system of three types of NBS based on two parameters. The parameters are based on the involvement of different components:

- *"How much engineering of biodiversity and ecosystems is involved in NBS?"*
- *"How many ecosystem services and stakeholder groups are targeted by a given NBS?"*

  (Eggermont et al., 2015, p.244)

The hypotheses of these parameters are, that a higher number of targets often lead to a lower number of complied expectations. Drawn from these parameters, according to Eggermont et al. (2015), are three types of NBS:

- Type 1: better use of natural/protected ecosystems
- Type 2: NBS for sustainability and multifunctionality of managed ecosystems
- Type 3: design and management of news ecosystems

  (Eggermont et al., 2015, p.245)

This typology was connected to other publications so therefore, the use and interpretation of NBS the way IUCN [5] framed it, is connected to type 1. The other two, type 2 and 3, are often demonstrated by actions of the EC [3] towards green growth and sustainable development. In further examples of NBS the importance of the specification, whether solutions are considered NBS or not, is emphasised. With the annotation that NBS are connected and relying on other concepts, the all-embracing and improved potential for environmental sustainability is stated. As the typology of Eggermont et al. (2015) is used in other publications this category approach seems to meet many relevant issues of NBS.

The IUCN's publication "*Nature-based solutions to address global societal challenges."* [5] giving the second main definitions of NBS - suggests quite a few approaches and clear structures of category proposition (Cohen-Shacham et al., 2016). This report provides several category systems, approaches and different principles many of those were interconnected. Starting with principles for the application and relating to the three types of NBS by Eggermont et al. (2015).

Defining NBS as an umbrella concept of the IUCN Cohen-Shacham et al. (2016) show different opportunities through NBS (see **Figure 17**) and provide some concrete categorisation structures for a somehow large scale. This perspective on NBS is deeply connected towards the ecosystem approaches (see **Table 13**). The report includes a large second part (Part B), which presents nine case studies with background details, main activities, results as well as reflections about important key lessons have been learned.

The publications of Ihobe, Environmental Management Agency (2017) *"Nature-based solutions for local climate adaptation in the Basque Country."* [6] basically builds a guideline for categorisation, approaches and applications of NBS towards climate adaption. Therefore, useful but specific categorisations are provided. These are on the one hand theme-correlated as on the other hand in some way area-related. As this publication, similar to Strosser et al. (2014), have already a separate main theme (NWRM) and focus on climate adaption, the categories and approaches are not quite as comparable with the other publications. In order to give an impression towards the direction of approaches, the generic terms of categorisations were divided. As this publication discusses many of the mentioned terminologies (see **Table 17**), the depth of specific information is misleading. So, the term goals/aims already apply for target groups and applications areas instead of overall NBS goals.
The guide provides a classification according to the level of interventions, relating to scopes on six different levels. Further on, NBS were categorised according to three different criteria: climate threats; social, economic and environmental co-benefits and implementation criteria.
According to these classifications and characterisation, NBS was processed and illustrated as factsheets. Those factsheets – e.g. sustainable urban drainage systems, renaturing rivers and streams and greening streets – related to specific SWB measures, such as woody plants, plant communities and combined construction methods. These are examples processed in RQ 4, connection certain NBS measures towards SWB measures.

The publication of Albert et al. (2017) on *"Nature-based solutions: criteria"* [7] is rather short and is as the title says a set of criteria of NBS as follows. This approach indicates a general insight in NBS and as titled describes the criteria which should be fulfilled. Therefore, the publication treats NBS as an umbrella concept and sets itself on the same general scale as many other publications in present literature (e.g. IUCN publication Cohen-Shacham et al., 2016).

In general, the analysis regarding the categories and approaches of NBS revealed that once more there is no single universal category system or approach. It appears that the varying scopes, focus of topics, goals, principles, and priorities, chosen by the respective author(s), significantly influence the types and details of categories and approaches. And although **Table 17** provides a collection of the variation of categories and approaches, even the ones allocated towards the same terminology can be dispersed in details.

5.4 Connection of NBS and specific SWB measures (RQ 4)

During the screening of publications and the following detailed analysis process, it became obvious that in the present literature most NBS concepts and measures are acting on a different level than specific SWB measures.

The following **Figure 23** provides an overview of the process chain as basis for the discussion. A summarised short answer of RQ 4 will be given in the conclusion (see chapter 6.1).

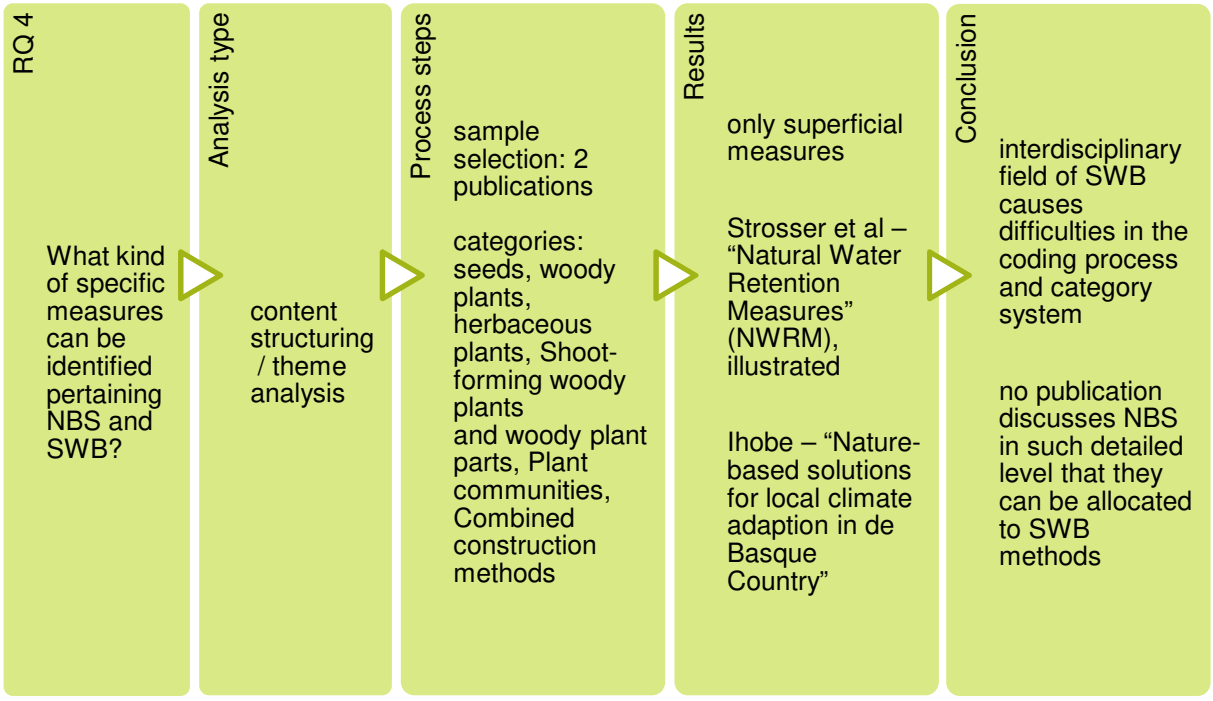

Figure 23 Process chain for Research Question 4

The two chosen publications from European Commission (s.a.) and Ihobe, Environmental Management Agency (2017) are presenting NBS measures which were divided into the generated SWB categories: seeds, woody plants, herbaceous plants, shoot-forming woody plants and woody plant parts, plant communities, and combined construction methods. This allocation of NBS measures to SWB categories is only possible if you are familiar with SWB measures, but this knowledge is not incorporated in the selected publications.

The in this thesis generated categorisation of SWB measures is overall in accordance with NBS measures as in the analysed papers, but not on the level of specific measures itself. Hence there is no further depth for a real connection towards single SWB measure methods identified. So, it can be concluded for the analysed publication period 2014-2018 that there are no publications connecting NBS and SWB on the detailed level of single specific SWB measures.

In this context, it is mentioned that the definition of SWB in current publications is rather vague in details as well. The main part of previously established definitions of SWB relate to the usage of plant and plant parts (Kruedener, 1951; Schlüter, 1986; Begemann and Schiechtl, 1994;

Florineth, 2012; Hacker and Johannsen, 2012; EFIB, 2015). As mentioned in chapter 2.2, measures are defined as SWB measure if they fulfil all of the following aspects: (1) organic parts and properties (2) technical constructions (3) renewability and sustainability. And this is, where I see the main difference in definitions of NBS and SWB: measures that fulfil only the first aspect (organic) can be defined as NBS measures, but not as SWB measures. Because SWB measures stand for certain ways of applications and detailed selection of plants regarding their properties, not only the usage of any organic material anywhere. Most of the recent publications do not discuss important differences in the technique and use of plants, although these differences build the specification as either SWB measure or NBS measures. Regarding the definitions of NBS leads to the assumption that all SWB measures are NBS measures. This has not yet been debated by any publication so far. In my opinion, all SWB measures could be stated as NBS because they are somehow related to plants and plant parts, which are products and constellations based on nature ("organic"). On the other hand, not all NBS measures are SWB, because for example greening roofs or facades are definitely NBS measures, as they also relate to specific plant usage and application knowledge, but therefore belong to the scientific expertise field of vegetation engineering. Specifically for roof and façade greenery technologies, the above identified aspects and claims 1) organic parts and properties (2) technical constructions (3) renewability and sustainability are not fully applicable.

As a short excerpt the level of details for SWB measures e.g. comparing live stakes (see chapter 2.4) and cuttings: these distinctions are not addressed at all in the present SWB literature. Live stakes are longer than cuttings and it is most important that they are inserted in a sloped angle to provide the aimed stability of the SWB measure (Zeh, 2007). Cuttings are simply used to vegetative reproduction of plants in garden centres and tree nurseries.

While working on these category titles to meet the level of NBS measures in the present literature it also occurred that SWB – as often mentioned in early literature – is an interdisciplinary science. This can be broken down towards single measures as well, as they are often mixed and overlapping and therefore a single choice category system is difficult or even impossible to work out, as the right application of SWB measures comparatively often demands combinations.

Further on, the categorisations of SWB often are divided in fields of applications, so that, therefore, the focus lies on water bodies and hillsides rather not connected to urban areas. As the SWB focus has been lying on stabilisation and protection of the existing natural environment rather than to improving conditions or recreating natural spaces in urban areas, published connection of SWB measures as NBS to urban environments and in order to restore lost ecosystems has not yet reached the scientific debate.

All in all, it can be said that there are relations of NBS and SWB in measures, but they are not more accurately discussed in the present literature, not even mentioning the fact that the scale of details is unsatisfactory.

5.5 Published interconnection of NBS and SWB (RQ 5)

The limited publications of interlinkages of NBS and SWB display the problem that this written connection is scarcely existent.

Even in the identified related publications discussing similar or related measures towards SWB the specific terms and methods are rarely covered.

The following **Figure 24** shows the process chain, leading to the results and conclusion of the two selected publications. The discussion of the proceeded publications is put hereafter and a short answer of RQ 5 is provided in the conclusion (see chapter 6.1.).

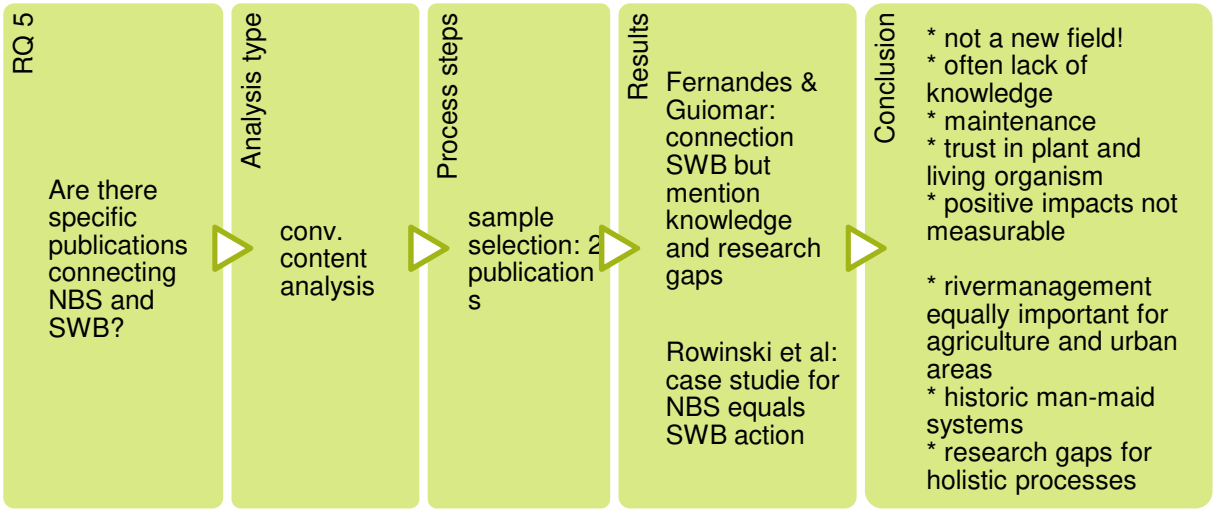

Figure 24 Process chain for Research Question 5

The publication of Fernandes and Guiomar (2018) "*Nature-based solutions: The need to increase the knowledge on their potentialities and limits"*, occurs as one of the first papers connecting NBS towards SWB. The aim of this publication is an analysis of areas and issues of NBS and emphasises the challenges of the general concept.

The authors divided the publication in three different fields of application – one being *"the interdisciplinary science of Soil and Water Bioengineering".* Fernandes and Guiomar, (2018, p.1926) pointed out that SWB is not a new field. The authors highlight that limitations due to the natural characteristics of working with plants and their specific operations and the usage in different surroundings are areas where the need of clarification and applications can be improved through further and more detailed research.

The authors present a lot of implementations presented in this publication, stated under the umbrella of the NBS concept, admitting that the knowledge of components or systems of measures are insufficient or even defective. I agree with them that these issues can be easily improved by further research and corresponding investigations. NBS can be a contribution towards holistic solutions in engineering questions. NBS should not be seen as one more initiative, but moreover as an area of technologies for feasible and profitable sustainable solutions towards a combination of working technology and a nature-respectful culture.

The second chosen publications "*How vegetation can aid in coping with river management challenges"* by Rowiński et al. (2018), discusses the basics of NBS in relation to the definitions of the EC and the IUCN as well as the typology by Eggermont et al. (2015). The fundamental part of the publication treats the topic of river management and the scientific knowledge and influence of the usage of vegetation. In the context of using vegetation Soil and Water Bioengineering measures, in general, are mentioned.
In this context, the high cost and the likelihood of implementation of restoration projects were questioned. However, the financial aspect as well of restoration projects as of technical solutions is rather excluded from scientific experiments and analyses. Therefore, I would like to point towards research and development of life cycle assessments. To provide a holistic overview of costs and benefits it is necessary to compare equal long-term expenses of both mere technical solutions and mixed approaches.
The closing comments of the authors stress that there is no guarantee of the success of NBS. However, I agree that it is better to try to find a sustainable way in learning from nature than to wonder if it would have brought benefits. In fact, many publications demand more research, and long-term experiments under real conditions, and monitored applications of NBS.

5.6 Development in the passage of time, 2019-2020 (RQ 6)

Similar to the processed publications of the time frame 2014 – 2018, the search hits of publications of 2019 and 2020 are increasing exponentially. Although publications resulting out of the keyword search connection NBS and SWB are rather low, the numbers are permanently rising.
As well as in the papers leading up to 2019, many publications mention research gaps towards NBS definitions and measures in further details.
There are publications following a deeper focus towards SWB measures (Rey et al., 2019) and even the connection of NBS and certain detailed topics of SWB (Arce-Mojica et al., 2019), but all of them highlight that research gaps as well about the functions and depth of details regarding SWB definitions and measures and connections and specific definition of NBS. Although Rey et al. (2019) write about the rising importance of SWB in connection of

frameworks and publications of the EC and IUCN, the correlation of NBS and SWB is not further discussed in detail. The publication of Arce-Mojica et al. (2019), provides a quantitative analysis of the topic NBS and shallow landslides. The conclusion is, although NBS is promoted in different policies and their systematic literature review was focused on vegetation in general, there is rather little published literature so far. Admitting an increase in the last decade, the authors support transdisciplinary studies to assimilate NBS for shallow landslide reduction.
These examples show that the interest, as well as the scientific publications, are increasing over time, but still, the correlations and published research in the topic NBS and SWB is showing a shortcoming.

6 Conclusion

The conclusion starts with a short recap answering the research questions. The second part builds a reflection about the working process and methods, revealing aspects, which should be changed in a remake, and the third part closes with recommendations for further research.

6.1 Recap towards the research question

1. **How many scientific publications were released considering both NBS and SWB? (RQ 1)**

   The database literature search for the timeframe 2014 – 2018 (main analysis) shows only 4 publications for the keywords “Nature-based Solutions” and “Soil and Water Bioengineering” / “Soil Bioengineering”. The complementary search for the timeframe 2019 till July 2020 lead to 12 search hits following the same search keywords.

2. **What common definitions of NBS can be found in the present literature? (RQ 2)**

   There are two main definitions of NBS, provided by frameworks of the IUCN (Cohen-Shacham et al., 2016) and EC (European Commission, 2015). Hardly any publication uses a completely independent definition, but rather builds on these publications not considering comparisons or discussions of the definition itself.

3. **Are there different categories and approaching types towards NBS concepts? (RQ 3)**

   The chosen review publications give examples for different categories and approaches, but all of them change with the scale, the focus of the goals and priorities of each concept. One of the most reoccurring category is the typology providing three application types by Eggermont et al. (2015).

4. **What kind of specific measures can be identified pertaining to NBS and SWB? (RQ 4)**

   Although there are publications providing activities and measures, which can be identified as NBS and SWB, the knowledge and discussion is not presented in the publications itself. Using a generated SWB categorisation in the analysis preparation, two publications identified in the main analysis were presented towards superficial SWB measures, but no publication discussed NBS in such detailed level that they can be allocated to specific SWB methods in the present literature.

5. **Are there specific publications connecting NBS and SWB? (RQ 5)**

   There are publications connecting NBS and SWB, but most of them are case studies of SWB concepts (e.g. Rowiński et al., 2018). Only Fernandes and Guiomar (2018) discuss the relation between SWB and NBS. But they are mainly pointing out the fact that SWB is not a new science or collection of methods, and that there is a huge lack of research connecting SWB and NBS.

6. **Are there significant developments after the main analysis timeframe? (RQ 6)**
   As well the rising number of publications as the content does not show too many divergent or new insights regarding the main research questions. The identified and processed publication of Arce-Mojica et al. (2019) shows a systematic literature research, followed by a quantitative analysis regarding research methods, publication types as well as main topics. The paper of Rey et al. (2019) provides a deeper insight towards necessary research demands about SWB techniques in connection towards natural hazard control and ecological restoration.

6.2 Reflection of methods and documentation

This section presents a collection of aspects, which I would re-think and adapt referring to the research design process and documentation of this thesis.

It turned out that BOKULIT:search is a good platform to provide an overview and an option to include publications which are not strictly scientific papers, but to include the detected publications into a literature management programme is rather cumbersome and difficult. It could not be found out why, but there are still many duplicates as well as equal publications headed with other authors or other similarities or other varying search hits numbers with no obvious reason.

As a second very important aspect, I noticed that the term “Soil and Water Bioengineering” seems to be underutilised or infrequently used. Therefore, I assume that the search hits combining the expressions SWB and NBS are probably lower than the real presence of the conjunction of these two topics. Probably it could be more successful to extend the keyword search with relating phrases (as e.g. biotechnical/ecological engineering), although in some papers (e.g. Arce-Mojica et al., 2019) using the keyword “vegetation” led to a rather high amount of publications, not necessarily relating towards SWB.

During the screening process, it became obvious that NBS is a European concept. So, there may be similar discussions and interesting publications on relating terms, e.g. “nature-based infrastructure” and “engineering with nature” as used in the US-American scientific world (US Army Corps of Engineers, 2013 in Nesshöver et al., 2017).

6.3 Recommendations

Working through different analysing types and different themes and foci of publications regarding NBS and SWB, it can be stated that almost all publications mention a difference between present concepts, measures, and research programmes and connecting scientific publications. Therefore, my recommendation is to work on research processes with closer details towards SWB measures. The countless areas and different interpretations and levels of scale of NBS, provide a large number of publications, but rather often it is just a superficial

touch of the concept. In order to connect NBS and SWB methods research and publications directly connecting both of them should be carried out.

Therefore, case studies and research experiments have to be presented on a deeper level and further processed and published to close the gap between concept frameworks, applied measures in reality and scientific proof.

References

Albert, C., Spangenberg, J.H., Schröter, B. (2017). Nature-based solutions: Criteria. *Nature*. [Online] 543 (7645), 315–315. doi:10.1038/543315b.

Anon (n.d.). *Definition of BIOENGINEERING*. [Online]. www.merriam-webster.com. Available from: https://www.merriam-webster.com/dictionary/bioengineering [Accessed: 16 January 2021].

Anon (2017). 'Nature-based solutions' is the latest green jargon that means more than you might think. [Online] 541 (7636), 133–134. doi:10.1038/541133b.

Arce-Mojica, T. de J., Nehren, U., Sudmeier-Rieux, K., et al. (2019). Nature-based Solutions (NBS) for reducing the risk of shallow landslides: Where do we stand? *International Journal of Disaster Risk Reduction*. [Online] 41101293. doi:10.1016/j.ijdrr.2019.101293.

Becker, F.G. (2012). *Zitat und Manuskript: erfolgreich recherchieren, richtig zitieren, formal korrekt gestalten ; eine praktische Arbeitshilfe zur Erstellung von wirtschaftswissenschaftlichen Arbeiten*. Stuttgart, Schäffer-Poeschel.

Begemann, W., Schiechtl, H.M. (1994). *Ingenieurbiologie: Handbuch zum ökologischen Wasser- und Erdbau*. 2., neubearb. Aufl. Wiesbaden, Bauverl.

Brauner, D.J., Vollmer, H.-U. (2004). *Erfolgreiches wissenschaftliches Arbeiten: Seminararbeit - Diplomarbeit - Doktorarbeit*. Wissen kompakt. Sternenfels, Verl. Wissenschaft & Praxis.

Cohen-Shacham, E., Walters, G., Janzen, C., et al. (2016). *Nature-based solutions to address global societal challenges*. [Online]. Gland, Switzerland, IUCN International Union for Conservation of Nature. doi:10.2305/IUCN.CH.2016.13.en.

EFIB (2015). *European Guidelines for Soil and Water Bioengineering*. [Online]. Available from: https://dspace.uevora.pt/rdpc/bitstream/10174/14589/1/Richtlinie%20pdf.pdf [Accessed: 14 January 2019].

Eggermont, H., Balian, E., Azevedo, J.M.N., et al. (2015). Nature-based Solutions: New Influence for Environmental Management and Research in Europe. *GAIA - Ecological Perspectives for Science and Society*. [Online] 24 (4), 243–248. doi:10.14512/gaia.24.4.9.

Elo, S., Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*. [Online] 62 (1), 107–115. doi:10.1111/j.1365-2648.2007.04569.x.

Erlingsson, C., Brysiewicz, P. (2013). Orientation among multiple truths: An introduction to qualitative research. *African Journal of Emergency Medicine*. [Online] 3 (2), 92–99. doi:10.1016/j.afjem.2012.04.005.

Escobedo, F.J., Giannico, V., Jim, C.Y., et al. (2018). Urban forests, ecosystem services, green infrastructure and Nature-based Solutions: Nexus or evolving metaphors? *Urban Forestry & Urban Greening*. [Online] 373–12. doi:10.1016/j.ufug.2018.02.011.

European Commission (s.a.). *Natural Water Retention Measures - 53 NWRM illustrated.* [Online]. Available from: http://nwrm.eu/sites/default/files/documents-docs/53-nwrm-illustrated.pdf [Accessed: 30 December 2020].

European Commission (2015). *Towards an EU research and innovation policy agenda for Nature-based Solutions & re-naturing cities: final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities': (full version)*. Directorate-General for Research and Innovation 2015 Climate Action, Environment, Resource Efficiency and Raw Materials (ed.). [Online]. Luxembourg, Publications Office of the European Union. doi:10.2777/765301.

Faivre, N., Fritz, M., Freitas, T., et al. (2017). Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*. [Online] 159 (Journal Article), 509–518. doi:10.1016/j.envres.2017.08.032.

Fernandes, J.P., Guiomar, N. (2018). Nature-based solutions: The need to increase the knowledge on their potentialities and limits. *Land Degradation & Development*. [Online] 29 (6), 1925–1939. doi:10.1002/ldr.2935.

Florineth, F. (2012). *Pflanzen statt Beton: sichern und gestalten mit Pflanzen*. 2. Aufl. Berlin, Patzer.

Hacker, E., Johannsen, R. (2012). *Ingenieurbiologie*. UTB Umweltplanung, Landschaftsarchitektur, Garten- und Landschaftsbau 3332. Stuttgart, Ulmer.

Hsieh, H.-F., Shannon, S.E. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research*. [Online] 15 (9), 1277–1288. doi:10.1177/1049732305276687.

Ihobe, Environmental Management Agency (2017). *Nature-based solutions for local climate adaptation in the Basque Country*. Laura Gutiérrez, Gemma García, & Igone García (eds.). [Online]. Bilbao, Ihobe, Environmental Management - Agency Ministry of the Environment, Territorial Planning and Housing - Basque Government. Available from: http://growgreenproject.eu/wp-content/uploads/2018/05/NBS-Climate-Adaptation-Basque-Country.pdf [Accessed: 10 August 2018].

Kornmeier, M. (2016). *Wissenschaftlich schreiben leicht gemacht: für Bachelor, Master und Dissertation*. UTB Schlüsselkompetenzen 3154. 7., aktualisierte und ergänzte Auflage. Bern, Haupt Verlag.

Kornmeier, M. (2011). *Wissenschaftlich schreiben leicht gemacht: für Bachelor, Master und Dissertation*. UTB Arbeitshilfen 3154. 4., aktualisierte Aufl. Bern, Haupt.

Kruedener, A. v. (1951). *Ingenieurbiologie: praktische Hinweise und Ratschläge für zeitgemäßes Planen und Bauen unter Anpassung an die landschaftlichen Verhältnisse und deren Ausnutzung*. München/Basel, Ernst Reinhardt Verlag.

Kuckartz, U. (2016). *Qualitative Inhaltsanalyse: Methoden, Praxis, Computerunterstützung*. Grundlagentexte Methoden. 3., überarbeitete Auflage. Weinheim Basel, Beltz Juventa.

Maes, J., Jacobs, S. (2017). Nature-Based Solutions for Europe's sustainable development. *Conservation Letters*. [Online] 10 (1), 121–124. doi:10.1111/conl.12216.

Mayring, P. (2000). Qualitative Content Analysis. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*. [Online] Vol 1No 2 (2000): Qualitative Methods in Various Disciplines I: Psychology. doi:10.17169/fqs-1.2.1089.

Mayring, P. (2014). *Qualitative Content Analysis. Theoretical Foundation, Basic Procedures and Software Solution*. [Online]. Klagenfurt, Austia. Available from: http://files.qualitative-content-analysis.aau.at/200000075-82241831d6/Mayring(2014)QualitativeContentAnalysis.pdf [Accessed: 22 May 2019].

Mayring, P. (2015). *Qualitative Inhaltsanalyse: Grundlagen und Techniken*. 12., überarbeitete Auflage. Weinheim Basel, Beltz Verlag.

Nesshöver, C., Assmuth, T., Irvine, K.N., et al. (2017). The science, policy and practice of Nature-based Solutions: An interdisciplinary perspective. *Science of The Total Environment*. [Online] 579 (Journal Article), 1215–1227. doi:10.1016/j.scitotenv.2016.11.106.

Rey, F., Bifulco, C., Bischetti, G.B., et al. (2019). Soil and Water Bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration. *Science of The Total Environment*. [Online] 6481210–1218. doi:https://doi.org/10.1016/j.scitotenv.2018.08.217.

Rowiński, P.M., Västilä, K., Aberle, J., et al. (2018). How vegetation can aid in coping with river management challenges: A brief review. *Ecohydrology & Hydrobiology*. [Online] 18 (4), 345–354. doi:https://doi.org/10.1016/j.ecohyd.2018.07.003.

Schiechtl, H.M., Stern, R. (1992). *Handbuch für naturnahen Erdbau: eine Anleitung für ingenieurbiologische Bauweisen*. Wien, Österreich. Agrarverl.

Schlüter, U. (1986). *Pflanze als Baustoff: Ingenieurbiologie in Praxis und Umwelt*. Berlin [u.a.], Patzer.

Strosser, P., Delacámara, G., Hanus, A., et al. (2014). *A guide to support the selection, design and implementation of natural water retention measures in Europe: capturing the multiple benefits of Nature-based Solutions.* [Online]. Luxembourg, Publications Office of the European Union. doi:10.2779/761211 [Accessed: 6 November 2018].

von der Thannen, M., Hoerbinger, S., Paratscha, R., et al. (2020). Development of an environmental life cycle assessment model for Soil Bioengineering constructions. *European Journal of Environmental and Civil Engineering*. [Online] 24 (2), 141–155. doi:10.1080/19648189.2017.1369460.

Webster, J., Watson, R.T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly*. 26 (2), xiii–xxiii.

WWAP (2018). *The United Nations world water development report 2018: Nature-based Solutions for water*. [Online]. France, Paris, UNECSO. Available from: http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2018-nature-based-solutions/ [Accessed: 29 May 2019].

Zeh, H. (2007). *Ingenieurbiologie: Handbuch Bautypen = Génie biologique = Ingegneria naturalistica = Soil Bioengineering = Ingeniería biológica*. EFIB (ed.). Zürich, vdf Hochschulverlag.

Index of tables

Table of figures

Table of Abbreviations

EC	European Commission
IUCN	International Union of Conservation of Nature
NBS	Nature-based Solutions
NWRM	Natural Water Retention Measures
RQ	Research Questions
SWB	Soil and Water Bioengineering

Appendix

Publications – review selection (2014 – 2018)

Albert, C., Spangenberg, J.H., Schröter, B. (2017). Nature-based solutions: Criteria. *Nature*. [Online] 543 (7645), 315–315. doi:10.1038/543315b.

Cohen-Shacham, E., Walters, G., Janzen, C., et al. (2016). *Nature-based solutions to address global societal challenges*. [Online]. Gland, Switzerland, IUCN International Union for Conservation of Nature. doi:10.2305/IUCN.CH.2016.13.en.

Eggermont, H., Balian, E., Azevedo, J.M.N., et al. (2015). Nature-based Solutions: New Influence for Environmental Management and Research in Europe. *GAIA - Ecological Perspectives for Science and Society*. [Online] 24 (4), 243–248. doi:10.14512/gaia.24.4.9.

Escobedo, F.J., Giannico, V., Jim, C.Y., et al. (2018). Urban forests, ecosystem services, green infrastructure and Nature-based Solutions: Nexus or evolving metaphors? *Urban Forestry & Urban Greening*. [Online] 373–12. doi:10.1016/j.ufug.2018.02.011.

European Commission (s.a.). *Natural Water Retention Measures - 53 NWRM illustrated.* [Online]. Available from: http://nwrm.eu/sites/default/files/documents-docs/53-nwrm-illustrated.pdf [Accessed: 30 December 2020].

European Commission (2015). *Towards an EU research and innovation policy agenda for Nature-based Solutions & re-naturing cities: final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities': (full version)*. Directorate-General for Research and Innovation 2015 Climate Action, Environment, Resource Efficiency and Raw Materials (ed.). [Online]. Luxembourg, Publications Office of the European Union. doi:10.2777/765301.

Faivre, N., Fritz, M., Freitas, T., et al. (2017). Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*. [Online] 159 (Journal Article), 509–518. doi:10.1016/j.envres.2017.08.032.

Fernandes, J.P., Guiomar, N. (2018). Nature-based solutions: The need to increase the knowledge on their potentialities and limits. *Land Degradation & Development*. [Online] 29 (6), 1925–1939. doi:10.1002/ldr.2935.

Ihobe, Environmental Management Agency (2017). *Nature-based solutions for local climate adaptation in the Basque Country*. Laura Gutiérrez, Gemma García, & Igone García (eds.). [Online]. Bilbao, Ihobe, Environmental Management - Agency Ministry of the Environment, Territorial Planning and Housing - Basque Government. Available from:

http://growgreenproject.eu/wp-content/uploads/2018/05/NBS-Climate-Adaptation-Basque-Country.pdf [Accessed: 10 August 2018].

Maes, J., Jacobs, S. (2017). Nature-Based Solutions for Europe's sustainable development. *Conservation Letters*. [Online] 10 (1), 121–124. doi:10.1111/conl.12216.

Nesshöver, C., Assmuth, T., Irvine, K.N., et al. (2017). The science, policy and practice of Nature-based Solutions: An interdisciplinary perspective. *Science of The Total Environment*. [Online] 579 (Journal Article), 1215–1227. doi:10.1016/j.scitotenv.2016.11.106.

Rowiński, P.M., Västilä, K., Aberle, J., et al. (2018). How vegetation can aid in coping with river management challenges: A brief review. *Ecohydrology & Hydrobiology*. [Online] 18 (4), 345–354. doi:https://doi.org/10.1016/j.ecohyd.2018.07.003.

Strosser, P., Delacámara, G., Hanus, A., et al. (2014). *A guide to support the selection, design and implementation of natural water retention measures in Europe: capturing the multiple benefits of Nature-based Solutions.* [Online]. Luxembourg, Publications Office of the European Union. doi:10.2779/761211 [Accessed: 6 November 2018].

Publications – review selection (2019 – July 2020)

Arce-Mojica, T. de J., Nehren, U., Sudmeier-Rieux, K., et al. (2019). Nature-based solutions (NBS) for reducing the risk of shallow landslides: Where do we stand? *International Journal of Disaster Risk Reduction*. [Online] 41101293. doi:10.1016/j.ijdrr.2019.101293.

Rey, F., Bifulco, C., Bischetti, G.B., et al. (2019). Soil and Water Bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration. *Science of The Total Environment*. [Online] 6481210–1218. doi:https://doi.org/10.1016/j.scitotenv.2018.08.217.

Publications – search hits NBS and SWB (2014 – 2018)

Fernandes, J.P., Guiomar, N. (2018). Nature-based solutions: The need to increase the knowledge on their potentialities and limits. *Land Degradation and Development*. [Online] 29 (6), 1925–1939. doi:10.1002/ldr.2935.

Krajter Ostoić, S., Salbitano, F., Borelli, S., et al. (2018). Urban forest research in the Mediterranean: A systematic review. *Urban Forestry & Urban Greening*. 31185–196.

Rey, F. (2018). Role of bioengineering structures made of willow cuttings in marly sediment trapping: assessment of three real-size experiments in the Southern French Alps. *Journal of Mountain Science*. 15 (2), 225–236.

Rowiński, P.M., Västilä, K., Aberle, J., et al. (2018). How vegetation can aid in coping with river management challenges: A brief review. *Ecohydrology & Hydrobiology*. [Online] 18 (4), 345–354. doi:10.1016/j.ecohyd.2018.07.003.

Publications – search hits NBS and SWB (2019 – July 2020)

Arce-Mojica, T. de J., Nehren, U., Sudmeier-Rieux, K., et al. (2019). Nature-based solutions (NBS) for reducing the risk of shallow landslides: Where do we stand? *International Journal of Disaster Risk Reduction*. [Online] 41101293. doi:10.1016/j.ijdrr.2019.101293.

Cerdà, A., Rodrigo-Comino, J. (2020). Is the hillslope position relevant for runoff and soil loss activation under high rainfall conditions in vineyards? *Ecohydrology & Hydrobiology*. [Online] 20 (1), 59–72. doi:https://doi.org/10.1016/j.ecohyd.2019.05.006.

Devkota, S., Shakya, N.M., Sudmeier-Rieux, K. (2019). Framework for assessment of eco-safe rural roads in panchase geographic region in central–western Nepal hills. *Environments - MDPI*. [Online] 6 (6). doi:10.3390/environments6060059.

Heravi, G., Abdolvand, M.M. (2019). Assessment of water consumption during production of material and construction phases of residential building projects. *Sustainable Cities and Society*. [Online] 51101785. doi:https://doi.org/10.1016/j.scs.2019.101785.

Kumar, P., Debele, S.E., Sahani, J., et al. (2020). Towards an operationalisation of Nature-based Solutions for natural hazards. *Science of The Total Environment*. [Online] 731138855. doi:https://doi.org/10.1016/j.scitotenv.2020.138855.

Lilli, M.A., Nerantzaki, S.D., Riziotis, C., et al. (2020). Vision-Based Decision-Making Methodology for Riparian Forest Restoration and Flood Protection Using Nature-Based Solutions. *Sustainability (Basel, Switzerland)*. 12 (8), 3305.

Lingwall, B.N. (2020). An Examination of the Foundations of Mega-Flora: Implications for Biomimetic Geotechnics. In: Budge A.S. Kavazanjian E. Hambleton J.P., Makhnenko R. (ed.). *Geotechnical Special Publication*. [Online]. 2020 American Society of Civil Engineers (ASCE). pp. 29–38. doi:10.1061/9780784482834.004.

Rey, F., Bifulco, C., Bischetti, G.B., et al. (2019). Soil and Water Bioengineering: Practice and research needs for reconciling natural hazard control and ecological restoration. *Science of The Total Environment*. [Online] 6481210–1218. doi:https://doi.org/10.1016/j.scitotenv.2018.08.217.

Scharf, B., Kraus, F. (2019). Green roofs and greenpass. *Buildings*. [Online] 9 (9). doi:10.3390/buildings9090205.

Stangl, R., Minixhofer, P., Hoerbinger, S., et al. (2019). The Potential of Greenable Area in the Urban Building Stock. In: *IOP Conference Series: Earth and Environmental Science*. [Online]. 2019 p. doi:10.1088/1755-1315/323/1/012080.

Tisserant, M., Janssen, P., Evette, A., et al. (2020). Diversity and succession of riparian plant communities along riverbanks bioengineered for erosion control: a case study in the foothills of the Alps and the Jura Mountains. *Ecological Engineering*. [Online] 152105880. doi:https://doi.org/10.1016/j.ecoleng.2020.105880.

Zaimes, G.N., Tardio, G., Iakovoglou, V., et al. (2019). New tools and approaches to promote Soil and Water Bioengineering in the Mediterranean. *Science of the Total Environment*. [Online] 693133677. doi:10.1016/j.scitotenv.2019.133677.