International Journal of Disaster Risk Reduction 13 (2015) 96–108

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

The Disaster-Knowledge Matrix – Reframing and evaluating the knowledge challenges in disaster risk reduction

Raphael Spiekermann [a,*], Stefan Kienberger [a], John Norton [b], Fernando Briones [c], Juergen Weichselgartner [d,e]

[a] University of Salzburg, Department of Geoinformatics-Z_GIS, Austria
[b] Development Workshop France (DWF), France
[c] Centro de Investigaciones y Estudios Superiores en Antropología Social (CIESAS), Mexico
[d] Politecnico di Milano, Department of Architecture and Urban Studies, Italy
[e] Ludwig-Maximilians-University Munich, Department of Geography, Germany

ARTICLE INFO

Article history:
Received 14 January 2015
Received in revised form
7 May 2015
Accepted 7 May 2015
Available online 8 May 2015

Keywords:
Knowledge
Science communication
Science-policy nexus
Disaster risk reduction
Climate change adaptation

ABSTRACT

Within the context of disaster risk reduction, including climate change adaptation, significant thematic discourse has been dedicated to the difficulty of implementing research-based knowledge in policy and practise. Not only has the discussion focused on the causes of this issue, but many recommendations for enhancing the use of information and knowledge have also been made. The authors first frame the knowledge challenges and, second, introduce a systematic means to identify the factors hindering the use of information and knowledge. The approach proposed allows determining core barriers in the co-production, exchange, and use of knowledge. Subsequently, we illustrate where further advancement is needed in the field of knowledge development, means of transmission and use for disaster risk reduction. We suggest a method that analyses cases considering the success or failure of information flows from and to different stakeholder groups. The aim is to identify causes for knowledge fragmentation at different phases in the disaster management continuum, and, subsequently, to strengthen both individual and institutional learning, as well as to determine social and functional changes required to address pressing issues of disaster risk reduction, including climate change adaptation, in a competent manner.

1. Introduction

In general, increasing knowledge of natural hazard-related risk and its relation to changes over time (e.g. through the impact of climate change or land use dynamics) ultimately leads to better understanding, improved management, and finally to risk reduction and adaptation. However, knowledge is unique to a person's mind and is often confused with information, which is merely a means of documenting and sharing knowledge. The rapid increase in research-based knowledge has led to an increased fragmentation of knowledge. Knowledge fragmentation has advantages in that it means that advanced, specialised expertise in various fields exists. However, linking and aggregating state-of-the-art knowledge, as well as the targeted provision of knowledge for evidence-based, informed decision-making is insufficient. This is reflected by the immense enlargement of disaster-related research and the increase of scientific activities that have so far had limited impact on reversing the upward trend in disaster damage, precisely expressed by White et al. [1] as "knowing better and losing even more". Obviously, there are gaps: between what is known about disaster risks, on the one hand, and how research findings are translated into policies and programmes, on the other; differences in understanding what households and communities consider to be disaster events and appreciating locally developed coping and prevention measures.

Today, a huge variety of information resources and knowledge systems with regard to the assessment and management of natural hazards attempt to increase the uptake of knowledge: governmental programmes and research projects, academic journals and public reports, research institutes and advanced technology, all supported by scientists, private companies, practitioners, and non-governmental organisations (NGOs) from various fields. Additionally, there is the vast knowledge related to the experience of communities, families and individuals that is not always capitalised on. A differentiated view on the knowledge production and sharing processes can facilitate an increased use of knowledge for improved disaster risk reduction (DRR), including climate change adaptation (CCA). As climate change is understood to be one driver

* Corresponding author.
E-mail address: spiekermann.raphael@gmail.com (R. Spiekermann).

http://dx.doi.org/10.1016/j.ijdrr.2015.05.002
2212-4209/

of disaster risk amongst many creeping environmental and social changes, climate change adaptation is integrated into disaster risk reduction as a contributing factor [2]. For this reason, when the term DRR is used here, it always includes CCA.

This in turn points towards the production of information and use of knowledge and raises the possibility that progress is being blocked by barriers: How does risk-related research-based knowledge relate to the apparent growing toll of losses? Is human knowledge and understanding of the causes of the losses inadequate despite the increasing research effort, or is it that existing knowledge is not applied or not used effectively? Is it that communication methods are inadequate for the task and that information transferred is not transformed into knowledge that can be acted on? The synthesis of these latter questions points to yet another problem: information may be available, but this does not necessarily imply that it is known, accepted and acted on. The diverse distribution of disaster risk-related knowledge can lead to good decision making by some, unfavourable decision-making by others. And we are often not sure how to characterise good decision-making as the long-term consequences of decisions are most often unknown.

Although a growing literature on 'knowledge-to-action' has been addressing the gap between the scientific community and the policy community from different perspectives e.g., [3–8], only punctual efforts have been undertaken to study the gap between risk interpretation and action [9]. Many aspects of the complex interface between information sharing, knowledge-making and decision-making are still unexplored and better appraisal is needed to effectively integrate information, knowledge, and expertise into the efforts directed at DRR, in particular with regard to mechanisms for positive exchange between science, policy, practise, and the public.

The current focus on the knowledge gap between science and policy needs to lead to an increased understanding on how barriers in knowledge implementation can be identified and overcome. An increase of research-based knowledge is not as significant as improving mechanisms for its increased application. Our findings show that barriers to knowledge sharing, transformation and implementation are generally greater than the means to overcome them. Understanding knowledge, its production, and use is very central in this process, as the aim is to implement knowledge in policy and practise by all stakeholders involved in DRR. Identifying where fragmentation of knowledge exists, as well as its causes, represents a primary aim of this study. Or, as Hayek [10] stated, the challenge is to understand how to utilise "knowledge which is not given to anyone in its totality". This is not only true for DRR, but is equally essential for CCA, a process growing in significance and recognition of its importance in the public arena. For this reason, it is important that synergies between DRR and CCA are identified so that identical or similar objectives are approached in a common effort.

The main objectives here are to explore the complex interaction of knowledge, decision-making, and implementation, and to understand and identify what hinders the use of knowledge to make appropriate decisions for risk mitigation. The first section of this paper shows how a differentiated view on information and various types of knowledge can facilitate improved decision-making. The second section discusses current deficits in knowledge production in the fields of DRR and delineates current challenges for both science and policy. We finally introduce an analysis tool, aiming to support the assessment of the knowledge production, sharing and implementation process, and in complement, a rapid interpretation system that visualises where information is (not) reaching target stakeholders and being acted on. A case study of the 2013 flood event in Salzburg, Austria, will provide a concrete example of how barriers can be reduced and overcome to enhance disaster risk management in the public sector, and how these can be rapidly visualised. Additionally, a case study in southern Mexico provides evidence on how a DRR initiative may not work if effective communication and knowledge exchange between decision-makers and disaster-affected people is not given.

2. Is reframing knowledge a solution?

It is important to understand the nature of knowledge. In so doing, understanding of knowledge production processes, the coexistence of different types of knowledge, and the causes hindering the transfer and use of information that can increase knowledge can be improved. Questions raised by Mittelstrass [11] illustrate that in a society where information technology has paved the way for an evolving information society, knowledge is increasingly being replaced and confused with providing information, which may remain untapped or unused, thus legitimising a discussion on data, information, knowledge, and wisdom: "From knowledge to wisdom? Which wisdom could that be, if its concept of knowledge is only that of information again?" [11, p. 22].

A closer look at what knowledge is can improve understanding of the intrinsic barriers within the knowledge process itself. Horrigan [12, p. 75] describes this process as follows: "Knowing always involves a knower knowing something. It involves a relationship between a knower and the known. It is an act which joins a mind with an object in a relationship which is unique and incomparable with any other. There is no such thing as knowledge without something known and a knowing subject knowing it. Each and every act of knowing is a synthesis of object and subject." At first, this description may seem utterly plausible. However, two major preconditions are required of the knower: awareness of the knowable object, and an incentive or willingness by the subject to be open to receiving or obtaining and understanding the knowable object, which is at that point the act of knowledge, or cognition. The known is thus appropriated by the knower so that (depending on the form of knowledge) it is understood and applicable, either through the use of this acquired knowledge in concrete actions or as guidance for decision-making. In this relationship between the object and subject, good communication is intrinsically important; it implies not simply transmission of information but information reception, understanding and action, or if one chooses, inaction, and which in either case has become the basis of an informed decision, constituting knowledge, for better or for worse, rather than one based on lack of information or knowledge. Knowledge may be lost through inability to express the known or the lack of capacity to understand the known.

According to Aristotle [13], three forms of knowledge may be distinguished depending on its telos, i.e., the purpose it serves: theoretical, productive, and practical knowledge. Theoretical, or speculative knowledge, is the pursuit of truth by means of contemplation for its own sake, i.e., because it fulfils the intellect. The purpose of productive knowledge is to know how to produce something. Practical knowledge relates to action, and is the necessary ingredient for making correct decisions, though prudence, the ability to correctly apply knowledge, is presupposed. This type of knowledge is of great importance in the context of DRR. Practical knowledge is such knowledge, which is used, or can be used, given the circumstances, and has an effect in a decision-making context. Based on Aristotle's Metaphysics [13, 981^{b}1], practical knowledge amounts to experience, or "knowledge of particulars", whereas theoretical knowledge is of universals. A decision-maker without experience will likely face many difficulties, not knowing how to apply theories; but a decision-maker with great experience might be capable of producing good results. Yet, the one who has the theoretical knowledge knows the principles and causes underlying experience, the "why", and is therefore said to be wiser than the one with only experience. The best decision-maker is one who has theoretical knowledge as well as experience, i.e. knowledge of universals and of how to apply them to particulars: "Clearly then wisdom is knowledge about certain causes and principles" [13, 982ᵃ1].

Younkins [14] describes Aristotle's understanding of speculative knowledge as the result of science, which generates "universal truths deduced from self-evident principles known by induction. The goal of speculative science is knowledge for its own sake. Mathematics and metaphysics would be speculative sciences for Aristotle". Generally, practical knowledge must presuppose and employ speculative knowledge to some degree. This is because all thinking presupposes knowledge of certain principles (such as the principle of non-contradiction). To illustrate this more clearly, one may consider that in order to be able to think about individual things, one must know that there are individual things, and that names/words denote specific kinds of things. This is the principle of identity of which Aristotle states: "If, however, [definitions] were not limited but one were to say that the word has an infinite number of meanings, obviously reasoning would be impossible; for not to have one meaning is to have no meaning, and if words have no meaning reasoning with other people, and indeed with oneself has been annihilated; for it is impossible to think of anything if we do not think of one thing" [13, 1006ᵇ1]. In order to discuss how to reduce disaster risk, one must know what the risk is and all it entails. Though this knowledge is gained from experience, it is abstracted from it, because the term 'risk' does not refer to any particular one, but embraces all. This knowledge of essences is speculative, according to Aristotle.

Other authors [11,15] distinguish between information knowledge (or factual knowledge) and orientation knowledge in a way similar to Aristotle's distinction between speculative knowledge and practical knowledge. Mittelstrass [11, p. 22] defines information knowledge as "knowledge of facts, that is, knowledge of what is the case. Orientation knowledge (or 'Socratic knowledge'), by contrast, may be defined as knowledge of aims and purposes, i.e., as knowledge of what (justifiably) ought to be the case". Information knowledge is thus of the causes, effects and means; it is the knowledge, which sciences and technology, given a particular purpose, may provide. Marotzki [16] further outlines that humans acquire and grow in understanding of the things of the world via instrumental, factual knowledge, and with the help of orientation knowledge they stand in a reflective relationship to it. This perspective is of great significance in order to understand DRR- and CCA-related decision-making of individuals, organisations, and society as a whole, as given circumstances and values need to be taken into account. The issues raised during evacuation procedures in the Xangsane typhoon event of Vietnam illustrate this use of knowledge [17]. Although the local population was well aware of the risks, the elderly did not want to leave their homes as it was unacceptable to die in another place. Even if a public decision-maker has sufficient facts on hazard-related issues available, one must have an agreed vision for the community to know in what direction to take action.

Understanding of knowledge appears to differ substantially in various scientific disciplines. Although similar to practical knowledge, the notion of knowledge according to the sociologist Stehr [18, p. 263] is defined as the "capacity to act (or capability of taking action), as the possibility of 'setting something in motion'. Knowledge is a model for reality. Thus, for example, social statistics are not necessarily (only) a reflection of social reality, but rather an explication of its problems; they refer to that which could be, and in this sense they confer the capability of taking action. Findings are not mere passive knowledge. Knowledge should be understood as the first step toward action; knowledge is in a position to change reality. Knowledge enriches human ability." Stehr's theory does not quite fit with the philosophical theories of Aristotle, Horrigan and Bordat, as persons generally have the "capacity to act" before they have the knowledge. Our capacity to act exists apart from the knowledge; that capacity is not a part of knowledge, but a part of us. Instead, it may be said that knowledge makes us capable of acting in a rational manner. According to Aristotle [13, 1046ᵇ20], the power to act does not imply the power to act well, whereas the power to act well implies the power to act. Knowledge thus gives a person not the power to act, but increases a person's capacity to make appropriate decisions.

Furthermore, the example by Stehr considers social statistics to not merely reflect a social reality, but much more explicate inherent social problems by referring to which action ought to be taken. Stehr therefore considers the statistics as a form of knowledge, i.e. a "model for reality" [18, p. 263]. But social statistics are not knowledge but a collection of data, i.e., information. Their significance or meaning requires an intellect, and the recognition of this meaning constitutes knowledge. This meaning can be identified with Horrigan's "knowable object"; it is potential knowledge and when it is known it becomes actual knowledge. In addition, knowledge of the meaning of statistical data of itself cannot give an "explication of its problems" or "refer to that which could be". These things require knowledge of how things should be (the ideal) or could be (the range of possibilities), for which knowledge of the essences of the things concerned are necessary (which is speculative knowledge). As an example, if one knows the essence of a certain plant, one knows what is good for it, i.e., the suitable climatic conditions, soil, nutrients etc. This can also be paraphrased in the terms used by Bordat [15] by saying that knowledge of the meaning of statistical data is the '*Verfügungswissen*' (i.e., information knowledge: the way things are), and in order to know how things should or could be, one requires '*Orientierungswissen*' (i.e., orientation knowledge). Orientation and information knowledge might correspond to Aristotle's speculative knowledge and practical knowledge, respectively.

An additional form of knowledge that is relevant to the DRR context and cannot be assigned to the specific types discussed above is that gained by experience. Such knowledge is not acquired by information received from an external source, but rather from lessons learned and one's own personal experience. To illustrate this point, one may consider an emergency relief manager, who on the one hand constantly receives and provides information. On the other hand, this person's action can be based on intuition and on previous experience, knowledge, and capacity. Polanyi [19, p. 4] describes this form of human knowledge by acknowledging "the fact that we can know more than we can tell". This represents a different kind of knowledge, a hidden, implicit or silent knowledge, called tacit knowledge [19]. It remains widely unknown how to transfer this type of knowledge and make it useful to others. Personal experiences, and the knowledge gained by such experiences, lead to behavioural changes that allow the person to act almost without reflection on what needs to be done, i.e., instinctively. This knowledge accumulation is very complex and somewhat different to the knowledge discussed previously and is typical for traditional societies where indigenous knowledge is the result of daily interaction and a long history of learning within their local environment.

The examples illustrate the need to combine understanding from multiple knowledge sources when conducting research as well as when taking decisions. Personal knowledge is related to the dilemma of individual knowledge versus the knowledge of groups of people and society, and has been subject to discussion in the past. Even though the thoughts of Hayek [10] revolved around the use of knowledge in economics, many ideas are also relevant in the DRR context. Again, one can reiterate that knowledge gained from personal experiences and unplanned circumstances can be of great value for decision-making and should therefore not be disregarded. On the contrary, every attempt should be made to gather local and thus personal knowledge born out of personal experience:

"The answer to our question will therefore largely turn on the relative importance of the different kinds of knowledge; those more likely to be at the disposal of particular individuals and those which we should with greater confidence expect to find in the possession of an authority made up of suitably chosen experts. If it is today widely assumed that the latter will be in a better position, this is because one kind of knowledge, namely scientific knowledge [research-based knowledge, i.e., knowledge produced by sciences and not knowledge of science], occupies now so prominent a place in public imagination that we tend to forget that it is not the only kind that is relevant. […] Today, it is almost heresy to suggest that scientific knowledge is not the sum of all knowledge. But a little reflection will show that there is beyond question a body of very important but unorganised knowledge which cannot possibly be called scientific in the sense of knowledge of general rules: the knowledge of the particular circumstances of time and place. It is with respect to this that practically every individual has some advantage over all others because he possesses unique information of which beneficial use might be made" [10, H8].

With this differentiated view on knowledge, the examination by White et al. [1] regarding the situation in which more is lost while more is known in the context of DRR can be better understood. Although this statement can be misleading, since 'more knowledge' implies there is more to lose, four possible explanations are explored:

(1) Knowledge continues to be flawed by areas of ignorance: on the one hand, available information can be ignored; on the other hand, ignorance of additional information can prevent the knowledge base from expanding.
(2) Knowledge is available but not used effectively within the limits of available resources, which refers to the inability or lack of capacity to implement knowledge in policy and practise. Reasons for this phenomenon are manifold and can include the lack of know-how to select the 'right' information for a specific purpose as well as the unsatisfactory transformation of existing information and knowledge into practical applications [20]. Such a view helps understanding why it is relevant to identify shortcomings, barriers and bridges related to the exchange and sharing of knowledge among and across different societal groups. Weichselgartner and Kasperson [21] related the paradox of concurrent increases in economic loss and in disaster-related research to the possibility that existing research-based knowledge is being blocked by fundamental barriers. This is in line with new international approaches to bridge that gap through 'integrated risk governance' [22].
(3) Knowledge is used effectively but takes a long time to have effect;
(4) Knowledge is used effectively in some respects but is overwhelmed by increases in vulnerability or, in different population groups, by discrepancies of wealth, poverty and other priorities where risk reduction is considered in a holistic context. Complementing these findings, scientists argued that the increase of disaster losses is less a consequence of insufficient knowledge than one of applying the knowledge effectively, as barriers to the implementation of knowledge often cause information to be disregarded or not understood by the intended users. Authors, such as Edgar et al. [23] and McNie [24], address the issue of "using existing knowledge better" [23, p. 190]. The problem of the use of existing knowledge is best explained with an example: The IPCC Fifth Assessment Report [25] contains a summary of state-of-the-art science-based knowledge on climate change and its possible impacts and adaptation needs. From the perspective of a decision-maker, to use such existing knowledge better, one has to be 1) aware of the existing knowledge; 2) be motivated to understand and make this knowledge 'one's own'; and 3) be capable of applying it effectively through practical applications given 'local' constraints.

Furthermore, the use of state-of-the-art knowledge, which is often research-based, has a significant time-lag as the findings filter through to all diverse groups of decision-makers, policy advisors and developers. Even if the information available is up-to-date, scientifically sound, credible, and salient, the information must first be accepted by the end-user and only then the possibility exists to implement it. Even if defined in policy, a major discrepancy between policy and practise is no rare occurrence for the same reason [26]. The acceptance of evidence and information is a function of values, beliefs, mentality and world views, and these are often underestimated factors. Such observations underline that better appraisal is needed of the actual results at community and other levels, applying the best available knowledge in the best possible way, as well as the need to build upon past achievements and to better integrate information and expertise into the efforts directed at risk reduction. These issues are well illustrated in the case study description related to the 2013 Salzburg flood (see chapter 5).

3. Challenges in disaster risk research

Despite increasing knowledge of the factors contributing to disaster risk, social intervention in the face of historical climate variability has not kept pace with the rapid increases in adverse economic and social effects suffered as a result of a parallel increase in vulnerability and exposure to disasters [27, p. 29]. Recent research work on DRR has revealed that science, as currently practiced, is inadequate to meet the challenges of disaster risk [28] and climate change [29]. One major deficit, for instance, is the assumption that scientific knowledge is the primary source of credible knowledge, which is still central to most literature, thus overlooking that scientific knowledge is embedded within larger systems of knowledge, power, cultural dynamics and context. The way in which that science was created, validated, or contested as a knowledge claim is rarely questioned and the normative goals and values that are ascribed to DRR- and CCA-related concepts are seldom made explicit [30,31]. More trans-disciplinary research and decision-support experiments are required when tackling questions of DRR and a need to apply different modes of knowledge production. Current debates on environmental and risk assessments recognise insufficiencies in public participation [32] and research results demonstrate that power is intimately involved in mediating the influence of the policy approach, in both positive (enabling) and negative (constraining) ways [33]. Recent studies suggest embracing the "epistemological pluralism" and overcoming "narrow interdisciplinarity", for instance by improving the quality of communication and applying a mixed-methods approach [34–36].

In mainstream hazard research, institutional and constitutional constraints are still too often ignored; social resilience and adaptive capacities are infrequently investigated and risk education as specific strategies of social capacity building is seldom highlighted [37]. Deficits also exist with regard to practical applications of conceptual thinking in vulnerability assessment, operational methodologies relevant for and applicable by practitioners, concrete measures that address the systemic underlying causes of vulnerability, and assessing the substantial costs of implementing vulnerability reduction strategies [38]. Existent scientific results and assessments of risks are frequently not used because they have been defined and framed to meet the needs of science rather than the needs of those making decisions including those addressing the immediate needs of the most vulnerable. Various studies point to different institutional settings and standards, differing cultural values, divergent understanding, lack of resources, and mistrust numbered amongst critical factors hindering efficient transfer of knowledge into action [38–41].

Moreover, present institutional structures are often proving unable to address or clearly communicate issues related to the current complex challenges of climate change. Climate science-society relationships are often much less linear and predictable than some actors involved tend to assume [42]. While there is a high degree of scientisation of the climate debate and politicisation of climate science, the role and actual significance of scientific knowledge in decision-making is not sufficiently understood yet and certainly not by many civil society actors where uncertainty prevails. More efforts are required to integrate perception and social-cultural meanings of climate change and to convert these research findings into understandable, targeted and concrete actions in practical mitigation and adaptation measures [34,43].

Deficits exist with regard to the mitigation of both low probability and extreme events [17]. Possible chain and potential cascading effects are seldom considered in the hazard assessment and thus, absent in risk planning and prevention. In particular, lack of experience and disaster memory result in a lack of a local prevention culture based on existing scientific, social and technical knowledge. Equally, scientific knowledge has been criticised for a lack of appreciation of local experience and disaster memory. For example, scientists barely contribute to activities taking place during the response phase after the hazard event and, in many cases, research on the issues of vulnerability, mitigation behaviour, and risk communication is not ranking high on their priority list. Frequently, research findings and the arguments of science for DRR do not find their way to key decision-makers. While scientists face difficulties in identifying the adequate responsibilities and legal mandates in the public sector, the practitioners lack the resources to acquire high quality and resolution data. Available scientific data is often only partly relevant or useful, of poor quality, not adjusted to the needs of decision-makers (e.g., regarding scale and resolution), or scattered among many sources. Overall, the fact that scientists regularly disregard local knowledge while local actors pay little attention to scientific data is in part due to the lack of a shared risk culture and poor exchange and communication between different actors. Such a gap in understanding of priorities is a fundamental constraint in addressing DRR in a locally social and economically viable manner.

Various barriers and bridges hinder and enhance the connectivity between DRR- and CCA-related science, policy, and

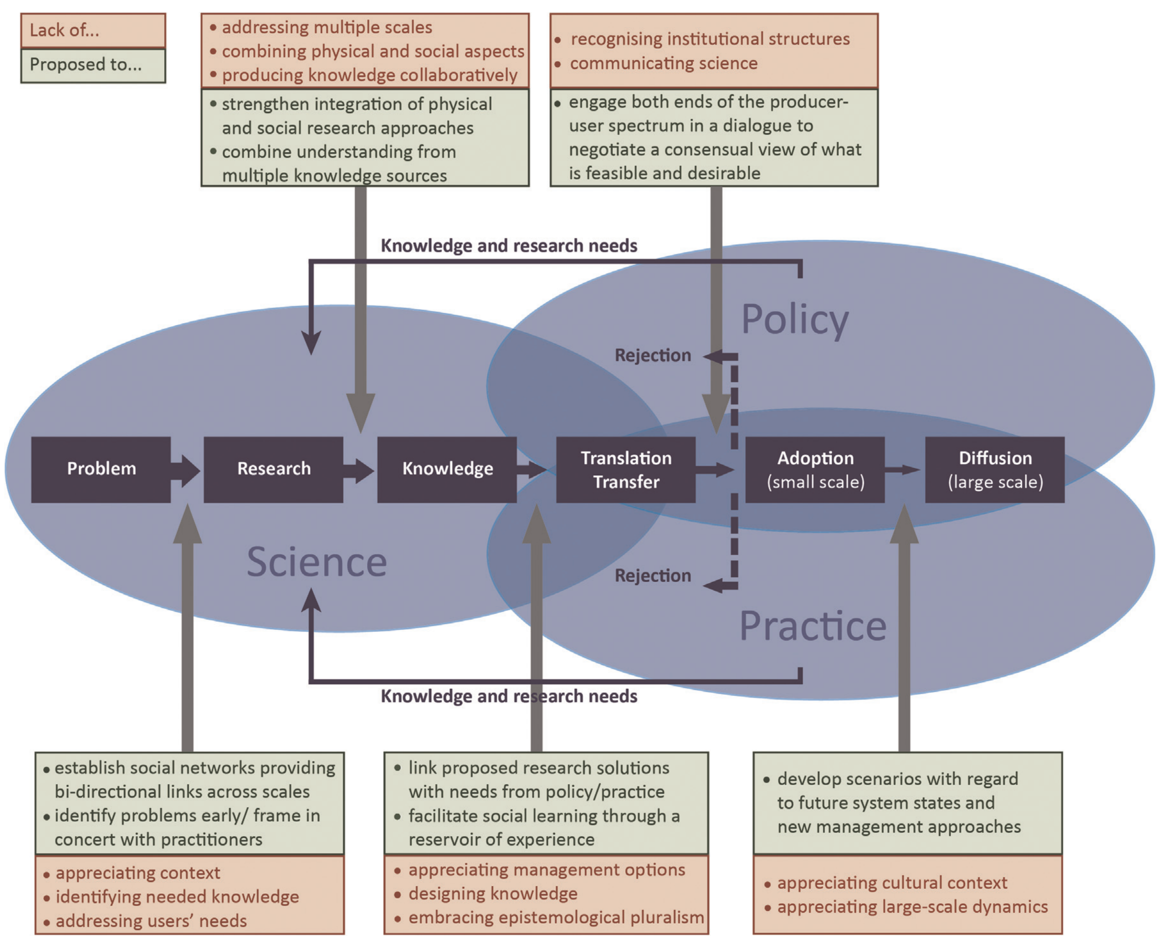

Fig. 1. Pitfalls of and propositions for research to increase effectiveness. Pitfalls (in red) that typically occur when knowledge is designed in academic isolation and transferred through the traditional pipeline mode (blue boxes), that is scientists set the research agenda, do the research, and then transfer the results to potential users, assuming that they diffuse automatically through the policy and practise communities. Proposed ways (in green) to enhance effectiveness of research-based knowledge would result in more socially robust and context-sensitive knowledge within the framework of knowledge-brokering, where the research and knowledge needs of end-users are explicitly expressed. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: Adapted from 36, p. 327].

practise (Fig. 1). More effective mechanisms are required to enhance collaboration and partnerships between research, policy-making, and the public [16]. It is assumed that such mechanisms have greatest success when (at least) the two-way flow of information or "inreach" and "outreach" is involved, where cross-sectoral integration of different kinds of knowledge is enabled, and mutual learning among different societal actors is emphasised.

Strategies are needed that are capable of integrating the systemic and multi-scale features of DRR and the related decision-making processes into a holistic concept. Regarding the science domain, two issues especially require attention: the achievement of scientific consensus on the output of scientific research, and the assessment and communication of uncertainty. Concerning the policy domain, attention should be paid to vulnerability, risk- and climate-related issues, as well as to the governance structures of decisions. Both domains should enhance their efforts by providing arenas where knowledge can be shared and jointly discussed, thus transforming their boundaries into lively interfaces among scientists of different disciplines and stakeholders of all different groups that promotes feedback and communication verification.

4. Identifying barriers to knowledge production, sharing, and implementation

A methodology for analysing fragmentation of knowledge has been developed by the authors. Two instruments are combined in a systematic way to identify barriers and bridges of knowledge production, sharing and implementation. The first instrument is the data-information-knowledge-wisdom (DIKW) framework, i.e., the knowledge accumulation process. It is both difficult and decisive to distinguish between data, information, knowledge, and, ultimately, wisdom. Understanding the relationship between these is the key for identifying and understanding barriers and bridges of knowledge production and transfer [44]. This knowledge production process is illustrated by the DIKW web (Fig. 2). The DIKW framework was initially illustrated by Ackoff [45] as a pyramid in the field of systems analysis oriented toward business applications. Since then, it was revisited by several authors who suggested different ways of interpreting and using it [46,47]. These

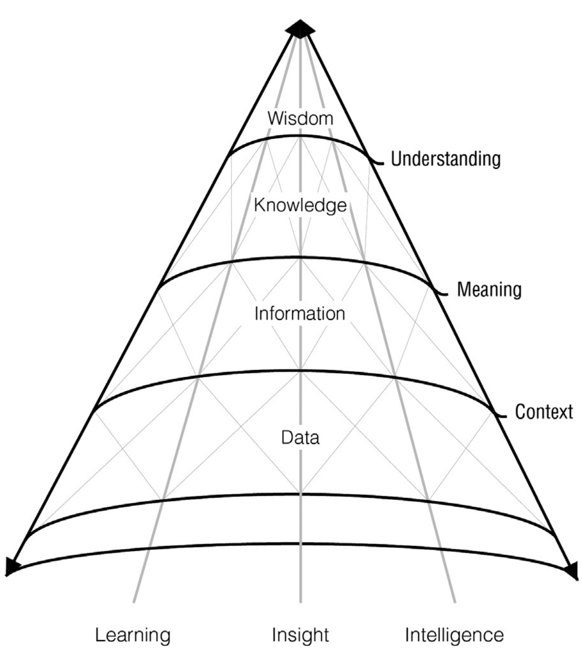

Fig. 2. The DIKW web.

authors understood that there must be several feedback loops in the data-information-knowledge pyramid. For example, the ability to select relevant information from an excessive quantity of available information demands orientation knowledge (the aims and purposes must be known). Furthermore, Jennex [47] recognises that while data and information are clearly the bricks of knowledge, productive knowledge is needed to produce data and information in the first place. In this way, knowledge production becomes more cyclical than linear.

Concerning the DIKW framework, a few issues require further discussion as the geometric form of a pyramid (linear rather than cyclical) may be misleading. For this reason, Fig. 2 illustrates the framework as a web with interweaving bi-directional threads so as to show that data, information and knowledge are intertwined more closely than a pyramid can illustrate. In accordance with perception and context, data is collected to improve understanding of a certain reality. Knowing the context in which data is collected and transformed into information (contextualised, categorised, calculated, connected and/or condensed) is highly significant [46]: why is this data collected? Is sufficient understanding and knowledge of the methodology for data acquisition available (feedback loops between knowledge and data)? For what purpose is the data being prepared as information (understanding the use of the data and information)? This requires the data analyst to not only have a profound understanding of the data itself (including the limitations), but to be aware of the wider system – i.e., the DRR methods and objectives. The meaning of the information is a second issue that must be understood by the person being informed prior to it becoming actual knowledge. Without understanding what the information is attempting to convey, including the context the information was produced in, the user may not fully receive the information in the intended way, i.e., the act of cognition would be imperfect. Only in full understanding of the knowledge gained can well-reasoned, informed decisions be made, taking into account possible long-term consequences.

Three further aspects are essentially connected to all elements within the DIKW web. Insight is an important factor when acquiring and applying data, information and knowledge in the decision-making process. This again requires a profound understanding of the processes being considered in the context of the problem at hand and apprehending the true nature of the knowledge being used. A further common attribute and essential criterion linking each instance of the DIKW web, which is required to ensure the transfer from one state to the next, is the use of intellect. Although this may appear to be a vague statement, intelligence is necessary in order to acquire data in a correct and accurate manner using state-of-the-art means, as well as producing information in consideration of the context. Again, the intended meaning of the information may only be received using intelligence. As an example, information provided to reduce the level of future flood losses needs to be understood with reference to this intention, rather than the intention to reduce potential damage caused by landslides. The third element depicted in Fig. 2 is learning, which extends all the way through the spider web. Throughout the knowledge production process, learning is intricately associated to each step and may impact the procurement of data, information and knowledge through feedback loops as understanding increases with time. The spines of the web can also be seen as feedback loops returning back from knowledge to data, which are intended to depict the necessity to take experience returns into account while addressing limitations of DRR. In full awareness of the meaning of information, informed, insightful decisions may be made, based on the knowledge gained and the proper use of intellect. When decisions are made in this way, one may refer to them as wise decisions, i.e., decisions that produce good results (useful or beneficial, positive in nature).

Correct understanding of context and meaning, sufficient insight, as well as proper use of the intellect and the capacity to learn, are all uncertain factors within the DIKW-web and inherent to the decision-making process. Incorrect understanding, lack of insight, and improper use of intellect may lead to human error and unwise decisions. For this reason, Eiser et al. [9, p. 6], based on the report from the International Council for Science [48], underlined the “need for a better understanding of human decision-making in the face of risk as a priority for disaster risk reduction” as “disasters cannot be properly understood, or indeed prevented, without attention to the critical role of human agency and societal processes”. This statement shows that DRR cannot be separated from human capital development since these processes are interdependent and must be given equal priority. The institutions of science and education are especially involved in this process. Often the incentives for researchers need to be adjusted to include the development of young scientists as well as policy-relevant research, not simply the quantity of research output.

The second instrument is the disaster management continuum (DMC). At each stage of the DMC, various stakeholders interact to produce data, information, and knowledge, and make decisions based on what, variously, is known (evidence-based), or with little or no consideration thereof (non-fact-based). The information produced and the decisions taken during one phase in the DMC often influence one or more of the following stages of the DMC. Both the IPCC-SREX [27] and the strategic goals of the UNISDR Hyogo Framework for Action (HFA) [49] stress the importance of community involvement, use of local capacities and resources, and multiple stakeholder involvement in decision-making in order to improve understanding of disaster risk and planning risk reduction measures. The DMC can also be used to facilitate the process of identifying the stakeholders and existing issues of fragmentation. This can be done by asking the following questions: Who produces what? Is the data/information/knowledge shared? How is it shared? Who actually knows what is needed to know in order to make appropriate decisions, and for whom? And does the knowledge produced actually lead to DRR? If not, why not?

The DMC is an important tool for evaluating decision-making, because barriers in risk governance may lead to knowledge fragmentation and therefore hinder DRR. By using the DMC to assess a specific case study, both bridges supporting and barriers hindering the use of knowledge for decision-making, can be evaluated. The DMC cannot be viewed without consideration of former events, previous policy limitations, and contextual processes and dynamics before the inception of any specific disaster cycle. If done so, contestations against disaster prevention policies may be fuelled. In this way, the DMC may be viewed as an open loop or a continuum, which also considers improvements of disaster risk management and the impact of CCA. Thus always greater time periods separate disaster events, the ideal being to break away from the traditional cycle, which would represent a case where mitigation measures (both prevention and preparedness) adequately deal with the hazards. The cyclic concept of disaster risk has led to the development of the notion of a ‘disaster risk continuum’, taking into consideration the fact that risk is constantly evolving and changing, requiring an equally constant adaptation process to risk (Fig. 3).

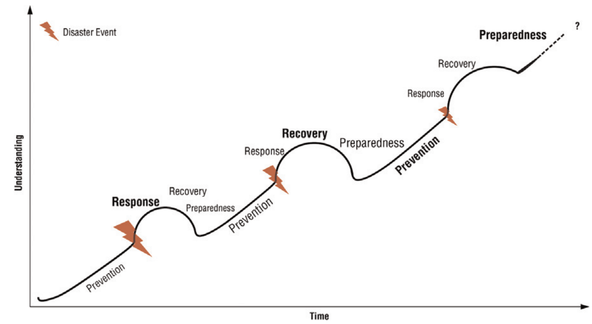

Fig. 3. Disaster Risk Reduction Continuum. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

In a first step, stakeholders and their competences involved at each stage of the DMC are mapped, according to four groups: scientists, public sector (decision-makers in policy and practise), private sector and civil society. The organisational structure can be complex and the actual responsibilities of the various entities and bodies associated with disaster risk management (DRM) can only be separated with much difficulty. All the more so, when CCA is differentiated institutionally from DRR, even though synergies in practise exist. The stakeholders often differ depending on the type of hazard. Multiple entities are involved with similar activities, often at different scales and levels, spatial settings or areas of specialisation. For instance, in Austria, within the public sector alone, four federal ministries share competences with the provinces and the local municipalities. The aim is to decipher who is responsible for what and how the tasks are co-ordinated between the various entities. The exact delineation of the management stages is not as crucial as the understanding of who is responsible for what. To do so, information related to disaster management in a given case study must be generated by interviewing relevant experts and stakeholders as well as conducting a comprehensive literature review, which includes newspaper articles and online news outlets. The results are classified according to who (stakeholders) does/did what before, during, and after a specific disaster event. In a second step, these experience reports are analysed using the Disaster-Knowledge Matrix (DKM) to identify barriers and bridges in knowledge production and use with regard to the four stakeholder groups.

Information pertaining to the respective management stages of the DMC is produced using different data and information as input, and various methodologies. The resulting information and knowledge gained during a certain phase provides a basis for decisions to be taken by the respective decision-makers and stakeholders. The decision-makers often differ depending on the hazard, the DMC phase and scale. Furthermore, adaptation to climate change is primarily integrated within, but not limited to, the prevention and mitigation phase (e.g., incorporating climate change scenarios in hazard assessments or vulnerability reduction measures), as well as the opportunity for adaptation measures during the recovery phase.

The implementation of knowledge within the disaster risk management continuum is analysed using the DKM with the phases of the DMC on the x-axis and the knowledge production flow, stemming from the DIKW web, on the y-axis (Fig. 4), thus combining the two tools described. The matrix illustrates how the experience reports can be systematically analysed, and includes the various stakeholders as a third dimension. The DKM can be used as an instrument to identify bridges and barriers of information and knowledge production and transfer. Each ‘box’ of the matrix can be assessed individually as well as the relationship between the boxes. As one particular stakeholder may be responsible for generating and providing information, another for transferring that information to other relevant stakeholders, information may be lost. The grey bars indicate this fragmentation of information and knowledge. The thin red arrows indicate the flow of information and knowledge and potential impact of decisions (e.g., the ‘knowledge output’ of the prevention and mitigation planning prior to the last event may be a flood risk map, which can form the basis for preparedness planning). Feedback loops of knowledge into the generation of data and information (as

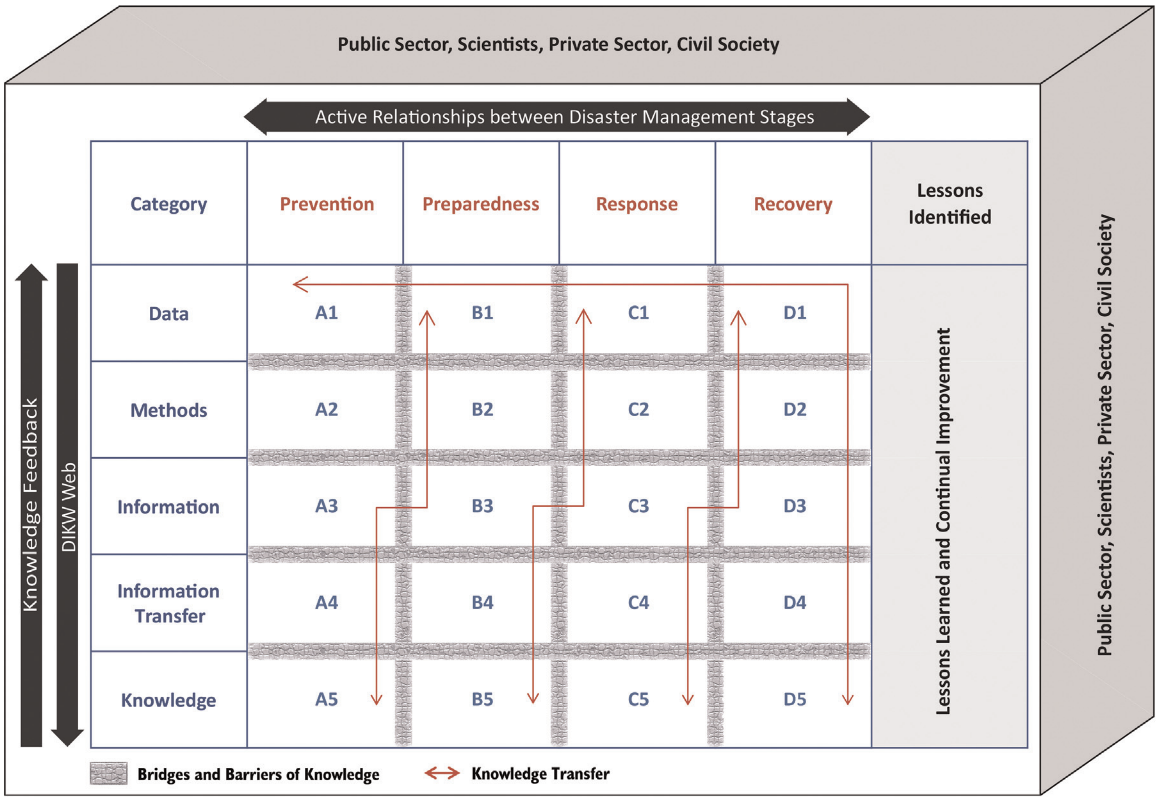

Fig. 4. Disaster-Knowledge-Matrix (DKM). (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

previously discussed) are symbolised by the vertical arrow; relationships between the disaster management stages by the horizontal arrow (Fig. 4).

The DKM is a simple schematic representation of knowledge production and sharing in DRR and due to its linear and static form cannot fully consider the complexities of real-world situations. However, the DKM facilitates the identification of the most significant aspects in dependence on the disaster event being assessed and helps to explain the gaps experienced as it recognises both DRM and knowledge production as social processes. The DKM structure integrates two basic and complementary approaches of the issue, in line with what can be learnt from international literature. This leads to the question of how to identify key influential factors that hinder the co-production of knowledge.

In order to identify the presence or absence of fragmentation of knowledge and its causes, knowledge gaps, shortcomings and barriers are categorised and summarised according to their social, functional, and structural nature [20]. Functional barriers, often related to resource issues (temporal and monetary), include divergent objectives, needs, scope, priorities, and lack of co-operation and co-ordination. Structural barriers include different institutional settings and standards that restrict the collaborative production and transfer of knowledge across boundaries. Social barriers include factors such as cultural values, communication, understanding, and mistrust. Bridges between boundaries can be categorised in the same way: functional, structural/institutional, and social. When the objectives, needs, and priorities of researchers and decision-makers are similar and well-co-ordinated, functional bridges are given. An example for a structural bridge is an institution that facilitates knowledge relationships between science, policy, and practise through partnerships, co-production of knowledge with stakeholders, and a wide range of incentives for researchers that include policy-relevance and human capital development. Social bridges include successful interdisciplinary work, cultural understanding, international communicative capabilities, and transparency regarding personal agendas in order to manifest trust. Based on the information provided, it is also possible to pinpoint knowledge gaps, where additional knowledge may have helped to improve procedures and to reduce disaster risk.

For a given case study, the DKM is designed to: a) identify who the stakeholders are; b) understand where and why fragmentation issues exist; and c) determine whether or not DRR is a successful process according to the type of risk(s) initially targeted. The hypothesis is that by completing the DKM, patterns will highlight what level of the knowledge web was reached. The DKM is only a model and does not reflect reality in its complex entirety. As Mittelstrass [11, p. 23] recognises, there are no “simple and straight paths between information, knowledge and wisdom. Whoever does not recognise this will lose knowledge and end up not with wisdom, but in a new, and dangerous, form of stupidity”. The knowledge system within the DMC is much more dynamic and complex than merely the two dimensions of knowledge on the one side, and disaster management on the other. Additional dimensions include the spatial and temporal scales and the level of decision-making. When completing the DKM, these additional dimensions need to be considered. The output from a certain stage of the DMC, e.g., risk maps prepared for preparation planning, can be strongly challenged by influential stakeholders, which may lead to a rejection of the assessment rather than its application and implementation – again demonstrating feedback loops. Usually, there is a need or request for information; it is not automatically transferred, so two-way communication is apparent.

5. Case studies

5.1. Flood event in Salzach River, Austria

High levels of precipitation and antecedent soil moisture in the Salzach catchment produced a flood discharge with a return period of about 100 years at the downstream reaches of the Salzach in June 2013 [50]. The Salzburg City water gauge station measured 8.51 m, 15 cm higher than catastrophic floods in 2002, which resulted in damage of an estimated three billion Euros for Austria [51]. Since then, national and regional authorities have invested in disaster mitigation have been implemented by national and regional authorities. These measures significantly reduced damages along the Salzach during the flood event in 2013. Furthermore, the hazard zone maps have been updated using state-of-the-art methodologies for all large waters of the province of Salzburg. These activities are an example of successful DRM, but improvements are still needed, particularly regarding communication between various stakeholders and actors in the entire disaster management continuum. The transfer of information from and between the hydrological agencies, weather forecast services, towards the media and responders was often unsatisfactory, misleading, or interpreted incorrectly [16]. A thorough analysis of media reports, supplemented by interviews with responsible decision-makers, and results from a local stakeholder workshop form the basis for the DKM analysis. The objective is to analyse knowledge fragmentation during the flood event in order to improve co-ordination and communication. The coloured boxes highlight where knowledge fragmentation occurred and reflects the reason for it, i.e., whether the barriers of knowledge production, transfer and implementation were of social, functional and/or structural nature.

Although a post-disaster evaluation of the Salzach flood event in the province of Salzburg shows that there were far more achievements than flaws, particularly compared to the flood in 2002, knowledge fragmentation did occur in 2013. An evaluation enables lessons to be learned and the knowledge acquired to be included in future disaster risk management strategies. The assessment demonstrates that the interaction between local administrators and authorities and research institutions is often very difficult and viewed with caution (see cell A2 in Fig. 5). Finding ways for greater collaboration and integrating results from research projects where possible could lead to improved management and transparency.

A problem associated with the media and public and related to methods during the early-warning stage, B2, is that the expectations towards what meteorologists can deliver have increased drastically. Highly accurate flood forecasts are now expected two days in advance. Due to the nature of the rainfall phenomenon causing the floods, i.e., the spatial variations of rainfall outbursts, it was only possible to provide accurate forecasts immediately prior to the incident, or even as it was happening. The reason for this lies in the model itself and the limitations of technical capabilities to accurately forecast the spatial variations of rainfall and consequently the flash floods in the different catchments, rather than in the communication between meteorologists and hydrologists [52,53].

The main shortcoming of the 2013 flood was one of communication. The information related to the early warning of floods, based on current rainfall forecasts by the meteorological service, issued by the hydrological service was passed on to the media on Friday afternoon, but only used on Saturday morning for the news reports, although information updates were being transmitted hourly all through the night since the accuracy of the information

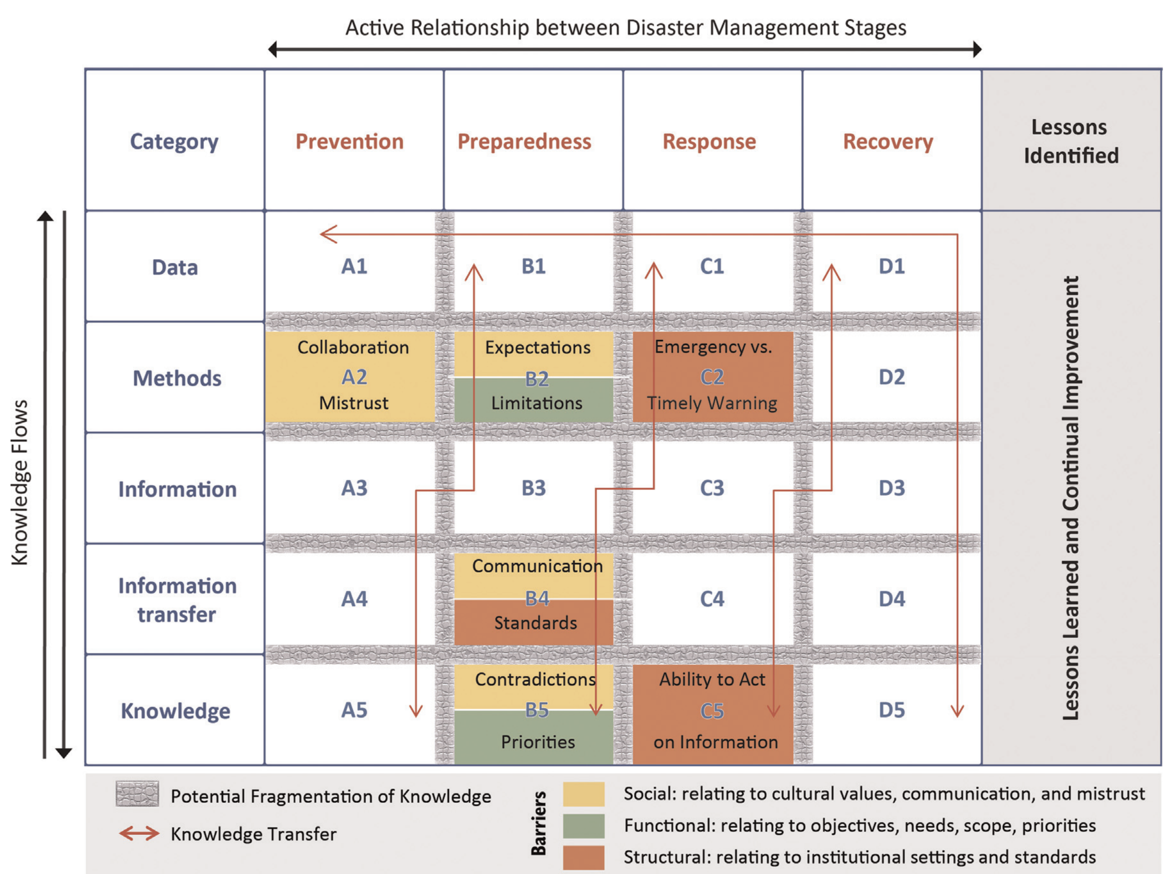

Fig. 5. DKM analysis for the 2013 flood in Salzburg. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

generated by rainfall forecasts and the hydrological models increased with time. Furthermore, the hydrological service communicated a much more severe event on late Saturday afternoon. The media, however, delayed the transfer of this information to the public until Sunday morning. A communication problem that did exist was thus with the media (B4). The meteorological service uses traffic-light symbols based on international standards of the National Weather Service (NWS) to communicate risk of extreme weather. The orange level had already been communicated. During consultancies with the hydrologist, the prospect of a 100-year event, i.e., red alert, was considered but then dismissed. Based on the media reports alone, there is no reason to think that the communication between meteorological and hydrological services was inadequate. However, a close scrutiny shows that the message was clearly misinterpreted. In some parts of the Province of Salzburg (e.g., Saalachtal), the fire brigade was also not actively preparing for a large-scale event on Saturday, despite the early warning they had received. The fire brigade is used to responding to immediate emergencies rather than preparing in advance based on 48-h warnings, which reflects a lack of guidance for decision-making.

Media training is given to meteorologists of the meteorological service, which occurs within the framework of general training where a media expert attends. According to the meteorological service, it very much depends on the journalist whether or not the information provided is transferred successfully. If the journalist knows from his/her own personal experience how the predicted event will likely impact the given social environment, he/she can more readily understand the meaning of the information. These points all portray a general lack of standards. A further issue is that the media aims to sell news and can therefore be polemic. In this case, three statements were cut (one or two sentences taken from each statement), causing disorientation so that it looked like each speaker was contradicting the other (B5). By undermining the importance of the information provided and focusing on individual priorities, appropriate preparation for the flood is inhibited and can lead to inaction by persons at risk. Related to the response by the provincial emergency centre during the flood event is the issue that no tangible plan is in place which guides decision-making in function of the information received (C2). Furthermore, emergency response teams are not trained to deal with information (such as the return period of a flood, which is often not a useful piece of information during an emergency event) provided well in advance (C4). They are trained to respond immediately to emergencies that are occurring in the present.

From this, one concludes that the information sent out by state authorities and meteorological agencies included model uncertainties and was changing in time, so that it was difficult for the media to interpret the information correctly, which lead in this particular case to an underestimation of the risk associated with the flood. The public media did not always use the early-warning information about flood risk in a consistent manner and there were delays in transmission of up to date weather information that media had received. This generated confusion amongst civil society who in many instances took no measures to prepare for the event and potentially reduce damage. Interestingly, there were inadequate mechanisms to control if information sent out was received and acted on by the target groups. Positively, however, there was considerable learning after the event, and this indicates that the systems and organisations both learned from the experience and determined to introduce improvements. This case shows that a detailed evaluation, on the basis of the DKM, can support the identification of knowledge fragmentation and facilitates the design of improved risk management. Based on this analysis, appropriate measures can be developed in order to avoid similar effects of knowledge fragmentation in future. Since the major barriers were of functional and social nature, a stakeholder workshop was organised together with key decision-makers in practise to discuss achievements and challenges of the 2013 flood event in Salzburg. Although many of the stakeholders invited relate to one another in a functional manner, but strong relationships are often lacking. By improving relationships and trust among the stakeholder groups, an environment that allows for improved DRR is established and will contribute to overcoming the many social and functional obstacles identified using the DKM. Additionally, improvements in early-warning procedures are currently being made and include the establishment of a single communication channel between the local authorities in charge of forecasting events and the media to avoid disorientation and conflicting messages in the future.

5.2. Relocation of landslide survivors in Chiapas State, Mexico

The second case study we present is that of the rural town of Juan de Grijalva, located in the municipality of Ostuacán, Chiapas (Mexico). In November 2007, a landslide slipped into the Grijalva River, which subsequently flooded and destroyed the homes of the people of Juan del Grijalva. 25 people were killed in the small community of 217 inhabitants. In addition, people from 11 other settlements were evacuated to the town of Ostuacán. This emergency served as an argument for the relocation that was subsequently developed based on the Sustainable Rural Cities (SRC) model. The SRC programme simultaneously addresses risk management, the management of rural areas, the population density needed to combat dispersion (related systematically to marginalisation), and the integration of rural producers into regional and national markets. SRC Nuevo Juan de Grijalva was built in 2008 on land halfway between its previous location and Ostuacán and inaugurated in 2009. The new settlement consists of more than 410 houses, and its population includes people from 11 previously dispersed communities.

Discrepancies between policy and its implementation reveal barriers between information and knowledge sharing among actors involved in the decision-making process: public institutions, the private sector, NGOs, and the relocated residents. Policies were implemented without adequately consulting those affected, i.e., a lack of participation in decision-making resulted in significant consequences during the post-disaster relocation.

The location of the settlement has a rugged topography and does not meet planning criteria, it does not guarantee the optimum potential for construction of the thousand houses that were initially planned, and of which only 410 were built on 300 m² lots with constructions of 60 m² each. The relocated families quickly identified the disadvantages of the location: strong winds, risk of erosion and landslides, and little commercial movement. Beneficiaries were given titles with a clause stipulating that they cannot sell the house for at least 25 years, to prevent them from returning to their previous settlements.

The architects who designed the project two years after the event only had 48 h to develop the plans. Since the disaster, affected people were living in temporary shelters. These distressed families were moved into the new houses built in a new town, an urban environment for rural dwellers. The design had neither considered the work needs, family lifestyle, nor the size of the families, and thus modifications were immediately required. From the beginning, the inhabitants showed discontent with the design and materials of the houses. Many homes had leaks and floods because the main construction materials had not received a waterproofed finish. The kitchens, originally located on the sides of the houses, were not accepted and most people have moved their kitchens to what was originally the patio. The kitchen is not only a place for preparing food but also the family gathering area; in that sense, setting it to the side was impractical for family culture dynamics. In the original proposal of the SRC, kitchens sought to reduce power consumption, thus stoves were installed which make use of wood for fireplace thermal efficiency and for avoiding smoke inhalation. However, these proved to be unattractive to villagers. The reason for this is not in the design of the stoves but in their spatial arrangement in the house. Moreover, timber resources are further away. Currently, people have to walk 10–15 km to collect firewood, or else pay for it. Another related aspect is the dissatisfaction with the dimensions of the housing. People were accustomed to modest but spacious buildings with larger outdoor spaces. The size of the rooms, which are designed for beds, does not allow for the traditional use of hammocks. This ends up producing overcrowding, or else changing of the use of some spaces.

Unable to grow enough in the plots of their new homes, people expressed the need to return to work their previous land or migrate to larger cities with more opportunities. This resulted in additional payments for public transport, a considerable number of hours per week in travel, and the repopulation of the area at risk. Far from work and livelihood opportunities, some of the families returned to their previous home location or used both places: the old location to work their lands and the resettlement to live. The objective of the relocation programme, i.e., the resettlement and integration of landslide-affected families in Nuevo Juan de Grijalva, was not met, since the settlers occupied the new homes while maintaining some presence in the high-risk area of the former settlement. The abandonment of the ancient settlement would represent losing a reliable source of income, based on subsistence agricultural activities in which they have an established domain, compared to the SRC production projects, which are subject to the regional market, lack of skills and unreliable subsidies.

Using the DKM to map the *Chiapas State*, *Mexico* case study highlighted serious failures to consult with the prime stakeholders about their needs. Importantly, it highlights a common occurrence, i.e., divergence amongst different stakeholder group priorities and agendas (e.g., political and financial) when determining what form of risk reduction action should be taken. By adjusting the perspective of the DKM, Fig. 6 addresses the stakeholder interaction to showcase the information flows during various disaster management phases in order to identify the reasons for difficulties faced. In contrast to the Salzburg case study, the analysis in Chiapas State focuses on how information/knowledge/wisdom was used and applied according to the stakeholders involved in the disaster process and not necessarily in the best interests of the most vulnerable. Thus, greater detail is given to the context of decision-making by individuals, groups, and organisations, which enables a complex problem to be broken down to a level at which stakeholder-specific intervention measures can be designed to strengthen the use of knowledge for decision-making in policy and practise. In effect, the decisions and actions taken by authorities, planners, and investors changed the nature of support to the primary stakeholders, i.e., the inhabitants, and in effect by shifting family vulnerability away from the previous risks of floods and landslides, created new forms of social and economic vulnerability which caused even more losses to the disaster-affected people.

So the question arises as to how discrepancies between political priorities and policy implementation, juxtaposed with the needs of families affected by the landslide disaster, can be understood. Policy implementation limitations reveal barriers between information and knowledge among involved actors and particularly poor citizen consultation and participation in the decision-making process. As a result of the temporary relocation of affected families to Ostuacán while the new settlement was being

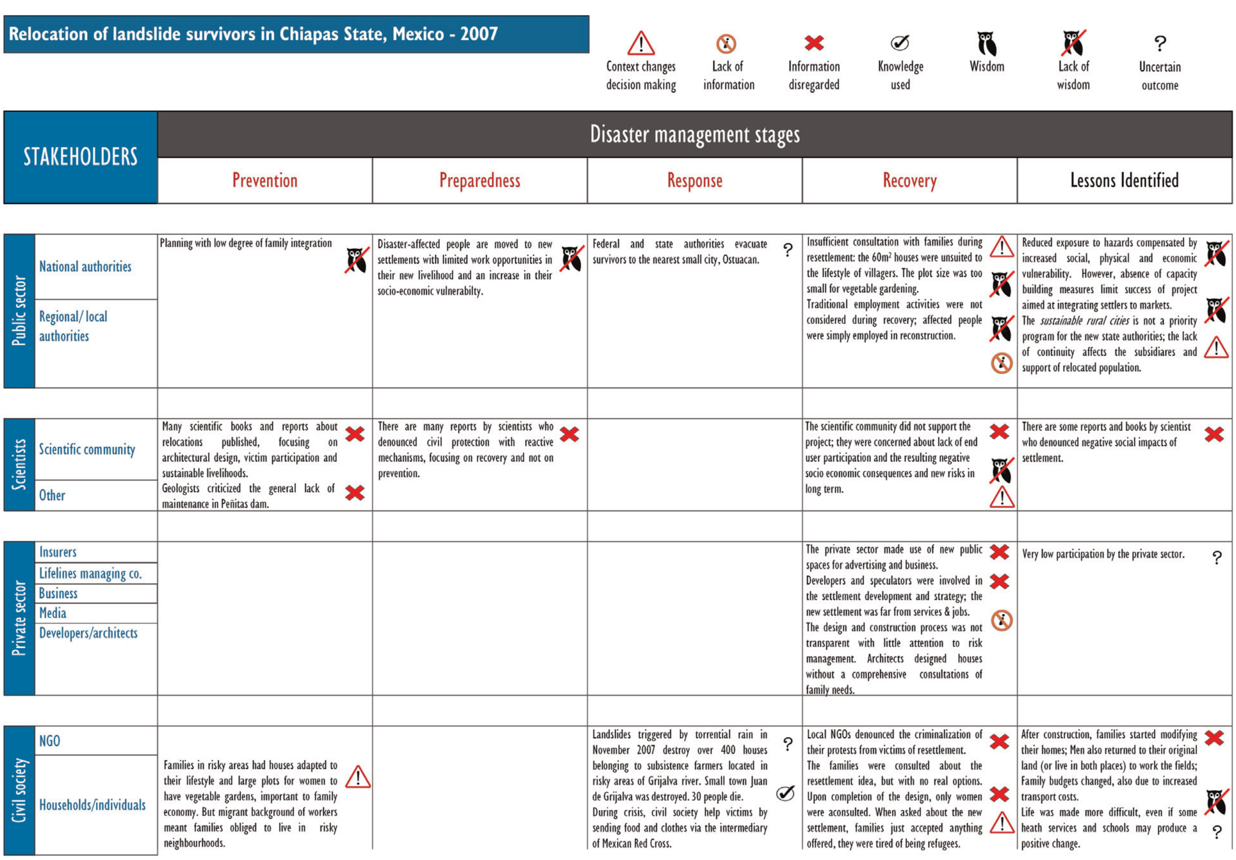

Fig. 6. Information flows in the Chiapas State case. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

developed, the people were excluded from the decision-making process. The population was very briefly consulted for some of the decisions regarding the new settlement, but those decisions were carried out in the context of family fatigue related to their refugee status. For example, the choice of the new settlement was – only in the official discourse – the "product of negotiations" between the victims and the state government, which bought the land with federal funds. Because of time pressure arising from the temporary dwelling of the families in Ostuacán, the decision resulted in an improvised and questionable choice. The housing design and allocation processes integrated the participation of the families only to a limited extent, including people who had remained two years in temporary shelters. The relocations were executed as 'shared actions' between the people and the different levels of government, however many aspects of the project were decided beforehand by the lobbying of groups with different private and public interests. The limited citizen participatory process was a way to legitimatise the relocation, otherwise what was actually a political outcome. The red crosses in Fig. 6 indicate a failure to communicate adequately with the prime concerned social group, the disaster-affected people. The case highlights the transfer of risk from the original vulnerability to floods and landslide, to a new form of social and economic vulnerability. The case also illustrates non-participatory 'assistance', giving rise to the exclusion of disaster-affected people.

6. Conclusion

The nature of knowledge-action is such that informed decisions can only be made with an intelligent use of available information and pre-existing knowledge. This requires a constant learning process, which necessitates an effective application of one's mind in order to understand context-specific information and utilise it. The capacity to learn is dependant on sufficient training and previous learning, as well as an awareness of current problems and the availability of accessible, relevant information. The transfer of knowledge is thus also a function of the individual capacity to gain knowledge, i.e., to learn, and therefore contains procedural, technical and cultural components that all need to be considered. The implementation of knowledge, including decision-making, is dependent on available instruments and the ability to design risk-reducing means that are knowledge-based, i.e., the capacity to utilise knowledge gained. To achieve knowledge implementation requires target-specific provision of information and incentives for individuals to acquire the knowledge needed to make well-reasoned, evidence-based decisions. Accordingly, knowledge adaptation, i.e. the adjustment of knowledge provision according to user needs, is an aspect that needs to be integrated into the design of knowledge management systems.

Although knowledge is steadily increasing, in the sense that expert and research-based understanding of how to reduce disaster risk has strongly advanced, it is–particularly due to its social nature – not immediately available to all. The problem related to knowledge is, therefore, that it is often stored away and difficult to access. Knowledge is most commonly lost or fragmented due to a lack of co-ordination, partnership, good and traceable communication, and sharing of the known. For this reason, decision-makers and all stakeholders involved in DRR need to reflect on their own capacity to make informed decisions and, in realisation of individual limitations, seek the lacking information, e.g., drawing on advice from experts, when essentially necessary. By turning to a colleague or trusting information from an external source, decision makers enter into a learning process, and will more readily be capable of gaining knowledge, which one was previously unaware of. Increasing incentives and possibilities for decision-makers to gain knowledge in order to improve decision-making is therefore imperative.

The (research) gap between knowledge of risk, its interpretation and action [8] allows us to re-confirm that a lack of knowledge is not the key challenge. The issue related to increasing disaster losses lies much more with risk interpretation and understanding, mentalities across scales, power structures, personal attitudes, values, world views and budget constraints. Greater emphasis needs to be attributed to the qualities of saliency, credibility and legitimacy in the science-policy interface. These are after all prerequisites for acceptance of knowledge. It appears that the focus on 'the knowledge gap' can legitimately be questioned. This is also the conclusion, which stems from our findings: social, structural and functional barriers in knowledge sharing and implementation are currently greater than the capabilities to overcome them, hindering an effective reduction of disaster risk. Available risk-related knowledge is not the problem of ineffective disaster risk management, but lack of knowledge on how to overcome barriers to implement the knowledge certainly is. One key barrier is thus the lack of resources to apply knowledge in practise and a lack of incentives for decision-makers in policy and practise to continue gaining knowledge for improved, evidence-based decision-making.

Furthermore, the many facets of knowledge are seldom comprehended or distinguished in the context of DRR. This leads to an increased ignorance, as well as a lack of appreciation and utilisation of important sources of information and knowledge aimed at effectively reducing risk. By reframing this problem of knowledge, in which more is lost while more is known, the focus is once more drawn towards improving understanding of the knowledge production cycle and to identify barriers in an analytical manner in order to deconstruct obstacles that are systematically leading to a fragmented use of knowledge. By integrating knowledge production processes into the disaster management continuum, barriers and gaps of knowledge action are identified and subsequently combated by designing appropriate, stakeholder-specific measures.

Following the generic discussion on current gaps and deficits in DRR, we suggest means by which research can ensure increased application and effectiveness of available information and knowledge. The way forward is a more socially robust and context-sensitive knowledge production, with the integration of (a) local knowledge, in the sense that tacit and practical knowledge based on local experience is understood, but also includes an understanding of local priorities and perceptions as well as a factual depiction of user needs, (b) provision of improved, target-oriented methods of communication, and (c) trans-disciplinary approaches to research.

To improve DRR, knowledge uptake by all stakeholders involved needs to be increased so that informed decision-making can take place. Overcoming barriers to knowledge implementation is considered to be a means to reduce the so-called knowledge gap in DRR. The DKM introduced offers an analytical tool to illuminate the causes of knowledge fragmentation and the possibilities to comprehensively transfer and apply it. The case study of Salzburg, Austria, illustrates a fundamentally social process, beginning with the identification of all stakeholders involved in dealing with a specific flood event, followed by an analysis aimed at evaluating why problems occurred during the event, to finally consider measures to improve local disaster management and counter the re-occurrence of similar problems. The case study of Chiapas State, Mexico, illustrates the importance of inclusion in knowledge production, in knowledge sharing, and the role of trans-disciplinary approaches to DRR. By shedding light on the use of information, knowledge, and wisdom, a learning process is initiated and supported by a clear illustration of where improvements in decision-making can be reached. The knowledge gap can be reduced by an elaborate confrontation with the nature of knowledge so that innovative ways to overcome social, functional and institutional barriers to the production, transfer and application of knowledge can be identified.

Acknowledgements

We would especially like to thank the local interview partners for their input. The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2013-2015) under Grant Agreement no. 603807 (KNOW-4-DRR, http://www.know4drr.polimi.it/). We are grateful to Dominic Spiekermann for valuable discussions on the philosophical aspects of knowledge presented in Section 2. We also thank Hans Wiesenegger and Bernhard Niedermoser for the details they provided on the Salzburg Flood 2013.

References

[1] G.F. White, R.W. Kates, I. Burton, Knowing better and losing even more: the use of knowledge in hazard management, Glob. Environ. Change B: Environ. Hazards 3–4 (2001) 81–92.
[2] I. Kelman, J.C. Gaillard, J. Mercer, Climate change's role in disaster risk reduction's future: beyond vulnerability and resilience, Int. J. Disaster Risk Sci. 6 (2015) 21–27.
[3] C. Argyris, Knowledge for Action: A Guide to Overcoming Barriers to Organizational Change, Jossey-Bass, San Francisco, 1993.
[4] D.H. Guston, Between Politics and Science: Assuring the Integrity and Productivity of Research, Cambridge University Press, New York, 2000.
[5] D.W. Cash, S.C. Moser, Linking global and local scales: designing dynamic assessment and management processes, Glob. Environ. Change 2 (2000) 109–120.
[6] H. Nowotny, P. Scott, M. Gibbons, Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty, Polity Press, Cambridge, 2001.
[7] D.W. Cash, W.C. Clark, F. Alcock, N.M. Dickson, N. Eckley, D.H. Guston, J. Jäger, R.B. Mitchell, Knowledge systems for sustainable development, PNAS 14 (2003) 8086–8091.
[8] S. Jasanoff, States of Knowledge: The Co-Production of Science and Social Order, Routledge, London, 2004.
[9] J.R. Eiser, A. Bostrom, I. Burton, D.M. Johnston, J. McClure, D. Paton, J. van der Pligt, M.P. White, Risk interpretation and action: a conceptual framework for responses to natural hazards, Int. J. Disaster Risk Reduct. 1 (2012) 5–16.
[10] F.A. Hayek, The use of knowledge in society, Am. Econ. Rev. XXXV (1945) 519–530.
[11] J. Mittelstrass, The loss of knowledge in the information age, in: E.D. Corte (Ed.), From Information to Knowledge, From Knowledge to Wisdom: Challenges and Changes Facing Higher Education in the Digital Age, Portland Press, London, 2010, pp. 19–23.
[12] P.G. Horrigan, Epistemology: An Introduction to the Philosophy of Knowledge, iUniverse, Lincoln, 2007.
[13] Aristotle, Metaphysics, in: J. Barnes. (Ed.), The Complete Works of Aristotle: The Revised Oxford Translation, Vol. 2, Princeton University Press, Princeton, 1984.
[14] E.W. Younkins, Aristotle and Economics. In Capitalism & Commerce [Online]. Montreal. Available from: 〈http://www.quebecoislibre.org/05/050915-11.htm〉, 2005 (accessed 20.11.13).
[15] J. Bordat, Vulnerabilität und Resilienz: Methodologische Bemerkungen. Proceedings of the 6. KatNet Tagung: Resilienz und Vulnerabilität Welchen Nutzen haben die Konzepte für das Katastrophenmanagement? Bonn, Germany, November 14–16. (〈http://katastrophennetz.de/downloads/resilienztagung2012/KatNet2012Bordat.pdf〉, 2012 (accessed 20.11.13)).
[16] W. Marotzki, Internet communities, in: T. Coelen, H.U. Otto (Eds.), Grundbegriffe Ganztagsbildung: Das Handbuch, VS Verlag für Sozialwissenschaften, Wiesbaden, 2008, pp. 402–410.
[17] S. Kienberger, R. Spiekermann, M.J. Jimenez, M. Garcia Fernandez, M. Dandoulaki, N. Valkanou, P. Pigeon, F. Briones, Analysis of main fragmentation issues within different stakeholder groups, 2013, Deliverable 1.2., KNOW-4-DRR Project Report.
[18] N. Stehr, What is socially relevant science? Society 46 (2009) 262–266.
[19] M. Polanyi, The Tacit Dimension, Doubleday, Garden City, 1966.
[20] J. Weichselgartner, M. Obersteiner, Knowing sufficient and applying more: challenges in hazards management, Glob. Environ. Change B: Environ. Hazards 2–3 (2002) 73–77.
[21] J. Weichselgartner, R.E. Kasperson, Barriers in the science-policy-practice interface: toward a knowledge-action-system in global environmental change research, Glob. Environ. Change 2 (2010) 266–277.
[22] P. Shi, Integrated Risk Governance: Science Plan and Case Studies of Large-scale Disasters, Springer, London, 2013.
[23] B. Edgar, N. Schofield, A. Campbell, Informing river management policies and programs with science, Water Sci. Technol. 9 (2001) 185–195.
[24] E.C. McNie, Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature, Environ. Sci. Policy 10 (2007) 17–38.
[25] IPCC, Summary for Policymakers, in: O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel, J.C. Minx (Eds.), Climate Change 2014: Mitigation of Climate Change, Cambridge University Press, Cambridge, 2014.
[26] P. Pigeon, Flood risk and watershed management conflicts in France: upper catchment management of the river Rhone, in: J. Warner, A. van Buuren, J. Edelenbos (Eds.), Making Space for the River: Governance Experiences with Multifunctional River Flood Management in the US and Europe, IWA, London, 2013, pp. 149–162.
[27] IPCC, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, Cambridge University Press, Cambridge, 2012.
[28] D. Alexander, I. Davis, Disaster risk reduction: an alternative viewpoint, Int. J. Disaster Risk Reduct. 2 (2012) 1–5.
[29] C.N. Knapp, S.F Trainori, Adapting science to a warming world, Glob. Environ. Change 5 (2013) 1296–1306.
[30] T.A. Muñoz-Erickson, Co-production of knowledge-action systems in urban sustainable governance: the KASA approach, Environ. Sci. Policy 37 (2015) 182–191.
[31] J. Weichselgartner, I. Kelman, Geographies of resilience: challenges and opportunities of a descriptive concept, Prog. Hum. Geogr. 3 (2015) 249–267.
[32] M.R. Partidario, W.R. Sheate, Knowledge brokerage: potential for increased capacities and shared power in impact assessment, Environ. Impact Assess. Rev. 39 (2013) 26–36.
[33] M. Cashmore, A. Axelsson, The mediation of environmental assessment's influence: what role for power? Environ. Impact Assess. Rev. 39 (2013) 5–12.
[34] J.Ø. Nielsen, D.'haen SAL, Asking about climate change: reflections on methodology in qualitative climate change research published in Global Environmental Change since 2000, Glob. Environ. Change 24 (2014) 402–409.
[35] ESF/COST, Responses to environmental and societal challenges for our unstable earth (RESCUE), European Science Foundation/European Cooperation in Science and Technology Strasbourg/Brussels, 2011.
[36] J. Weichselgartner, C.A. Marandino, Priority knowledge for marine environments: grand challenges at the science-society nexus, Curr. Opin. Environ. Sustain. 3 (2012) 323–330.
[37] C. Kuhlicke, A. Steinführer, C. Begg, C. Bianchizza, M. Bründl, M. Buchecker, B. De Marchi, M. Di Masso Tarditti, C. Höppner, B. Komac, L. Lemkow, J. Luther, S. McCarthy, L. Pellizzoni, O. Renn, A. Scolobig, M. Supramaniam, S. Tapsell, G. Wachinger, G. Walker, R. Whittle, M. Zorn, H. Faulkner, Perspectives on social capacity building for natural hazards: outlining an emerging field of research and practice in Europe, Environ. Sci. Policy 7 (2011) 804–814.
[38] A. Newton, J. Weichselgartner, Hotspots of coastal vulnerability: a DPSIR analysis to find societal pathways and responses, Estuar. Coast. Shelf Sci. 140 (2014) 123–133.
[39] S.C. Moser, J.A. Ekstrom, A framework to diagnose barriers to climate change adaptation, PNAS 51 (2010) 22026–22031.
[40] E. Lövbrand, Co-producing European climate science and policy: a cautionary note on the making of useful knowledge, Sci. Public Policy 3 (2011) 225–236.
[41] L. Dilling, M.C. Lemos, Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy, Glob. Environ. Change 2 (2011) 680–689.
[42] R.A. Pielke, The Honest Broker: Making Sense of Science in Policy and Politics, Cambridge University Press, Cambridge, 2007.
[43] W.N. Adger, J. Barnet, K. Brown, N. Marshall, K. O'Brien, Cultural dimensions of climate change impacts and adaptation, Nat. Clim. Change 2 (2012) 112–117.
[44] R.E. Kasperson, M. Berberian (Eds.), Integrating Science and Policy: Vulnerability and Resilience in Global Environmental Change, Earthscan, London, 2011.
[45] R. Ackoff, From data to wisdom, J. Appl. Syst. Anal. 16 (1989) 3–9.
[46] T.H. Davenport, L. Prusak, Working Knowledge: How Organizations Manage What They Know, Harvard Business School Press, Boston, 1998.
[47] Jennex M.E, Re-visiting the knowledge pyramid, in: Proceedings of the 42nd Hawaii International Conference on System Sciences, 2009.
[48] ICSU, A Science Plan for Integrated Research on Disaster Risk: Addressing the Challenge of Natural and Human-Induced Environmental Hazards, International Council for Science, Paris, 2008.
[49] UNISDR, Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters, United Nations Office for Disaster Risk Reduction, Geneva, 2005.
[50] G. Blöschl, T. Nester, J. Komma, J. Parajka, Perdigão RAP, The June 2013 flood in the Upper Danube Basin, and comparisons with the 2002, 1954 and 1899 floods, Hydrol. Earth Syst. Sci. 17 (2013) 5197–5212.
[51] R. Gremli, B. Keller, T. Sepp, M. Szonyi, European floods: using lessons learned to reduce risks, Zurich Insurance Group, Zurich, 2014.
[52] D. Kneis, G. Bürger, A. Bronstert, Evaluation of medium-range runoff forecasts for a 50 km² watershed, J. Hydrol. 414–415 (2012) 341–353.
[53] H.M. Habersack, G. Krapesch (Eds.), Hochwasser 2005: Ereignisdokumentation der Bundeswasserbauverwaltung des Forsttechnischen Dienstes für Wildbach- und Lawinenverbauung und des Hydrographischen Dienstes, Universität für Bodenkultur Wien, Wien, 2006.