Flood risk communication - Visualization tools and evaluations of effectiveness

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ABSTRACT: Visual risk communication can be used to reduce damages due to floods. The first objective of this study is to review the current state of the field by inventorying examples of visual communication in terms of purpose, content, audience, phases of risk management and means. As maps appear to be predominantly used, the second objective is to review flood risk mapping research and practice. The third objective is to analyze examples of evaluation of effectiveness. It appears that although visual risk communication is quite advanced, there are still gaps to fill such as integrating the prevention and preparedness in the same communication tools. Risk mapping is currently designed for risk management. Further research should be conducted to make it serve risk communication. Although evaluation examples exists in terms of users' needs, the assessment of the real impact of visuals is never done.

1 INTRODUCTION

1.1 *Communication for disaster risk reduction*

The increasing attention to disaster risk reduction is reflected by the creation in 2005 of the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disaster (UNISDR, 2007). This framework acknowledges that vulnerability to disasters is increasing, among others due to demographic changes, urbanization, environmental degradation and climate change. This poses a threat to the world's economy, and its population and the sustainable development of developing countries. Examples such as the Katrina hurricane in 2005 and the tsunami disaster in Japan in 2011 show that this is also true for developed countries.

In the risk management cycle, communication is a key instrument for managing the consequences of disasters. It is important in the prevention phase but even more so in case of a crisis. Communication can influence the response of all parties concerned and in that way help decrease damage and save lives.

Risk communication mainly aims to raise awareness, change behavior of the stakeholders (exposed people, experts and managers, authorities, general public and media), enable dialogue (Höppner et al. 2010) and improve knowledge. Risk communication can be oral, textual or visual. Our study focuses on the latter. We define visual risk communication as a process of sending and receiving risk information with a significant visual component (cf. Trumbo 1999).

Visual communication can be implemented through a wide range of means: pictures, movies, charts, graphics, maps or objects such as flood marks. Increasing use is made of new technologies such as Geographic Information System (GIS), web-based platforms and smartphone applications.

Visualization has become an important topic of research in the last decade due to the extension of the size of data sets produced by the most recent data acquisition techniques (Post et al. 2002). Due to increasing computing power, new research fields such as 'Information Visualization' and 'Data visualization' have emerged.

1.2 *Objectives*

The objective of this paper is to provide an overview of existing visual flood risk communication practices and to draw lessons for future use of visuals. We focus specifically on maps because they represent the majority of the practices and approaches that were inventoried and scientific results of risk assessments are usually presented using maps. Moreover, the EU Flood Risk Directive (2007/60/EC) requires the creation of flood hazard and risk maps. Although the main hazard that we are interested in is floods, we have included other natural hazards in our inventory because we can learn from the field of other natural hazards as well.

After a brief explanation of the methodology, we present the results of the inventory of visual risk communication instruments. Subsequently we zoom in on maps. Then we continue with an overview of

the evaluations of visual communications. We conclude that visual communication is well developed in some field but not in others and that there is a lack of evaluations of the real impact.

2 METHODOLOGY

2.1 *Data collection*

For this paper, we first collected concrete risk communication practices, using the excellent review of risk communication efforts produced by Höppner et al. (2010). In addition, we searched for examples on the Web and in the academic literature. Using the snowball method, we collected approximately 500 articles on the general topic of risk communication, which we scanned for their relevance for this paper.

Secondly, we zoomed in on flood risk mapping practice and research. For this we relied on the scientific literature.

Thirdly, we reviewed the examples of evaluation of the effectiveness of visualization for risk communication. These too were found in the scientific literature. Hence, we did not include internal evaluations.

2.2 *Data analysis*

The data were analyzed using the framework for risk visualization developed by Eppler & Aeschimann (2009) (Figure 1). We focused on the purposes of the risk communication, the contents of the message communicated, the target groups of the message, the phases in the risk management cycle in which the communication takes place (prevention, preparedness, response, recovery), and formats or visualization means used.

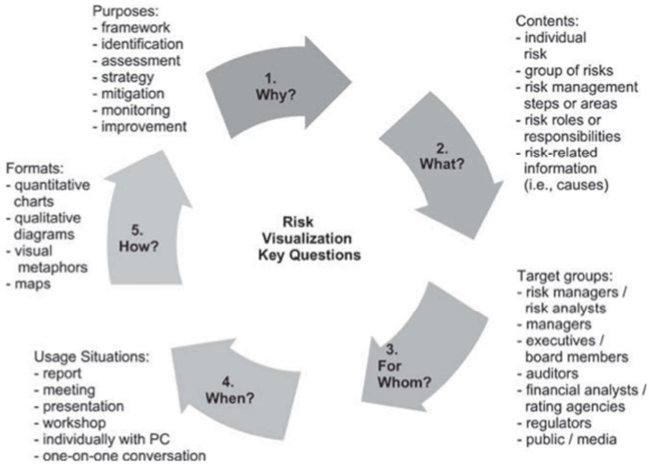

Figure 1. Key questions of the risk visualization framework. From Eppler & Aeschimann (2009).

3 VISUAL RISK COMMUNICATION PRACTICES

In total, 31 risk visualization practices were collected (Table 1). Fifteen of these concern floods only, while 4 are related to snow avalanches. Other natural hazards included are storms, hurricanes, fog, cold and heat waves, hail, snow falls, landslides, earthquakes, volcanic eruptions, tsunamis, surges, droughts and forest fires. Twenty-three focus on one type of natural hazard only, while the other eight refer to – in principle – all natural hazards in the relevant area (e.g. Österreichische Unwetterzentrale).

3.1 *Purposes (why?)*

The purposes of the communication practices are usually not explicitly stated and often not easily distinguishable. Nevertheless, different purposes can be discerned. The main purpose is commonly to raise awareness and inform about natural hazards. In some cases, these purposes are combined with warning (e.g. Hochwassernachrichtendienst Bayern) and/or inducing protective behavior (e.g. WSL Institute for Snow and Avalanche research). Some communication practices have a special purpose, such as keeping memories alive (e.g. Flood sculptures, Höppner et al. (2010)) or sharing information (e.g. The PREVIEW Global Risk Data Platform, Giuliani & Peduzzi (2011)). However, none have the purposes suggested by Höppner et al (2010): reassurance, improved relationships (build trust, cooperation and networks) and stakeholder involvement in decision-making.

3.2 *Content (what?)*

The content of the communication practices varies a lot, but they often provide information on the level of danger (e.g. snow avalanche danger: the Österreichische Lawinenwarndienste), of risk (e.g. flooding risk: the English Environment Agency), of susceptibility (e.g. flood susceptibility: Mines and Geosciences bureau of the Department of Environment and Natural Resources of the Republic of Philippines), of warning (e.g. Österreichische Unwetterzentrale) or of river discharge (e.g. Hochwassernachrichtendienst Bayern). Especially concerning flooding, information is often given on the spatial extent of the hazard (e.g. Koln Hochwassergefahrenkarten) or actions to take (e.g. video clips on floods in Bangkok, Roo Su Flood).

Table 1. Inventory of visual risk communication practices.

Tools	Keywords	Link
Flood forecasting Service - Czech hydrometeorological Institute	Floods - map - web	hydro.chmi.cz/hpps/
Flood Information Service - Hochwassernachrichtendienst	Floods - map - web	hnd.bayern.de
Flood Portal - Baden-Wurttemberg	Floods - map - web	rips-dienste.lubw.baden-wuerttemberg.de/rips/hwgk_internet/
Flood Portal - HSK Koln	Floods - map - web	hw-karten.de/koeln/
Three-days flood forecasting - Environment Agency England	Floods - map - web - three days forecasting	environment-agency.gov.uk/homeandleisure/floods/3days/125305.aspx
Flood Portal - Environment Agency England	Floods - map - web	maps.environment-agency.gov.uk/
Flood Portal - Scottish Environment Protection Agency	Floods - map - web	go.mappoint.net/sepa/
Risk Portal - Netherlands	Floods - map - web	risicokaart.nl/
Hochwasserschutz Regensburg	Floods - map/marks	
Austrian peak discharge information system	Floods - map -tv	
Plan Vidourle	Floods - marks	
Flood video - Terre.tv	Floods - video clip - web	terre.tv/
Flood cartoons Roo Su Flood	Floods - cartoons - web	youtube
River-Works	Floods - sculptures	
Documentary - Malborghetto-Valbruna municipality	Flash floods - documentary - dvd	
Snow avalanche Portal - Österreichische Lawinenwarndienste	Snow avalanches - map - web	lawine.at
Snow avalanche bulletins - Institute for Snow and Avalanche Research SLF	Snow avalanches - map - web	slf.ch
White Risk - Institute for snow and avalanche resarch SLF and SUVAlife	Snow avalanches - map - smartphone	
im Banne der Lawinen	Snow avalanches - documentary - dvd	
North Carolina Coastal Hazards Decision Portal	Storm surges - map - web	coastal.geology.ecu.edu/NCCOHAZ/
Severe weather warnings - MetOffice UK	Weather - map - web	metoffice.gov.uk/weather/
Graphical Tropical Weather Outlook - National Hurricane Center	Hurricanes - map - web	nhc.noaa.gov/gtwo_atl.shtm
US National Drought Mitigation Center	Droughts - map -web	droughtmonitor.unl.edu/
Weather Warnings Portal - Osterreichische Unwetterzentrale	Multirisk - map -web	uwz.at
Multirisk Portal eHora	Multirisk - map -web	hora.gv.at
Prim.net Portal (Photothèque/Aleas.tv)	Multirisk - pictures/videos - web	prim.net
PREVIEW Global Risk Data Platform	Multirisk - sharing platform - map - web	preview.grid.unep.ch
Swiss Common Information Platdorm For Natural Hazards (GIN)	Multirisk - map - sharing platform	
GeoAnalytics Visualization (GAV) toolkit	Multirisk - map - sharing platform	
Geohazard maps - Filipino Mines and Geosciences Bureau	Multirisk - map -web	mgb.gov.ph/lhmp.aspx
Stop Disasters UN/UNISDR	Multirisk – game (map) - web	stopdisastersgame.org

3.3 *Target groups (for whom?)*

The large majority of the communication practices (22 of 31) are Web-based and can be accessed by anyone with an Internet connection. This suggests that the targeted audience is the general public. However, given the specific content, we can assume that the actual target group is the public at risk. The communicators are experts, institutions or authorities. The fact that nearly all practices found target the general public is probably due to the fact that the practices targeting others audiences are not public.

Only three practices targeting other audiences, such as experts, decisions-makers, authorities or institutions, were found. These are the Swiss Common Information Platform for Natural Hazards (GIN) (Heil et al. 2010), the PREVIEW Global Risk Data Platform and the GeoAnalytics Visualization (GAV) toolkit (Jern et al. 2010). Moreover, only these three practices have the special purpose of sharing information. Risk communication targeting the general public is usually treated as a one-way process, despite the importance that some authors attach to two-way communication (e.g. Höppner et al. (2010).

3.4 *Phases of risk management (when?)*

The phases of risk management in which the communication takes place are mostly prevention and preparedness. The majority of the cases (27 on 31) concern only one phase, e.g. the communication of flood warning for preparedness and the representation of flood extents for prevention. Only four practices aim to provide information for both prevention and preparedness. For example, in the case of the North Carolina Coastal Hazards Decision Portal, flood risk maps are available along with a map of real-time coastal hazards. This shows that using the same communication means can serves different phases of the risk management cycle.

3.5 *Means (how?)*

The map is undoubtedly the visual means that is most commonly used in visual risk communication (24 of the cases; see the next section). Other visual means identified include video clips, pictures and objects such as flood marks or sculptures.

4 RISK MAPPING

From the inventory of visual risk communication practices, we observed that maps are the most used visual means. Like other visual means, they can have different purposes, contents and target groups and can be used in different phases. Maps can be either static, such as the Flood susceptibility maps of Philippines' provinces, or dynamic, allowing interactivity. For instance, users could zoom in and out (e.g. Indicative river & coastal flood map of the Scottish Environment Protection Agency), or choose different layers of information (e.g. Dutch risk web-portal Risicokaart).

4.1 *Purpose (why?)*

According to Dransch et al. (2010, p. 294), 'natural hazards have a strong spatio-temporal component' and therefore maps of any type can improve awareness and understanding of risks. Based on this, they specify a large variety of potential objectives of maps: to improve risk perception (increasing knowledge and understanding, enabling appropriate risk assessment, allowing information accessibility), to support personal risk framing (creating a personal view, allowing confirming information with others through interaction) or to establish credibility (informing objectively or giving consistent information). Their study goes a step further by integrating findings from psychology and social sciences to propose a frame for cartographic principles in terms of objectives, tasks, and suitable map application and design.

If the study of Dransch et al. (2010) is a demonstration of the interest of research in the use of risk maps for communication, this is also highlighted by the applied field and in particular by the legislation. At the European level, it is emphasized by the fact that the development of flood hazard and risk maps is required by the EU Flood Directive (2007/60/EC). Although the primary objective of the maps is to be 'a basis for flood risk management plans' (Kellens et al. 2009, p. 2), another requirement of the Directive is to make the flood maps 'available to the general public' (Hagemeier-Klose & Wagner 2009, p. 564). This reflects that 'cartography can play an important role in communicating flood risks' (Kellens et al. 2009, p. 2).

4.2 *Content (what?)*

In theory, the contents of risk maps can differ widely: probability of hazards; exposure; vulnerability and potential harm to people, built environment and physical environment; or capacity to recover from such an impact (Cutter 2008). In practice concerning floods, this variety cannot be observed.

Studies by van Alphen et al. (2009), de Moel et al. (2009) and Kellens et al. (2009) show that, in Europe, flood hazard maps showing parameters such as flooding probability, extent and depth are much more developed than flood risk maps including potential damage or evacuation maps. If flood extent maps are available for the large majority of the European countries, only seven of them developed risk maps (qualitative risk: France, Switzerland, Spain and Italy; and quantitative risk: Flanders, Germany and Croatia). This shows the amount of work that has still to be done to meet the requirements from the EU Flood Risk Directive. The effects of flood defenses and climate change and uncertainty are usually not represented (de Moel et al. 2009).

Since "flood risk" can be interpreted in different ways, it is important to be clear to prevent misinterpretation and misunderstanding. An explicit code of practice may be useful in this respect (Moen & Ale 1998).

4.3 *Target groups (for whom?)*

The choice of target groups determines the type of map that is required. However, the review by Dransch et al. (2010) of the current state of research in the field of maps in risk communication shows that differences in target groups are rarely taken into account. Most studies discuss only maps for risk managers and authorities, while the use of maps directed to the public is rarely studied. Interestingly, this is in contrast to the predominance of communication with the general public found in the inventory of current practice. An exception is Kellens et al. (2009) who do discuss the use of maps to communicate risks to the public. They assume that, due to the spatial dimension of floods, maps are ideal for this purpose and audience.

4.4 *Phases of risk management (when?)*

While maps are clearly of use in different phases of risk management the literature found makes no explicit distinction between the phases. However, we can deduce that the existing risk maps are designed to be used in the prevention phase. For example, Dransch et al. (2010) categorize maps according to their purposes, but these are all are related to prevention.

4.5 *Means (how?)*

Maps consist of several components such as colors, background information and legend that have specific characteristics and purposes. All these components can influence 'the effectiveness of the information transfer to the user' (van Alphen et al. 2009, p. 290). The choice of the components (e.g. scale, basemap or geographic unit) depends on the purpose of the map (general information, preventive information, assistance to negotiation and decision, crisis management and regulation) (Chesneau 2004). Risk perception, communication process and information presentation 'have not been considered systematically in the map design process' (Dransch et al. 2010, p. 295) in spite that they 'give indications on the design of effective media' (Dransch et al. 2010, p. 299). Moreover, Chesneau (2004) encourages further research and design solutions as risk mapping still presents limits due to a partial exploitation of the graphical semiology and to issues related to superposition of information and uncertainty representation.

5 INVENTORIES OF EVALUATION OF VISUAL COMMUNICATION PRACTICES

The effectiveness of visual communication practices can be defined as the degree to which the purpose or purposes of the communication has been met ("outcome evaluation": Rohrmann 1992, 1998). We consider visual communication practices to be effective if they result in a change in the target group's risk awareness, knowledge, beliefs or behavior.

In the literature, we could not find any evaluation of the degree to which the purpose or purposes has been met. Instead, the evaluations that could be found focus on audience, content and mean, or on the relations between those.

Haynes et al. (2007) provides an example of an evaluation in which different means are compared, i.e. aerial photographs, contour maps and 3D maps. They assessed the ability of inhabitants of the Montserrat Island to locate, orientate, identify and decode mapped information and to identify, interpret and understand volcanic hazard information. They observed that aerial pictures are more effective than 3D maps, which are better than contour maps, for conveying information. However, they did not assess the impact of this information on risk awareness, knowledge, beliefs or behavior.

Similarly, Bell & Tobin (2007) tested the relative effectiveness for communicating flood risk (actually flood probability) of three different probability descriptions (a 100-year flood, a flood with a 1 percent chance of occurring in any year, and a flood with a 26 percent chance of occurring in 30 years) and of a map showing the 100-year floodplain. Their study suggests that the map is approximately as good as the descriptions concerning the understanding of the uncertainty. In addition, the map contains relevant information to people living in flood prone areas.

The use of the 'return period' concept was investigated in two studies that focused on the relation between content and target group. Hagemeier-Klose & Wagner (2009) evaluated 50 flood maps and 3 web-mapping services by investigating experts and lay-people's specific needs. It is not surprising that experts and general public have different needs, as they have undoubtedly different levels of pre-existing knowledge. More specifically, the authors observed that when targeting the general public, the content of the communication should be clear and easy to understand and that technical terms such as 'return period' should be replaced by simpler expressions, e.g. "very frequent flood event". This finding is confirmed by the evaluation of flood marks present on flood information tables in three German municipalities conducted by Hagemeier-Klose (2009). From these two studies, we can conclude that the experts framing (i.e. return period) should be translated in more understandable concepts when the general public is targeted. This users' requirement approach is based on the assumption that if they are taken into account, this would 'lead to an increased awareness and a heightening of knowledge about flood topics' (Hagemeier-Klose & Wagner 2009, p.567).

This assumption is similarly present in the studies of Spachinger et al. (2008) and Fuchs et al. (2009). In these studies, flood risks maps were evaluated by means of eye movements tracking crosschecked by a cognitive survey. They demonstrate that different readers (specialists, sensitized people and laypersons) have different map reading strategies and that the layout and level of detail of the maps influences their strategy. Hence, layout and level of detail may influence the transfer of information. The main result of the studies is a conceptual map (Figure 2) for enhancing risk communication and awareness building of the public. However, in their study they did not assess whether the information was truly understood or remembered or that awareness actually increased.

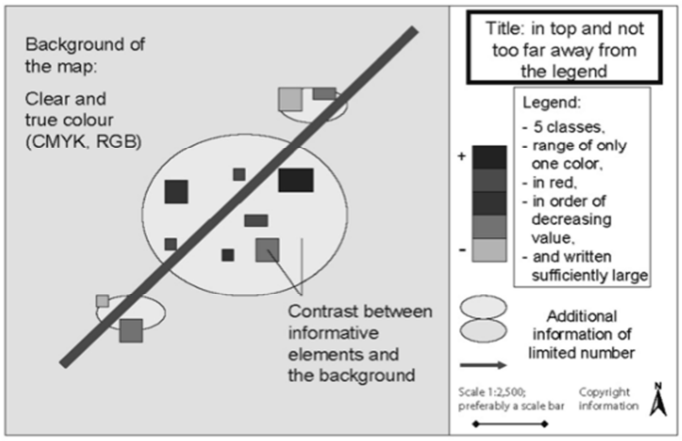

Figure 2. Conceptual map. From Fuchs et al. 2009.

In two studies users were asked to judge the appropriateness of the means. In Hagemeier-Klose (2009), experts and residents of three German municipalities were invited to evaluate flood marks. These showed either the boundary of the designated flood plain, the inundation depths of flood events with different occurrence probabilities, or the gauge levels of different discharges. In addition, the opinion of the opening ceremony's visitors on 15 flood sculptures (River-Works, Moosburg, Germany) was studied. The flood marks were viewed to be appropriate means of communication, but the addition of pictures of past events and the avoidance of technical terms could be beneficial. The only conclusion of the evaluation of the flood sculptures is that people saw them as an innovative means of communication.

The second example is the study of Flüeler et al. (2006). The authors conducted an evaluation of a slope stability web-application developed as a decision support system and a communication platform (*Slope Stability on Nisyros Island (Greece)*). Using standardized questionnaires, experts and lay persons were asked to evaluate the application according to usability, map design and interactivity criteria. It appeared that the participants were satisfied and considered the interactivity functions (moveable legends, spatial navigation tools, reference map and attribute display) to be useful to them. Again, the impact of these visuals was not evaluated.

In one study, map readability and the impact on decision-making and intended behavior was investigated. Kain and Smith (2010) conducted face-to-face interviews with North Carolina residents to assess the interpretation of hurricane advisory maps. They observed that people who interpreted the maps better thought that they would have time to decide whether to leave the area or stay. On the contrary, people who interpreted the maps less correctly said they would prepare to leave. Although the real change in behavior was not evaluated, the behavior that participants envisaged to have was. One can argue that that it is not sure that what people think they will do, is the same as what they will do in a real situation, especially a stressful one like an evacuation due to a dangerous event. Nevertheless, this study indicates that the use of visuals could have an impact on decision-making.

6 CONCLUSION

The inventory of current visual risk communication practices has shown that many are related to floods. The purpose of the communication practices was difficult to establish, but it appears that the aim is mostly to inform and warn. The content of the visual risk communication practices is highly diverse but usually covers the level of danger, warning or risk. The main target group is the general public. In a few cases decision-makers were targeted. The phases of the risk managed cycle covered are prevention, preparedness; response and recovery are not covered. Moreover, the most common means were maps, but many other means are used as well.

We can conclude from this inventory that visual communication is used quite extensively. The majority of the practices are maps aiming at informing the general public in the prevention or preparedness phases. However, visual communication aiming at other purposes, using other means, for other target groups and in other phases is less common, at least in the practices we found. Further developments of visuals could be profitable as we believe that risk communication should be as complete as possible in terms purposes, contents, audiences, phases and means in order to lead to an effective risk management. In this sense, we suggest that visual risk communication tools should be integrative, e.g. representing together multiple phases information such as risk level, warning level and actions to take.

The review of flood risk mapping results in similar conclusions. Although in practice the use of risk maps seems to be more directed to the creation of risk management plans (as stated in the EU Flood

Directive), maps can potentially support other risk communication purposes as well. At this stage, the use of risk maps for communication to the general public is not really considered in research. Flood risk maps are mostly designed for use in the prevention phase, but if additional information such as effects of protective measures or evacuation roads was included, the risk maps could be used for communication in preparedness and response phases. We can also imagine that development of real-time flood risk mapping could serve crisis management as it would make it more effective and hence reduce consequences of a disastrous event.

No published evaluations of visual risk communication practices exist that assess the ultimate impact in terms of risk awareness, knowledge, beliefs or behavior. The examples of evaluations in this review focus on users' requirements, ability to read the communication means, ability to understand the content, or satisfaction with the diverse components of the tool(s).

We can conclude that there is a big need for more research on the effectiveness of visual risk communication in terms of risk awareness, knowledge, beliefs or behavior. A good method for this would be to compare the situation prior and after the dissemination of the visual communication, as has been done by Lee & Mehta (2003) concerning blood transfusion risk communication. Their methodology, consisting basically in a pre-test, the dissemination of the message and a post-test with several groups, could be adapted to assess visual flood risk communication. Other types of experiment designs, such as games or evacuation exercises, could also be considered to assess the effectiveness of visual risk communication. Such designs would be especially useful to assess crisis' behavior as they simulate real life situations.

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