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## Analysing current practices

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# Risk governance of potential emerging risks to drinking water quality: Analysing current practices

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ABSTRACT

The presence of emerging contaminants in the aquatic environment may affect human health via exposure to drinking water. And, even if some of these emerging contaminants are not a threat to human health, their presence might still influence the public perception of drinking water quality. Over the last decades, much research has been done on emerging contaminants in the aquatic environment, most of which has focused on the identification of emerging contaminants and the characterisation of their toxic potential. However, only limited information is available on if, and how, scientific information is implemented in current policy approaches. The opportunities for science to contribute to the policy of emerging contaminants in drinking water have, therefore, not yet been identified.

A comparative analysis was performed of current approaches to the risk governance of emerging chemical contaminants in drinking water (resources) to identify any areas for improvement. The policy approaches used in the Netherlands, Germany, Switzerland and the state of Minnesota were analysed using the International Risk Governance Council framework as a normative concept. Quality indicators for the analysis were selected based on recent literature. Information sources used were scientific literature, policy documents, and newspaper articles.

Subsequently, suggestions for future research for proactive risk governance are given. Suggestions include the development of systematic analytical approaches to various information sources so that potential emerging contaminants to drinking water quality can be identified quickly. In addition, an investigation into the possibility and benefit of including the public concern about emerging contaminants into the risk governance process was encouraged.

## 1. Introduction

Human activities affect the chemical and microbial composition of the aquatic environment. The effects on water quality may be both direct and indirect. Direct effects include the release of anthropogenic chemicals into freshwater resources as a result of industrial and municipal wastewater discharges (Pal et al., 2010). An example of an indirect effect is the positive correlation between the temperature increase caused by climate change and pathogen survival in aquifers (Sterk et al., 2013). Because of demographic and environmental changes such as rapid urbanisation and extreme rainfall, the intensity and number of these direct and indirect effects is expected to increase (Gavrilescu et al., 2015; Lindahl & Grace, 2015).

Newly recognised potential hazards in the aquatic environment are often referred to as emerging contaminants and may be of both microbial and chemical nature. In this study, we focus on emerging chemical contaminants. The presence of emerging chemical contaminants in the aquatic environment may be a threat to human health, as water resources are being used for recreation as well as food and drinking water production. In addition, even if some of these emerging contaminants were not of concern from a public health point of view, their presence might still influence the public perception of drinking water quality (Schriks et al., 2010). Negative risk perception of drinking water quality might lead consumers to search for alternatives to tap water.

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Alternatives include bottled water and sweetened beverages, which are related to sustainability issues and in some cases even human health concerns (Doria et al., 2009; Doria, 2006; Lustig et al., 2012). Therefore, emerging contaminants are defined here as any chemical compound that may pose a new, or increased, threat to public health through the exposure to drinking water. The threat might be real, perceived or expected.

In regard to drinking water production, it is the emerging chemical contaminants found in groundwater (Lapworth et al., 2012), and surface water resources (Pal et al., 2010) that are of particular concern. Examples include pharmaceuticals, personal care products, and microplastics (Houtman et al., 2014). Technological advances in analytical techniques will enable the detection of even more contaminants in the future. Thus, the effective risk governance of emerging contaminants in drinking water and its resources is and will remain very important in order to protect public health.

Over the past years, much research has focused on emerging contaminants in the aquatic environment (Noguera-Oviedo & Aga, 2016). Studied topics include: the identification of emerging contaminants through screening efforts (Richardson & Kimura, 2016), the prioritisation of monitoring programmes (Smital et al., 2013), and the investigation into the toxicological potential of emerging contaminants (Houtman, 2010; Schwarzenbach et al., 2010). The risk management of emerging contaminants in drinking water (Murphy et al., 2012), and in the environment in general, has also been studied (Naidu et al., 2016a). However, as far as we understand, any research into the risk governance of emerging contaminants in drinking water and if, and how, scientific knowledge is implemented into current policy approaches has not yet been published.

This paper describes a comparative analysis of a range of existing policy approaches to the risk governance of emerging contaminants in drinking water and its resources. The objective is to identify areas in current risk governance approaches that are suitable for improvement and make suggestions for future scientific research, which will add to the proactive risk governance of emerging contaminants in drinking water.

## 2. Analytical approach

### 2.1. The IRGC risk governance framework

In this study, the risk governance framework issued by the International Risk Governance Council (IRGC) was used as a normative concept. Risk governance refers to the identification, assessment, management, and communication of potential chemical risks to drinking water quality (IRGC, 2012). The IRGC framework was chosen because of its proven applicability to the risk governance of emerging chemical and microbial risks (Assmuth et al., 2016; Roodenrijs et al., 2014).

The IRGC risk governance framework consists of five elements: pre-assessment, risk appraisal, risk evaluation, risk management and risk communication. We redefined two steps of the five elements to make them more readily applicable to the governance of drinking water contaminants. Pre-assessment and risk evaluation were redefined into identification of emerging contaminants and risk acceptance respectively.

### 2.2. Selected countries and state

Transboundary differences in a river catchment area were examined using the policy approaches for emerging contaminants in drinking water employed by the Netherlands, Germany and Switzerland, countries which all lie within the Rhine River catchment area. The Rhine is a multifunctional river that is used for transportation purposes, power generation, and urban sanitation, while at the same time providing drinking water for 25 million people (Uehlinger et al., 2009). These characteristics make the Rhine highly susceptible to the influence of emerging contaminants and thus interesting for the purpose of this paper.

Minnesota is one of the few jurisdictions which has a specific programme in place aiming explicitly at the identification and risk assessment of emerging contaminants in drinking water (The Minnesota Department of Health Contaminants of Emerging Concern (MDH CEC) program) (http://www.health.state.mn.us/cec). Therefore, the policy approaches used in the Netherlands, Germany and Switzerland were compared to the approach used in the state of Minnesota (the United States of America). This programme has also been analysed by Naidu et al. (2016b).

### 2.3. Quality indicators

For the analysis of the risk governance process, suggestions for best practice in the governance of emerging contaminants proposed by Naidu et al. (2016a) and Naidu et al. (2016b) were used for defining quality indicators. The suggestions for best practice that were considered were (1) the integration of science into policymaking, (2) the acceptance of the risk governance process by all stakeholders, (3) the defensibility of decisions made, and (4) the consideration of other factors as well as public health-risk reduction when choosing remediation strategies.

Number 2 was not used as a direct indicator. To analyse the acceptance levels of all the relevant stakeholders during the risk governance process required having insight into which stakeholders were involved in the process first. However, this information was not available. We therefore evaluated the stakeholders who were involved in each of the five elements of the risk governance process.

Furthermore, the defensibility of decisions made (3) can be ensured by creating transparency. Indeed, transparency is stated by the IRGC (2012) and the Organisation for Economic Co-operation and Development (OECD, 2015) as one of the principles of good governance. We therefore chose to assess transparency as a quality indicator. Transparency was evaluated upon the sharing of information with involved stakeholders during all the elements of the risk governance process.

### 2.4. Incidences of PFOA in drinking water or its resources

Four incidences of the same emerging contaminant in drinking water resources and/or treated drinking water were assessed. The emerging contaminant of choice was Perfluorooctanoic acid (PFOA). Additional information on PFOA is included in Appendix A.

Table 1 shows the selected incidences of PFOA in drinking water per country/state. From now on, these incidences of pollution will be referred to as cases. A description of each case study can be found in Appendix B.

### 2.5. Risk communication

In risk communication, two different models of communication can be distinguished, described by Ramirez-Andreotta et al. (2014) as the technical and the cultural models. The technical model uses one-way communication to inform the public, change behaviour and assure people of the acceptability of the risk as determined by experts. In contrast, the cultural model is based on two-way communication and includes the opinions of the affected public in the risk assessment element.

In this study, the type of communication model used in the different cases was determined. Furthermore, a quantitative analysis of the risk communication process during the four selected cases was performed. During this process, we assumed that less media coverage meant that there would be less tumult in the affected society, and thus less public concern. Although it is recognised that the relationship between news media coverage and public opinion is a dynamic process, studies have

**Table 1**
Overview of the selected incidences of PFOA contamination of drinking water resources and/or treated water.

| Case | Method by which the contaminant was identified | When identified | Source of pollution | Time of pollution | References |
|---|---|---|---|---|---|
| PFOA in the rivers Ruhr and Möhne, Germany | A scientific publication | 2006 | Soil improver containing industrial waste | Not known | Kleeschulte et al. (2007) ; (Wilhelm et al., 2010, 2008) |
| PFOA in Dordrecht, the Netherlands | A publication of an investigation into the same polluter in the United States | 2016 | Industrial wastewater | 1970-2012 | Bokkers et al. (2016); Zeilmaker et al. (2016) |
| PFOA in Basel, Switzerland | Target monitoring of drinking water for per- and poly-fluorinated compounds | 2011 | Not known | Not known | Wiedemann (2011) ; Zwick and Ackerman (2012) |
| MDH response to new health advisory Environmental Protection Agency (EPA), Minnesota | A publication of lower health advisory level by the EPA | 2016[a] | Industrial waste | Not known | EPA (2016); MDH (2017) |

[a] First discovery of contaminated groundwater was in 2002 (MDH, 2017).

shown that information on risks provided by news media may influence public risk perception (Bakir, 2010). The analysis was therefore based on the number of published newspaper articles before, during and after the incident of pollution. Newspaper articles were searched in LexisNexis® using search strings listed in Appendix B.

Fig. 1 is a graphical representation of the analytical approach used in this study. The comparative analysis of the risk acceptance, risk management and risk communication approaches is illustrated by the selected cases (see paragraph 2.4). In Appendix E, a short description of what the main elements are based on and the key questions used for the interpretation of the quality indicators are shown.

## 3. Results

The results of the comparative analysis will be described per element of the risk governance framework as shown in Fig. 1. The evaluation of one of the quality indicators, namely stakeholder involvement, is described separately for practical reasons.

### 3.1. Identification of emerging contaminants

In Minnesota, the first step in the identification process of possible emerging contaminants in drinking water was voluntary nomination by stakeholders via the website of the MDH CEC program.[1] By November 2016, state government agencies, advocacy organisations, and citizens had nominated 117 contaminants (MDH CEC program, 2016). Nominations were mostly based on monitoring studies or studies that revealed new toxicity data (Katie Nyquist, personal communication). Nominated contaminants were selected for further review if (1) they were, or potentially could be, found in surface water or groundwater in Minnesota (2) there were no Health Based Guidance Values (HBGVs) in Minnesota (3) they posed a real or perceived health threat, or (4) there was new or changing health or exposure information (Lewandowski et al., 2016). A list of nominated contaminants including argumentation for nomination (if available) and whether the contaminant was selected for further review was published on the MDH CEC webpage.

In Switzerland, Germany and the Netherlands, identification of emerging contaminants was mainly based on the monitoring of drinking water (resources) and the screening efforts made by drinking water suppliers as well as national government agencies (Bucheli, 2012; Kleeschulte et al., 2007; Sacher, 2013; van der Aa et al., 2017). Details on the trigger values used can be found in Appendix D. The identification process was less transparent compared to that of Minnesota, as not all monitoring and screening data were publicly available.

Scientific literature (Wilhelm et al., 2010) and media articles were also found to be sources for the identification of possible emerging contaminants to drinking water. However, none of the analysed policy approaches appeared to contain formal procedures for any evaluation of these information sources to be made.

### 3.2. Risk appraisal

In the Netherlands, Germany and Switzerland, the aim of the hazard assessment was to determine whether there was a need to develop HBGVs and whether it was feasible to do so. In the MDH CEC program, the hazard and exposure assessments were merely two of the factors that were taken into account by the MDH CEC program staff when evaluating the need for developing HBGVs. Other factors that were taken into account include the need for and feasibility of developing HBGVs (Lewandowski et al., 2016).

#### 3.2.1. Hazard assessment

The potential risk posed by the contaminants selected for review in

[1] http://www.health.state.mn.us/divs/eh/risk/guidance/dwec/nominate.cfm.

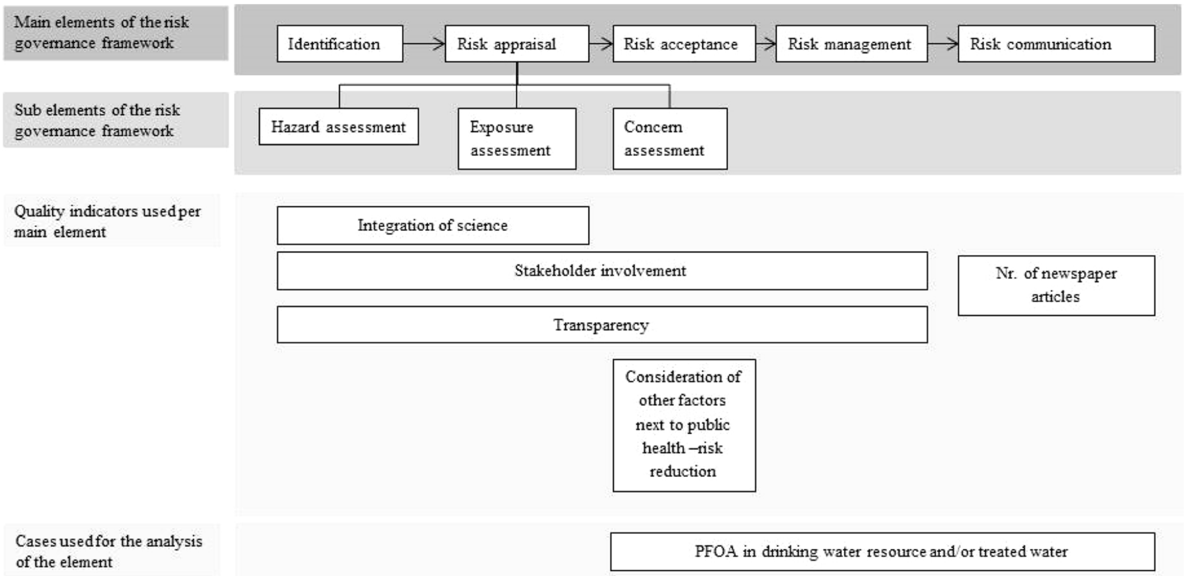


**Fig. 1.** Graphical representation of the analytical approach used in this study.

the MDH CEC program was evaluated by scoring the contaminant using relevant potency and exposure data. The method used for scoring the contaminants was described extensively in a recent review by Lewandowski et al. (2016). The hazard assessment was based on a combination of scoring available threshold toxicity data (e.g. no observed adverse effect levels) and non-threshold toxicity data (e.g. cancer classifications from the International Agency for Research on Cancer) into one potency score.

In the Netherlands, the hazard assessment of unregulated contaminants found in drinking water (resources) was compound-specific and highly dependent on the availability and reliability of toxicity data. When reliable and sufficient toxicity data were available, these were used to derive a Tolerable Daily Intake (or comparable) value, which was then used to calculate a HBGV for the contaminant in drinking water. Also, HBGVs derived by other national or international organisations were considered for evaluation (e.g. by the German Environment Agency) (van der Aa et al., 2017). In Switzerland, a similar approach was used (Bucheli, 2012).

However, in relation to emerging contaminants, toxicity data are often insufficient or unreliable. In those cases, experts in the Netherlands and Switzerland were able to use the Threshold of Toxicological Concern (TTC) or the Read-Across approach. The TTC was first developed by the U.S. Food and Drug Administration and is considered to be a level of human exposure below which negligible risk is expected even though toxicity data are unavailable (Mons et al., 2013). The TTC approach allocates chemicals to five different chemical groups based on their chemical structure (International Life Sciences Institute, 2005).

For some compounds the TTC approach is not applicable, e.g. inorganic compounds, proteins, and steroids, as is described by the European Food Safety Agency (2012). If the identified emerging contaminant belongs to one of these groups, the Read-Across-approach can be used instead of the TTC-approach (Brüschweiler, 2010; European Chemicals Agency, 2013). The use of the TTC approach to determine safe levels in drinking water has been explained in depth elsewhere for the Netherlands (van der Aa et al., 2017) and Switzerland (Brüschweiler, 2010; Bucheli, 2012).

Although the Netherlands and Switzerland used similar approaches during the hazard assessment element, several differences can be identified. Different standard body weights (70 vs. 60 kg), exposure allocations to drinking water (20% vs. 100%), and human exposure threshold values for the different classes in the TTC approach (European Food Safety Agency (2012) vs. International Life Sciences Institute (2005)) were used. These differences resulted in diverse HBGVs.

In Germany, the hazard assessment of emerging contaminants with insufficient or unreliable toxicity data was based on a scheme of health related indication values that was first published in 2003 by the German Environment Agency. The scheme consists of four possible health related indication values, namely 0.1, 0.3, 1, and 3 μg/L. Health related indication values increase with sufficient and reliable toxicity data, and decrease with the severity and irreversibility of the toxic endpoints, as described by Dieter (2014).

### 3.2.2. Exposure assessment

The exposure assessment in Minnesota was based on a different exposure-related data that are combined into three indicators for potential exposure via drinking water intake. These indicators include persistency (e.g. log $K_{ow}$, biodegradability), emission and disposal rates (wastewater and industrial releases), and a measure of occurrence (detected concentrations in different waterbodies and drinking water). The scores as well as the data they are based on are not published on the MDH website.

The exposure assessments performed in the Netherlands, Germany and Switzerland were very similar to one another. Preferably, concentrations of the contaminant in treated drinking water were used. When unavailable, concentrations in the drinking water resource were used. The expected concentration in drinking water can then be calculated using estimated removal rates by the drinking water treatment system.

### 3.2.3. Concern assessment

The IRGC (2012) has suggested relevant factors for the concern assessment, such as the assessment of perceptions associated with the hazard and the relationship between the perception and behaviour.

In three out of four cases (not in the Swiss case), public meetings were held. It was unclear to the authors whether a formal concern assessment of all stakeholders had taken place during the public meetings, as no minutes of these meetings were available. Also, in Minnesota, the opportunity for anyone to nominate a contaminant could be interpreted as part of the concern assessment. However, these concerns and the assessment of potential concern during the public meetings, do not appear to have had any influence on the further decision-making and risk management steps to be taken. None of the analysed policy approaches seem to have formal procedures in place for the concern assessment.

### 3.3. Risk acceptance and risk management

Risk management is the combination of actions taken to avoid, decrease or retain the potential risk posed by a hazard. The need and choice of risk reduction measures is based on the outcome of the risk acceptance element.

The risk acceptance element is based on the decision of the involved stakeholders on whether an identified risk is *acceptable* (no measures need to be taken), *tolerable* (risk reduction measures are needed), or *intolerable* (should be avoided) (IRGC, 2012). The IRGC framework is unclear about who to involve and not involve in the concern assessment and risk acceptance element respectively. It was thus decided that, in this study, the concern assessment would include the assessment of public associations with the hazard. In contrast, the risk acceptance element included only the risk evaluation of professionals.

In the selected Dutch case no measures could be taken to reduce or eliminate the risk, as the source of pollution had already been eliminated and exposure to it had gone on since 2012 (Zeilmaker et al., 2016). Also, considering the fact that the company had phased out the PFOA on a voluntary basis, no relevant risk management steps initiated by Dutch government agencies could be pointed out. The risk acceptance process and the resulting risk management steps in the remaining cases are described below. Also, flowcharts of the risk management processes can be found in Appendix F.

No measures were taken in the Swiss case, where the drinking water treatment system was able to remove PFOA. The risk of PFOA in drinking water was thus considered acceptable. During the German and Minnesotan case, the threat posed by PFOA was considered intolerable, because the drinking water treatment system in place was not able to remove PFOA from the resource water. However, by adding activated carbon to the drinking water treatment system, the potential risk posed by PFOA moved from being intolerable to tolerable (Kleeschulte et al., 2007).

In all selected cases, the decision as to whether the posed risk by PFOA was acceptable, tolerable or intolerable was solely based on the ability of the drinking water treatment system to remove PFOA and thus on the human health impact. No other aspects, such as economic implications, were taken into consideration. This illustrates the need for the timely identification of emerging contaminants to drinking water quality and the inclusion of the risk acceptance element as soon as possible after identification.

### 3.4. Risk communication

The technical risk communication model was used in all the selected cases. The communication was one-way in order to induce protective behaviour (in the German and Minnesotan case) or to reassure people that the drinking water was safe despite the presence of PFOA (in the Swiss and Dutch case).

Fig. 2 shows the number of articles published per month about PFOA in drinking water in German newspapers from January 2005 to January 2008 (N = 137). The articles were divided based upon publication in national or regional newspapers, as the selected cases were local incidents of PFOA contamination. Also, a timeline of the most important risk communication incidences by local, regional or national government agencies is shown (based on Kleeschulte et al. (2007)). Before May 2006 and after June 2007, no articles about PFOA in drinking water were published in Germany. This indicates that the articles shown in Fig. 1 are a reaction to the incidence of PFOA in the Rivers Ruhr and Möhne. A clear decline in newspaper articles can be seen after August 2006 indicating a decrease in public concern. This is based on our assumption that lower media coverage indicates lower public concern.

Fig. 3 illustrates the number of articles about PFOA in drinking water published in Dutch newspapers from January 2015 to May 2017 (N = 50). In contrast to the German case, there was no clear decline in the number of newspaper articles after the last communication incidence. This indicates no decline in public concern. This is in line with the fact that, in the Netherlands, research has been focussing on the potential health effects of the alternative for PFOA that has been used by industry since 2012 (Heydebreck et al., 2015; Smit, 2017). However, it is recognised that differences in the type of incidence, such as other routes of exposure to PFOA (e.g. via air in the Dutch case), as well as the timing of the incident, might have also contributed to the differences in media coverage.

No results that correlated to the selected Swiss case were found between October 2010 and January 2014. Also, the search for articles about PFOA in drinking water between January 2016 and June 2017 in Minnesotan newspapers resulted in only two articles. This indicated low to no public concern in the Minnesotan and Swiss case.

The presented cases show the influence that risk communication has on public concern about an emerging contaminant. Comparing the German and Dutch case illustrates the need for timely risk communication.

### 3.5. Stakeholder involvement

Fig. 4 shows the range of stakeholders involved in the selected risk governance approaches to emerging contaminants in drinking water. In this analysis, stakeholders were defined as all those parties, which had an interest in the matter of emerging contaminants in drinking water. The risk appraisal element is divided into its sub elements. However, as the concern assessment element was not represented in either of the analysed policy approaches, it is not shown in Fig. 4. The analysis of stakeholder involvement was based on different information sources, mainly grey literature. An overview of the references used per element is shown in Appendix G.

## 4. Areas identified for improvement

This study has shown that, with regard to proactive risk governance, a key area for improvement in the risk governance of emerging contaminants is their timely identification. Timely identification enables appropriate risk management options to be taken, allows other factors as well as public health to be included in deliberating the need for risk remediation measures, and can positively influence risk communication as was illustrated by the selected cases.

The identification process used by the MDH CEC program appeared to be more proactive, as identification was based on the nomination of contaminants and not necessarily on monitoring data. However, the main reasons for contaminants to be nominated in the MDH CEC program came from screening and monitoring data or from studies that revealed new toxicity data. Therefore, it can be concluded that the information sources used in the selected risk governance approaches are comparable. However, based on recent scientific literature, several additional information sources could be used by government agencies for the timely identification of possible emerging contaminants.

Firstly, the use of product registration under REACH (European Regulation (EC) 1907/2006 on the Registration, Evaluation, Authorisation and Restriction of Chemicals) for the identification of persistent, mobile, and toxic contaminants has been suggested by Reemtsma et al. (2016) and Arp et al. (2017). This could be a valuable added classification of chemicals next to the persistent, bioaccumulative, and toxic-chemicals, by which physical-chemical properties indicate the possible threat a compound poses to drinking water quality. The use of other product registration databases besides REACH is also encouraged, such as the Biocidal Products Regulation.

Secondly, analysing driving forces behind current emerging contaminants in drinking water could be valuable. Driving forces in this

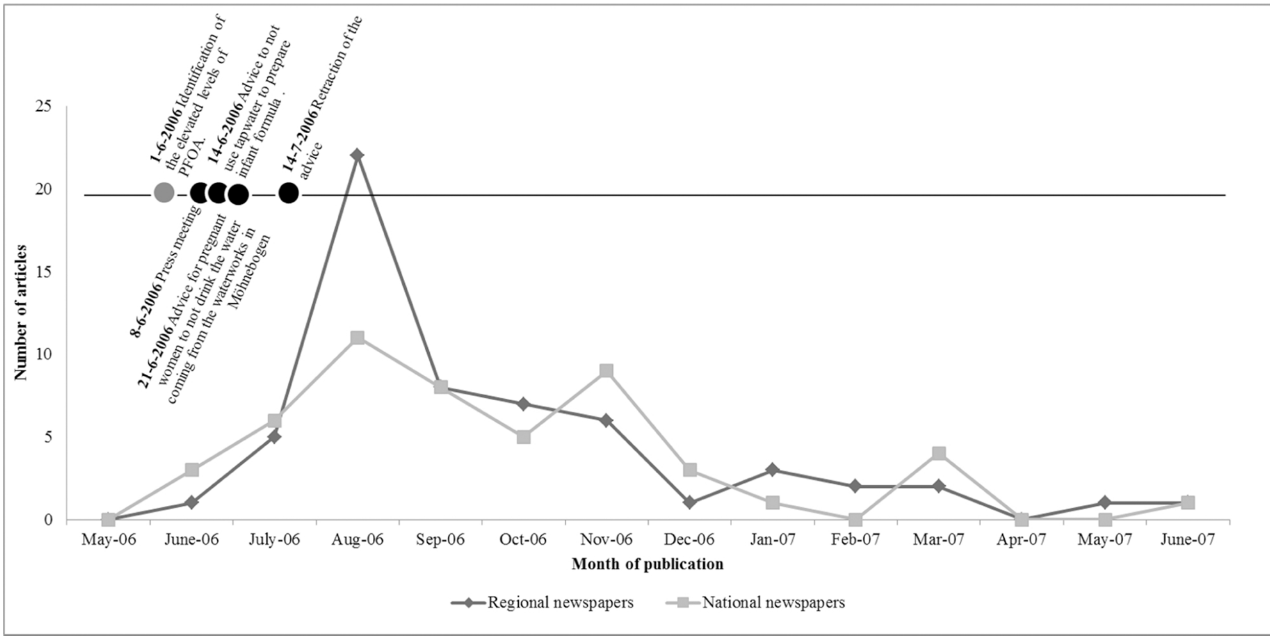


**Fig. 2.** Number of published articles about PFOA in drinking water per month in Germany (May 2006 to June 2007) in relation to important risk communication event times during the selected German case.

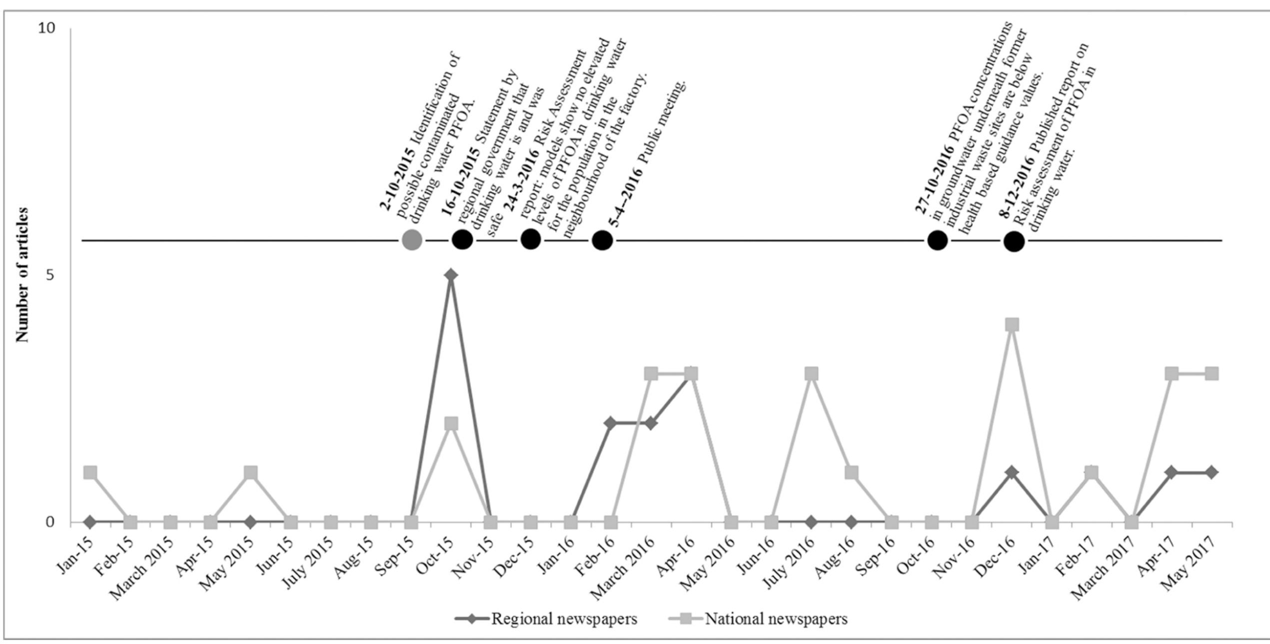


**Fig. 3.** Number of published articles about PFOA in drinking water per month in Dutch newspapers (January 2015 to May 2017) in relation to important risk communication events during the selected case.

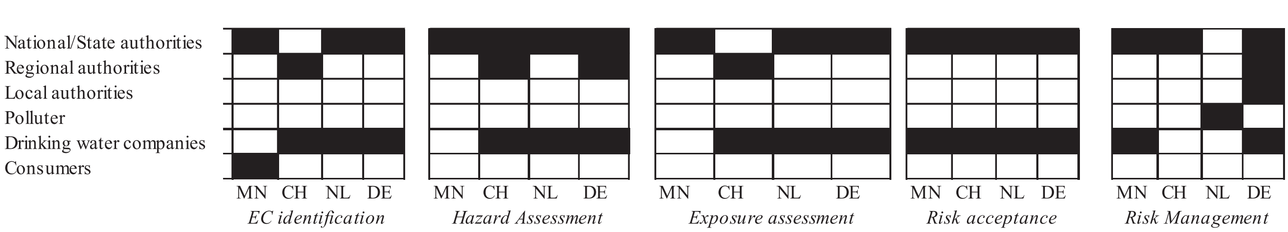


**Fig. 4.** Stakeholders involved in the risk governance of emerging contaminants in drinking water in Minnesota, Switzerland, the Netherlands and Germany.

case relate to social, economic, technical and political processes that have initiated drinking water contamination in the past. Correlating driving forces to risks has been done for infectious disease threats in Europe (Semenza et al., 2016) and chemical risks to biodiversity (Maxim & Spangenberg, 2009). Finding relevant driving forces for chemical and microbial risks to drinking water quality can result in proactive risk governance by enabling timely interventions on relevant drivers.

Thirdly, the systematic review of newspaper articles could accelerate the identification of possible emerging contaminants. This was illustrated by the Dutch case. Investigation into the same polluter in the United States started already in 2001 (Krimsky, 2007). Therefore, systematic analysis of international newspaper articles would have accelerated the identification of the possible PFOA contamination near Dordrecht. However, to make the analysis of international news relevant, the chance of false positives has to be minimised. Well-structured analytical approaches, such as the media monitoring approach by Alomar et al. (2015), are thus needed.

An additional area for improvement could be expanding the range of involved stakeholders by including consumers in the risk governance process. Participatory governance has been shown to positively influence stakeholder acceptance (Kochskämper et al., 2016; Ramirez-Andreotta et al., 2014). However, who to involve and not to involve still needs critical reflection and further study.

Also, in terms of transparency, the results show that not all information is publicly available. Making monitoring data on micropollutants publicly available could positively influence risk perception since studies have suggested that people evaluate drinking water quality based on their expectations (Doria, 2010). By sharing monitoring data, expectations can be managed. It is recognised that in order to make this kind of information understandable for non-experts, thorough explanation is needed.

Finally, harmonisation of the hazard assessment is encouraged for contaminants with limited toxicity data. Different approaches are shown to result in very different HBGVs, which impedes risk communication as communication on chemical drinking water contaminants is mainly based on water quality standards (Johnson, 2008). A harmonised shift from chemical specific risk assessment to assessing groups of chemicals based on their modes of action and physical-chemical properties is suggested (Murphy et al., 2012). This will enable the timely hazard assessment of contaminants with limited toxicological information.

## 5. Limitations

Some limitations of this study have to be considered. Firstly, it is recognised that the selected cases are considerably different from one another, both in terms of the size of the affected population and in terms of the knowledge level on human health effects of PFOA. These differences may have had an effect on the differences in the risk management and risk communication processes. In addition, the analyses of which stakeholders were involved in the risk assessment, risk management and risk communication elements of the risk governance process were based on the selected cases. The overview of the involved stakeholders in these elements, as shown in Fig. 4, is therefore specific for the selected case and may not be representative for each incident of an emerging contaminant in a drinking water resource.

Furthermore, the LexisNexis® database is limited in terms of included newspapers, which may have affected the results. Also, the framing of the risk event by news media was not taken into account. Recent literature shows that the framing of risk communication in case of emerging contaminants in drinking water can have a positive and negative effect on risk perception (Tobias, 2016). Therefore, further analysis of the risk communication during the selected cases is considered valuable.

Finally, the analysis focused on policy approaches and did not include voluntary actions taken by drinking water companies or other involved stakeholders.

## 6. Conclusions

The IRGC framework with a few modifications was found to be a valuable instrument for identifying areas for improvement in current risk governance approaches for emerging contaminants to drinking water quality. A key area for improvement was found to be the timely identification of and subsequent communication on emerging contaminants in drinking water. Similar results have been found for the risk communication on infectious diseases (Roodenrijs et al., 2014).

## 7. Future research suggestions

Based on the areas identified for improvement, the following suggestions for future scientific research that will add to the proactive risk governance of emerging contaminants in drinking water can be made:

- The development of systematic analytical approaches for the timely identification of emerging contaminants to drinking water quality using product registration databases, news media, drivers of risk, and scientific literature is encouraged.
- The possibility and benefits of integrating the concern assessment into the risk governance process of emerging contaminants in drinking water and improving transparency by sharing monitoring data should be investigated.
- The risk communication process and consequent public risk perception and risk behaviour that took place in past incidences of emerging contaminants in drinking water should be further analysed.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi: https://doi.org/10.1016/j.envsci.2018.02.015

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