

## **Clusters of water governance problems and their effects on policy delivery**

Kirschke, Sabrina; Franke, Christian; Newig, Jens; Borchardt, Dietrich

*Published in:*  
Policy and Society

*DOI:*  
[10.1080/14494035.2019.1586081](https://doi.org/10.1080/14494035.2019.1586081)

*Publication date:*  
2019

*Document Version*  
Publisher's PDF, also known as Version of record

[Link to publication](#)

*Citation for pulished version (APA):*  
Kirschke, S., Franke, C., Newig, J., & Borchardt, D. (2019). Clusters of water governance problems and their effects on policy delivery. *Policy and Society*, 38(2), 255-277. <https://doi.org/10.1080/14494035.2019.1586081>

### **General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

### **Take down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



## Clusters of water governance problems and their effects on policy delivery

Sabrina Kirschke, Christian Franke, Jens Newig & Dietrich Borchardt

To cite this article: Sabrina Kirschke, Christian Franke, Jens Newig & Dietrich Borchardt (2019) Clusters of water governance problems and their effects on policy delivery, *Policy and Society*, 38:2, 255-277, DOI: [10.1080/14494035.2019.1586081](https://doi.org/10.1080/14494035.2019.1586081)

To link to this article: <https://doi.org/10.1080/14494035.2019.1586081>



© 2019 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



Published online: 07 Mar 2019.



Submit your article to this journal [↗](#)



Article views: 540



View Crossmark data [↗](#)




Citing articles: 2 View citing articles [↗](#)

ARTICLE



## Clusters of water governance problems and their effects on policy delivery

Sabrina Kirschke<sup>1</sup>, Christian Franke<sup>2</sup>, Jens Newig<sup>3</sup> and Dietrich Borchardt<sup>3</sup>

<sup>1</sup>Faculty of Sustainability, Leuphana University of Lüneburg, Lüneburg, Germany; <sup>2</sup>Faculty of Life Sciences, Humboldt Universität zu Berlin, Berlin, Germany; <sup>3</sup>Department Aquatic Ecosystem Analysis and Management, Helmholtz Centre for Environmental Research, Magdeburg, Germany

### ABSTRACT

Public policy problems are increasingly being characterised as wicked or tame problems, assuming that this classification is also meaningful for attempts to effective problem-solving. But do distinct ‘wicked’ or ‘tame’ problems empirically exist? We investigate 37 water-related problems in Germany, based on interview-based data on problem wickedness and official data on policy delivery. Our analysis clearly reveals four clusters of water governance problems (system complexity, uncertainty, tame and wicked problems), based on variations of three factors of wickedness (goals, uncertainty and system complexity). These clusters of problems vary in their effects on different dimensions of policy delivery (goal formulation, stages and degrees of implementation of measures), with significant effects on goal formulation and the number of measures ‘in construction’. These empirical insights may contribute to a more systematic design of governance strategies for addressing water governance problems in practice.

### KEYWORDS

Cluster analysis; complex problems; European Water Framework Directive; water pollution; water quality

## Introduction

Identifying types of public policy problems, their effects and governance arrangements has become an important topic in public policy analysis (e.g. Howlett & Lejano, 2013; Howlett, Mukherjee, & Woo, 2015; Peters, 2005; Peters & Pierre, 2015). One important factor to characterise types of policy problems is their degree of ‘wickedness’. Whereas wickedness was originally established as a general characteristic of problems (Churchman, 1967; Rittel & Webber, 1973), analyses along different types of problems such as wicked or tame problems have been increasingly put into play (Head, 2008; Head & Alford, 2013). This goes back to the assumed diversity of public policy problems, which may also influence their solutions and governance arrangements. In the field of water management, for example, problems apparently differ from tame to wicked and have various effects such as more or less symbolic decision-making. Take, for instance, the more hands-on technical problem of removing nutrients (e.g. nitrogen, phosphorous) from wastewater on the one hand and the emerging, apparently more wicked problem of micropollution (e.g. pharmaceuticals, antibiotic resistance genes) on

**CONTACT** Sabrina Kirschke  [kirschke@unu.edu](mailto:kirschke@unu.edu)  Faculty of Sustainability, Leuphana University of Lüneburg, Scharnhorststrasse 1, Lüneburg 21335, Germany

© 2019 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

the other hand. It is reasonable to assume that these differences also influence the role of different participatory modes of governance to address these problems in practice.

There is, however, a lack of empirical evidence regarding different types and effects of public policy problems (e.g. Peters, 2017). A large number of studies have identified highly wicked or complex (environmental) problems, which are prone to failure (Cilliers et al., 2013; FritzGibbon & Mensah, 2012; Huntjens et al., 2012; Jentoft & Chuenpagdee, 2009; Metz & Ingold, 2014; Pahl-Wostl, Lebel, Knieper, & Nikitina, 2012; Patterson, Smith, & Bellamy, 2013). Many researchers analyse the effects of single dimensions of wickedness such as linear dynamics on solutions but do not combine various dimensions in one study design (e.g. Cronin, Gonzalez, & Sterman, 2009; Sweeney & Sterman, 2000). An increasing body of scholars advocates analyses along types of public policy problems but provides theoretical arguments and illustrations rather than larger empirical studies of various problem types and their effects on policy delivery (Head, 2008; Head & Alford, 2013; Kirschke & Newig, 2017).

Against this background, this study aims at providing empirical evidence for the existence and effects of public policy problems, based on the application and test of conceptualisations of wicked problems. To achieve this, we empirically *explore* clusters of water governance problems and their effects on policy delivery by public authorities. 'Clusters' refer to sets of similar types of problems which emerge from empirical cluster analysis. Our empirical case refers to the wicked issue of poor water quality in Germany (BMUB/UBA, 2016), and more particularly to 37 pollution-related problems, such as micropollution or leaching in agriculture. These problems have been officially defined by German water authorities as priority issues in implementing the European Water Framework Directive (WFD). They were analysed based on 65 expert interviews on wickedness and 11,000 measures related to these problems. This study uses these data to identify more hands-on clusters of water governance problems than in previous studies. Moreover, the relevance of these clusters is to be analysed, based on their impacts on policy delivery. Results may help to more effectively design governance strategies to address these problems than based on general ascriptions of wickedness only.

Following this introduction, the next section details our conceptual starting points. Drawing on literature on complex and wicked problem-solving in psychology and public policy analysis, we establish our multi-dimensional understanding of wickedness and policy delivery. The following section describes the studied water governance problems, the qualitative and quantitative data sources, and methods for data analysis. We then present our findings on clusters of water governance problems and their effects on policy delivery. In the final section, we discuss our findings in the light of theoretical discussions on wicked problems.

## Conceptual background

### *Wicked problems as an analytical concept*

Problems can be more or less wicked (Alford and Head, 2017; Head, 2008). In the field of water management, for instance, problems such as an integrated management or diffuse source pollution are reasonably described as highly complex or wicked problems (Duckett, Feliciano, Martin-Ortega, & Muñoz-Rojas, 2016; Lach, Rayner, & Ingram,

2005; Metz and Ingold, 201; Pahl-Wostl et al., 2012; Patterson et al., 2013). However, other problems such as point source pollution seem rather simple to be addressed. The concept of wickedness has to provide the analytical tools to analyse these differences in a useful manner for public policy analysis. Dimensions (e.g. uncertainty, complexity) and degrees (e.g. low and high uncertainty, complexity) of wickedness should be differentiated in a way that allows both to map diversity of political problems and to express that these differences can have an impact on solutions to problems and governance strategies.

Considering dominant operationalisations in the literature on wicked problems, this seems, however, only to be given to a limited extent. This first applies to the dimensions of wickedness. Research on wicked problems generally emphasises that there are several dimensions of wickedness (Alford and Head, 2017; Head, 2008; Head & Alford, 2013; Levin, Cashore, Bernstein, & Auld, 2012; Peters, 2017; Rittel & Webber, 1973; Xiang, 2013). Some concepts (Levin et al., 2012; Rittel & Webber, 1973; Xiang, 2013), however, do not always clearly differentiate underlying structures of problems and their effects. It might also be questioned if the analytical differentiation of the high number of dimensions in the concept of Rittel and Webber (1973) and others actually affects solutions and governance arrangements. In contrast to these concepts, the conceptualisation of Head (2008) clearly differentiates a small set of problem structures (divergence, uncertainty and complexity), which also possibly impact on solutions and governance. However, the dimension of complexity could be specified in more detail since complexity apparently encompasses a larger number of dimensions that can influence governance strategies (Funke, 2012; Kirschke & Newig, 2017).

Turning to the degrees of wickedness, we find that many studies contrast (super)-wicked from tame problems (Levin et al., 2012; Rittel & Webber, 1973). Levin et al. (2012), for instance, argue that most public policy problems are wicked (based on the 10 dimensions of Rittel & Webber, 1973), whereas only a small number of problems are super-wicked (characterised by an additional lack of time, adequate problem solvers, central authorities and solutions). While the existence of (super)-wicked problems seems plausible when considering international negotiations related to climate change, this can be questioned if we think about some small-scale point-source problems in the field of water management. Gradual variations on a scale from more simple or tame to more complex or wicked (Ingraham, 1987; Voss, Newig, Kastens, Monstadt, & Nölting, 2007) may, however, not prove to be more helpful, given limited impacts of gradual varieties on solutions and governance arrangements. What kind of impact would, for instance, a gradual differentiation of each of Rittel and Webber's 10 dimensions have on common strategies to addressing wicked problems (see for strategies, e.g. DeFries & Nagendra, 2017; Durant & Legge, 2006; Ferlie, Fitzgerald, McGivern, Dopson, & Bennett, 2011; Head & Xiang, 2016; Jentoft & Chuenpagdee, 2009; Loorbach, 2010; Voss & Kemp, 2006; Weber & Khademian, 2008)?

On acknowledging limitations of existing operationalisations, Head (2008) convincingly differentiates low, medium and high values of dimensions of wickedness. Here again, however, we need to clarify what kind of aspects actually characterise these three categories.

Against this background, we suggest applying a more nuanced version of the concept of Head (2008). While we pick up his core dimensions and degrees of wickedness, we

further specify three dimensions of complexity as well as low, medium and high values of the five dimensions of wickedness. In doing so, the concept of wickedness is congruent with five-dimensional operationalisations of complex problems in psychology (Funke, 2012) and as adapted in environmental governance research (Kirschke, Borchardt, & Newig, 2017a):

- (1) Goals, including their number and relationship with each other (e.g. ecological and economic goals), varying from 'goal singularity' to a 'plurality of prioritised goals' up to a 'plurality and non-prioritised goals';
- (2) Variables, referring to the number of factors that characterise problems (e.g. number of pollutants, natural conditions, stakeholders), varying from a 'low and manageable number' to a 'challenging number' up to an 'overcharging number of variables';
- (3) Dynamics of these variables, meaning how strongly their values change over time (e.g. climate change, population increase), varying from 'no dynamics' to 'linear dynamics' up to 'exponentially evolving variables';
- (4) Interconnections of the variables (e.g. connected social-ecological systems), describing the extent to which the variables are interrelated, varying from 'none' to 'slight' up to 'strong interconnections';
- (5) Informational uncertainty, referring to how much information is missing for problem-solving (e.g. on the impact of micropollutants on ecological systems, behaviour of actors), varying from 'informational certainty' to 'manageable uncertainty' up to 'an important, non-manageable lack of information'.

We assume that our understanding of wickedness allows for systematically comparing problems in terms of different dimensions and degrees of wickedness. This, again, is essential to analysing relationships between different features of wickedness and policy delivery.

### ***Policy delivery: a quantitative approach***

Policy delivery through public authorities can vary tremendously. In water management, for instance, public water authorities can be more or less active in setting pollution-related problems on the agenda; or goals may be more or less fully implemented on the ground (e.g. BMU, 2013). The concept of policy delivery has to provide the analytical tools to analyse these differences in a systematic, comparative way.

In the literature on wicked and complex problems, however, the dependent variable seems rather fuzzy. Researchers generally deny the possibility of (good) solutions to wicked problems, and focus, instead, on processes such as information gathering and structuring (e.g. Xiang, 2013). The reasons for this are perfectly understandable. Referring to solutions presupposes that there is agreement on both the current and the target state – a condition that is, of course, often not met (Batie, 2008; Durant & Legge, 2006; Hoppe, 2011; Voss et al., 2007). And even if there is agreement on the target state, it is often difficult to determine whether this state has been achieved since complex problems tend to entail untraceable side effects of actions (Batie, 2008; Funke, 2012; Rittel & Webber, 1973; Weber & Khademian, 2008). We argue, however, that at

least a rough understanding of the dependent variable is crucial if we wish to understand the effects of wickedness in a comparative way.

Against this background, we suggest defining the dependant variable of policy delivery in a quantitative way, by considering the existence of decisions. Are there any decisions to address problems? Are decisions implemented? And are these decisions taken in a rather fast or slow way? Analysing these aspects of policy delivery can serve as first indicators for problem-solving if one assumes that authorities only shoulder costs to take and implement decisions if they also expect to gain something. Such an approach might also be in line with the idea of ‘small wins’ (Termeer, Dewulf, Breeman, & Stiller, 2015), ‘small steps’ (Ducket et al., 2016) or an ‘incremental advancement’ (Head & Xiang, 2016) in addressing wicked problems, despite the ubiquitous possibility of negative side effects of actions or symbolic policies. Such an approach may also be combined with qualitative measurements of solutions in small n-comparative case study designs.

In line with classic works on public policy-making, we thus understand policy delivery very broadly as the performance of public policy-making along policy cycles (van Meter & van Horn, 1975). Given our empirical focus on the implementation of the WFD, we focus on the ‘secondary’ policy cycle induced by the WFD to implement the goal of ‘good water status’ (Newig & Koontz, 2014). This includes two stages of policy delivery:

- (1) Goal formulation, referring to the formulation of concrete objectives to implement problem-oriented measures (e.g. decision on upgrading a wastewater treatment plant or establishing buffer strips to reduce pollution by phosphorus);
- (2) Implementation, referring to actions to implement problem-oriented measures (actual upgrading of a wastewater treatment plant, establishment of a buffer strip).

In analysing these stages of policy delivery, we apply an absolute understanding of good and bad deliveries (‘the more the better logic’), given unclear baselines for the right number of activities per problem.

## Methods

### *The empirical case of water governance problems in Germany*

Our empirical analysis refers to the implementation of the European Water Framework Directive in Germany (Directive 2000/60/EC). European freshwaters such as rivers and lakes often have a poor ecological and chemical status, which can have a negative impact on ecosystems and human health. The WFD, a major regulation for water management in Europe, aims to achieve a good ecological and chemical status in European freshwaters. To achieve this goal, there are several management cycles (2009–2015, 2016–2021, 2022–2027). In its first management cycle, public authorities in all member states had to produce river basin management plans by 2009, which had to be implemented by 2015. In doing so, public authorities had to address various water-related pressures such as morphological alterations (e.g. straightening of river courses) or pollution (e.g. by the input of nitrogen,



phosphorus and micropollutants). This study focuses on pollution only and thus omits problems such as hydro-morphological alterations. In accordance with German public authorities (LAWA, 2013), pollution officially encompasses 37 specified types of pressures which relate to different types of sources (diffuse and point source pollution), waters (surface waters and groundwater) and polluter groups (e.g. agriculture, mining). A detailed overview on the 37 problem types of problems is provided by Kirschke et al. (2017b, Appendix A).

Referring to the WFD as an empirical reference point is beneficial to our comparative analysis since measures to address problems are to be implemented under similar legal conditions and within a set time frame. Further, referring to officially defined pressures in our analysis has several important benefits. These pressures can easily be understood as problems since they all refer to barriers that have to be overcome to achieve water quality targets. From a policy perspective, referring to these pressures (hereafter ‘problems’) addresses major issues in current water policy (BMU, 2010; Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA), 2013; COM, 2007) for which official data on implementation are available. Elsewhere, Kirschke et al. (2017a) have shown that the 37 problems under study here vary from simple to complex – independent of the type of water, source or polluter group – which is a precondition for examining clusters and their effects on policy delivery.

## ***Data and analysis***

### ***Wicked problems***

In terms of the independent variable ‘problem wickedness’, this research relies on original data collected by Kirschke et al. (2017a). This data set provides a systematic quantitative assessment of problem complexity in different dimensions. It encompasses data on (i) the general complexity degree of the 37 water-pollution-related problems (overarching complexity), as well as (ii) the degrees of the five dimensions of goals, variables, dynamics, interconnections and informational uncertainty (disaggregated complexity). The data set is thus congruent with our conceptualisation of wickedness.

Data were collected between November 2014 and January 2016 through 65 semi-structured interviews with leading experts from science (mainly natural science and engineering, social science) and practice (mainly public authorities and associations such as members of river basin organisations, associations for sewage treatment) in the field of diffuse and point source pollution in Germany, allowing for an in-depth assessment of the problem from different points of view. Questions related to (i) a general description of the problem, (ii) an assessment of the five dimensions of complexity along guiding questions based on a operationalisation of complexity and (iii) a summary of numerical assessments and qualitative arguments. Interviews lasted around 90 min, on average, allowing for an in-depth discussion and validation of assessments. The interviews resulted in 158 individual assessments of complexity degrees of problems, equalling two to three assessments per expert and about four assessments per problem. Experts provided and approved (i) numerical assessments for each complexity dimension from low (0) via middle (0,5) to high scores (1) (structured questions), as well as (ii) arguments to substantiate the numerical assessments (open questions), based on their personal judgement and experience.



The numeric assessments of complexity served to calculate mean values for each dimension of complexity of a problem, whereas the arguments substantiated similarities and differences between the problems. As a main result, this data set shows that the 37 pollution problems differ in their degree of complexity, which is based on both varying numerical values and argues for complexity (e.g. number, dynamics and interconnections of socio-ecological variables, related uncertainties and conflicts). Kirschke et al. (2017a) provide a comprehensive description of the process of gathering and analysing data, as well as the list of interviewees and the results of the interviews.

For the purpose of this analysis, the results of the numerical assessments of this data set are represented in a correlation matrix between the five dimensions of wickedness (see annex Table A1). This correlation matrix is the basis for building factors through factor analysis. Factors can be interpreted as latent variables, which represent causations for the correlation among variables. By factorizing the correlation matrix, we aimed at identifying these non-correlated factors in the data set, as a precondition for subsequent cluster analysis. Factorisation often reduces the number of dimensions, which typically comes along with losses of information. The identification of non-correlated factors is, however, a necessary condition for common methods of cluster building such as single linkage and WARD. Turning to cluster analysis, analyses based on the single linkage method first showed that there are no outliers. We thus used the hierarchical, agglomerative cluster method WARD in order to identify rather compact, homogeneous groups of problems.

### *Effects on policy delivery*

In terms of the dependent variable ‘policy delivery’, this research draws on data provided by public authorities in the German reporting system WasserBLICK. For each water problem, the number of measures to be implemented from the beginning of 2009 and their implementation status in 2012 were determined in a 2012 interim evaluation (BMU, 2013, for an overview). So, this data set refers to implementation measures which have, at least officially, all the same starting points, whereas their implementation was also measured at the same moment in time.

This interim evaluation generally had the form of a closed questionnaire. Federal public authorities were obliged to report on the status of measures per waterbody related to the type of problems as defined by LAWA (2013). In terms of the status of implementation, the questionnaire provided a rough four-point ordinal scale, encompassing the categories ‘not yet started’, ‘planning ongoing’, ‘construction ongoing’ and ‘completed’ for each type of problem (e.g. the establishment of buffer strips). In terms of the measures indicated, water authorities were free to define which measures related to the respective type of problem. However, general guidelines (Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA), 2013) indicated typical measures in the respective field. Also, public authorities were limited to indicate one measure per problem and waterbody. Thus, two buffer strips implemented within one waterbody generally counted as one action. As a result of this procedure, the interim evaluation provides information on the status of implementation of 11,193 measures each to be implemented since 2009, related to these 37 problem areas.

In order to analyse policy delivery based on this data set, different indicators were used, based on Kirschke et al. (2017b):

- (1) The total number of identified measures per problem was used as an indicator for goal formulation.
- (2) The percentage of measures that were (a) 'not yet started', (b) 'in planning', (c) 'in construction', and (d) 'completed' was used to define stages of implementation when goals to address problems had already been formulated.
- (3) An index was built to define the degree of implementation for each problem type. To this end, all four implementation categories were assigned a figure (0 for 'not yet started' up to 3 for 'completed'). The index is computed by multiplying each category figure with the number of measures in that category for a given problem type, and dividing the result by the total number of measures for that problem type.

An ANOVA was used in order to analyse if clusters of problems vary in their policy deliveries. The post-hoc test 'Tukey' served to identify which types of clusters establish variance between clusters as indicated by the ANOVA. The coefficient Eta-squared detected what percentage of the observed variance goes back to the clusters. As a precondition to applying these methods, we assumed the interval scale of the dependent variable and tested variance heterogeneity based on the Levine Test.

## Results

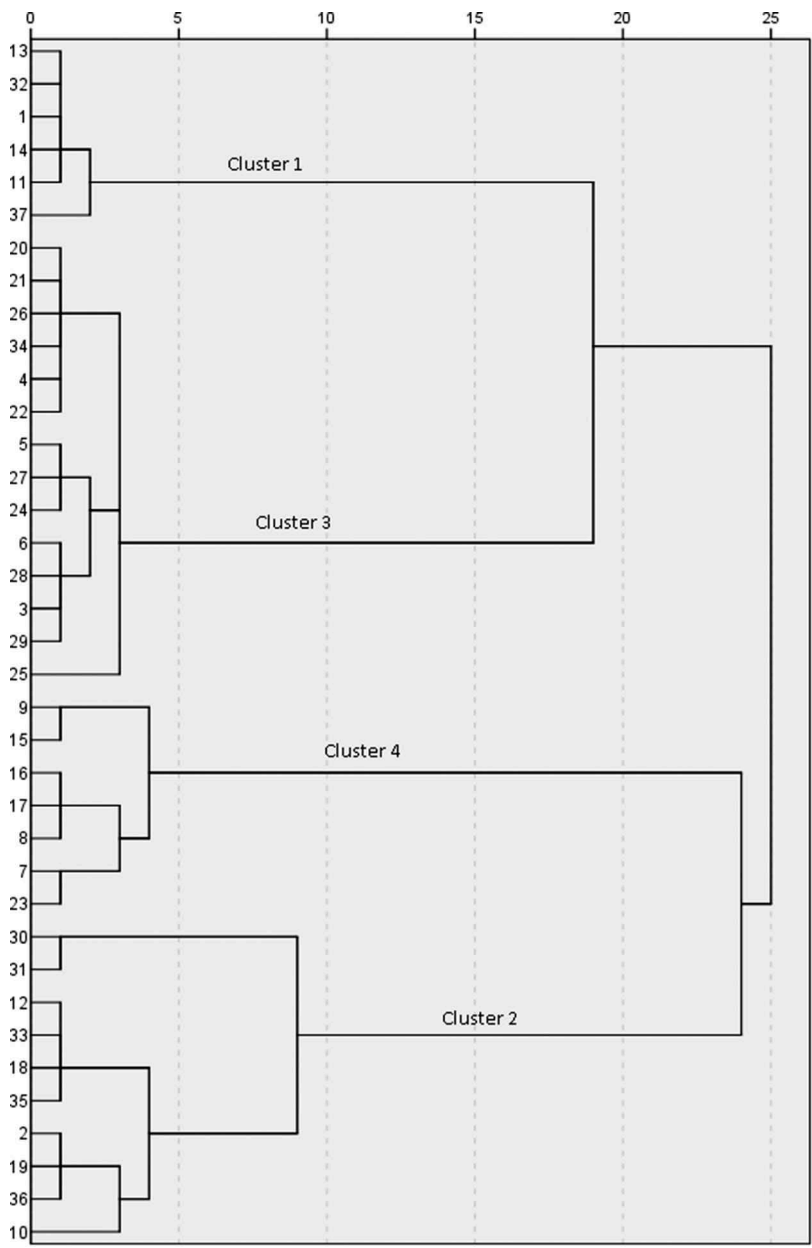
### *Factors and clusters of wicked problems*

Factor analysis shows that the five dimensions of wickedness can be reduced to three factors, namely factor 1 ('system complexity'), factor 2 ('goals') and factor 3 ('informational uncertainty') (see annex, Table A2). Factor 1 is influenced by the dimensions 'variables', 'dynamics' and 'interconnections', whereas factor 2 is mainly influenced by the dimension 'goals' and factor 3 by the dimension 'uncertainty'. The reduction to these three factors comes along with an acceptable loss of information (about 15%).

Cluster analysis based on WARD shows that we can differentiate four clusters of water governance problems (see Figure 1). These four clusters are completely homogenous ( $F < 1$ ) and differ clearly along the three factors 'system complexity', 'goals' and 'informational uncertainty' (see Figure 2 and annex, Table A3 and Table A4). The clusters include problems of different types of waters (surface waters and groundwater), sources (diffuse sources and point sources) and polluters (agriculture, mining, abandoned sites, constructed areas, urban wastewater, storm water, industry and others) (see annex, Table A5).

### *Cluster 1: 'complex systems' problems*

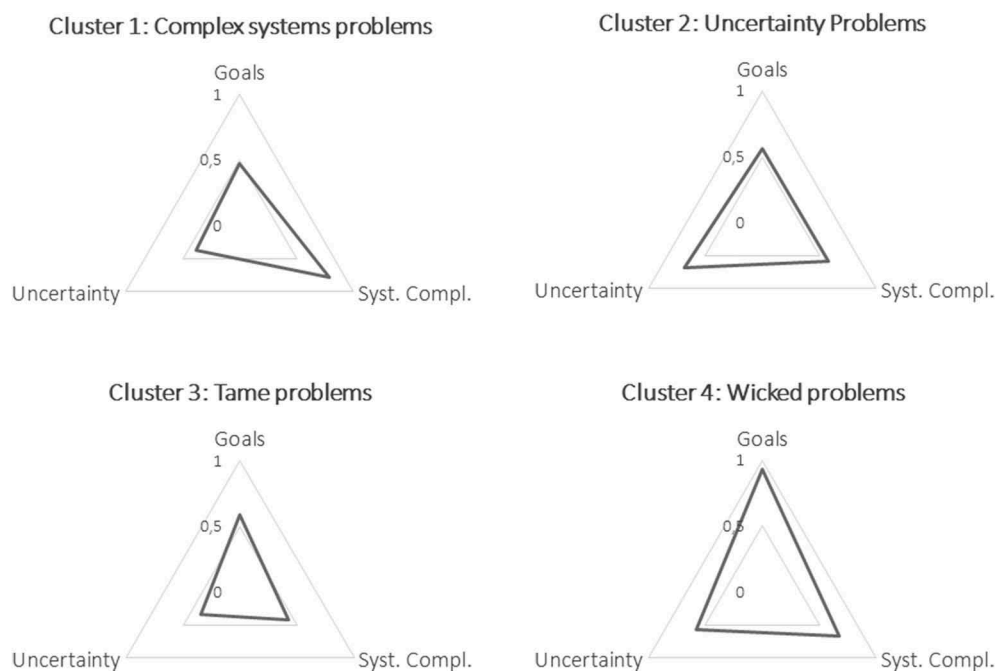
Cluster 1 ('complex systems' problems) includes six water-related problems that are characterised by a high system complexity, in particular, and a rather low degree of goal conflicts and informational uncertainty. These problems refer to both surface waters and groundwater, as well as to diffuse sources and point sources. The dominant polluter



**Figure 1.** Cluster analysis dendrogram. Depicted are four clusters of water governance problems.

group is mining. However, two problems refer to other polluters, namely waste disposal and soil acidification by various polluters.

The rather low degree of goal conflicts is explained by a particular strong interest of societal actors to reduce the input of matters. In terms of problems related to mining, for instance, an important industry attaches importance to good standing in the region, as a precondition to further mining activities. In terms of waste disposal and soil acidification,



**Figure 2.** Four clusters of water governance problems. Depicted are clusters of 'complex system', 'uncertainty', tame and wicked problems.

there are clear legal frameworks to reduce the input of related matters, e.g. due to experiences with important negative impacts such as forest decline.

The high system complexity refers to natural and non-natural locational factors, as well as to social actors and interests, in particular. In the field of mining, for instance, varying groundwater levels, weather and soil conditions heavily complicate initiatives to reduce the input of pollutants. Furthermore, there is a large set of actors such as responsible administrations and stakeholders that are affected by mining activities, resulting in particularly difficult decision-making processes at basin scale.

Informational uncertainty, however, is rather low, given rather stable interests of stakeholder groups, or a generally good knowledge base on matters, their dynamics and interconnections. Such a good knowledge base depends, however, to a certain extent on the respective financial prerequisites. Within the Erftverband, for instance, polluters invest strongly in maintaining a very good knowledge base on natural, technical and social data as a prerequisite for decision-making, which may not be the case in other regions.

### **Cluster 2: 'uncertainty' problems**

Cluster 2 ('uncertainty' problems) includes 10 problems. Compared with cluster 1, these problems are characterised by a high degree of informational uncertainty, in particular, and a rather low degree of system complexity and goal conflicts. Just as cluster 1, these problems consider surface waters and groundwater, as well as diffuse sources and point sources. In contrast to cluster 1, however, this cluster is more diverse in terms of

polluter groups, given the existence of problems related to agriculture, mining, abandoned sites, industry and other polluters (accidental inputs).

Just as for cluster 1, the rather low degree of goal conflicts is explained by a particular strong interest of societal actors to reduce the input of matters. This becomes rather clear with regard to problems related to drinking water protection zones. Drinking water is a particularly important good for society, resulting in society's willingness to compensate farmers to intensify farming practices. Another example regards abandoned sites. Given the particularly strong negative effects of certain sites for society (e.g. health of children if a kindergarten was built on contaminated soil), there are clear regulations to reduce the input of related matters.

In contrast with cluster 1, however, this cluster seems to include a smaller number of relevant natural and non-natural locational factors. Here again, problems related to drinking water protection zones are a descriptive example. Whereas farmers and managers generally have to keep in mind a large set of dynamic and interconnected variables to address a problem (e.g. natural conditions, market prizes, regulations), this number is reduced if there are clear agreements to conduct organic cultivation for a certain period of time. This does not, however, regard all problems in this cluster, as the high standard deviation suggests.

In contrast to cluster 1, this cluster of problems is characterised by a particularly high degree of informational uncertainty regarding matters, natural locational factors and actor behaviour, among others. Industries or abandoned sites can pollute in various ways and it is sometimes not clear which type of matter is of relevance and how this matter pollutes the environment. Abandoned sites are particularly challenging given various natural conditions, and agricultural and industrial actors can act in various ways – which is often not transparent for water managers.

### ***Cluster 3: 'tame' problems***

Cluster 3 ('tame' problems) comprises 14 problems that share overall low factor values. Low system complexity and information uncertainty are the most distinctive factors of this cluster. In contrast to clusters 1 and 2, these problems mostly refer to surface waters and point sources. However, this group also includes one groundwater problem and four diffuse-source problems. Within this cluster, urban wastewater is the dominant polluter group. Other polluters are industry, storm water and agriculture.

Just as in clusters 1 and 2, there is a potential for goal conflicts, given the high costs for technical and non-technical solutions. Examples refer to the expansion of urban sewage treatment plants to reduce the input of nitrogen and phosphorus. Such expansions are cost-intensive and the underlying problem might better be addressed by agricultural measures. However, just as the problems in clusters 1 and 2, oppositions might not always be high and there might, at times, even be potential for win-win situations. This regards, for instance, the optimisation of urban wastewater plants, the construction of small sewage plants, inter-communal associations of existing sewage treatment plants or erosion in agriculture.

In contrast to cluster 1 and just as in cluster 2, there are rather few dynamic and interconnected variables as regards, for instance, natural conditions, actors and governance arrangements. The dominant polluter group in this cluster, urban sewage treatment plants, is not strongly affected by natural conditions such as soil conditions. There

are also rather few polluters (e.g. as compared with agriculture), and the set of governance strategies to address this problem seems rather low (e.g. sewage fees instead of compensation, persuasion and obligatory regulations). There are, however, important exemptions within this cluster, such as a possibly high number of actors and natural factors in storm water, among others.

Similar to cluster 1 and rather different from cluster 2, there are rather low uncertainties as regards the underlying factors such as natural and non-natural conditions, solution options, actors, responsibilities and governance arrangements. In the field of point source pollution of surface waters by urban wastewater treatment plants, these factors are rather clear, which may also simplify the solution to these problems. One exemption, however, are matters, given the growing importance of emerging pollutants such as micropollutants which may play, in some cases, an important role.

#### ***Cluster 4: wicked problems***

Cluster 4 (wicked problems) encompasses seven problems which are characterised by strong goal conflicts, in particular, and rather high system complexity and uncertainty. Cluster 4 thus contrasts quite well with cluster 3. Just as clusters 1 and 2, this cluster encompasses quite equally both surface water and ground water problems. In contrast to all other clusters, the number of diffuse source problems is particularly high. The dominant polluter group is agriculture. However, there are also two problems related to constructed areas and one problem related to point sources.

Compared with all other clusters, cluster 4 is characterised by particularly high goal conflicts. We find such goal conflicts in various types of problems such as leaching and drainage in agriculture, input of substances from constructed areas and the expansion of urban sewage treatment plants to reduce the input of other substances. Reducing pollution is very cost-intensive and society is not necessarily willing to compensate the polluter. In some cases, such as in the field of leaky sewage treatment plants, polluters also question the relevance of the cost-intensive measures to achieve WFD quality goals.

Just as in cluster 1 and in a certain contrast with clusters 2 and 3, the problems in this cluster involve a high number of natural (and non-natural) conditions and actors, among others. As most of the problems regard diffuse sources, these problems have a particularly high number of actors. This relates to micropollution just as to leaching in agriculture or to constructed areas. In some cases, there is also a large number of dynamically involving conditions such as weather and soil conditions. In terms of micropollution, a myriad of about 10,000 matters (e.g. different components of pharmaceuticals) complicate solutions to this problem.

These high numbers of dynamic and interconnected factors come along with rather high uncertainties, which further contrast problems in this cluster from clusters 1 and 3. We find uncertainty with regard to actor behaviour in particular. Managers simply do not know how much liquid manure farmers discharge on their soils, or how much fungicides landlords apply on the face of buildings – even though there are simulations for specific regions and towns. Furthermore, there are uncertainties regarding the impacts of natural conditions (e.g. pyrite as protection layers in soils) or substances (e.g. pharmaceuticals, antibiotic resistance genes) on solutions to problems.

### Impacts of types of water governance problems on policy delivery

This section depicts the effects of the clusters of problems on goal formulation, stages and degree of implementation.

#### Goal formulation

Figure 3 indicates that goal formulation – rated by the number of measures formulated per problem – varies significantly between clusters. This applies to both problems defined by LAWA (dataset of 37 water problems) and problems treated by public authorities (dataset of 34 water problems). German public authorities planned a particularly high number of measures related to problems in cluster 3, followed by clusters 4, 2 and 1.

The Levene-test attests to this first impression. Significant results beyond a .05 error level for both problems defined ( $p = .017$ ) and problems treated ( $p = .016$ ) indicate variance heterogeneity for both problems defined and problems treated, meaning that at least two clusters differ significantly in the two data sets.

The ANOVA further suggests that variance caused by the clusters is about three times higher than variance caused by unknown effects (problems defined:  $F = 2.758$ ; problems treated:  $3.020$ ). These results are significant for problems treated only ( $p = .045$ ; problems defined:  $p = .058$ ), which partly supports the theory that clusters differ significantly in their effects on goal formulation. Post-hoc tests, however, do not substantiate significant variance between specific clusters of water governance problems.

The effect size as indicated by Eta-squared shows that about 20% of the identified variety in the dependent variable can be traced back to clusters of water governance problems (problems defined:  $\eta^2 = .2000$ ; problems treated:  $\eta^2 = .232$ ). Given general multi-causality, this can be interpreted as a rather high value.

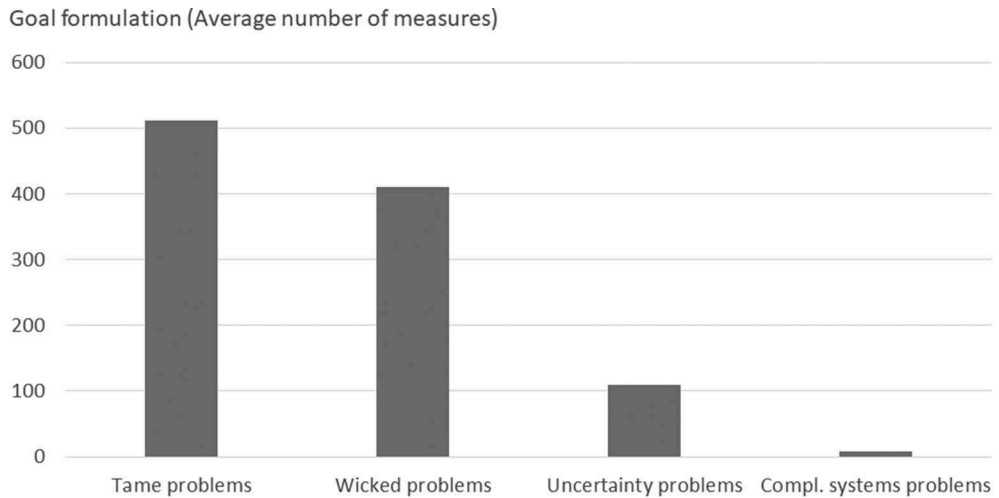


Figure 3. Goal formulation as indicated by the average number of measures per cluster of water governance problems.



### Stages of implementation

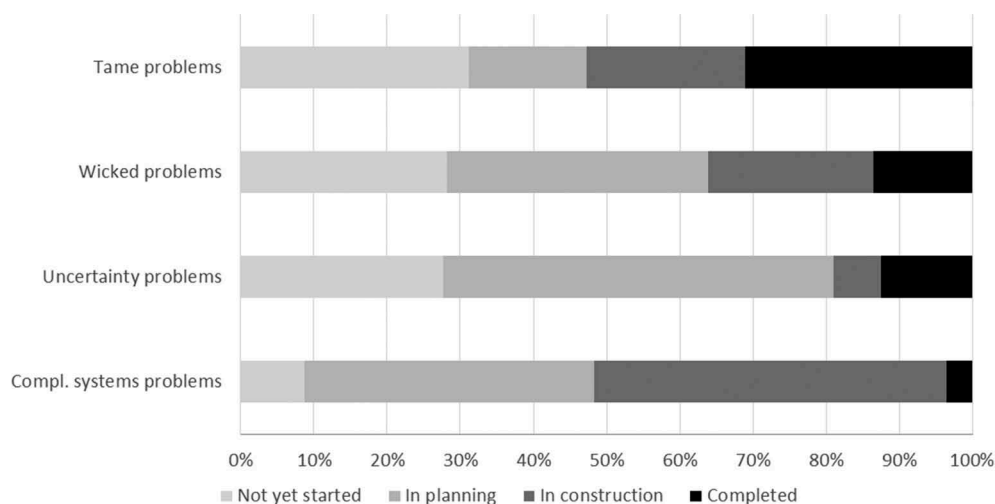
Based on a data set of 34 problems, Figure 4 indicates that the percentage of measures that are 'not yet started', 'in planning', 'in construction' and 'completed' vary between clusters.

The Levene-test partially substantiates this first impression. We find significant results beyond a .01 error level for measures 'in planning' ( $p = .008$ ) and measures 'in construction' ( $p = .094$ ), indicating that at least two clusters differ significantly in these two data sets. There is, however, variance homogeneity for the measures that are 'not yet started' ( $p = .181$ ) and measures 'completed' ( $p = .094$ ).

The ANOVA further suggests that variance caused by the clusters is generally higher than variance caused by unknown effects. The treatment variance and their significance depends, however, from the phase of implementation, with rather low effects for measures 'not yet started' ( $F = .652$ ), and rather high effects for measures 'in planning' ( $F = 2.270$ ), 'in construction' ( $F = 3.114$ ) and 'completed' ( $F = 3.090$ ). These results are significant beyond a .05 error level for measures 'in construction' ( $p = .041$ ) and 'completed', and non-significant for measures that are 'not yet started' ( $p = .588$ ) or 'in planning' (.101). This supports the idea that clusters differ significantly in their effects on measures 'in construction' and do not vary in their effects on measures 'not yet started', 'in planning' and 'completed'.<sup>1</sup>

The post-hoc tests substantiate these results giving significant results only for measures 'in construction'. These results show that clusters 1 and 2 differ significantly beyond a .05 error level ( $p = .023$ ), with a high number of measures 'in construction' in cluster 1 and a particularly low number of measures 'in construction' in cluster 2.

Furthermore, the effect size as indicated by Eta-squared is rather high for measures 'in planning' ( $\eta^2 = .185$ ), measures 'in construction' ( $\eta^2 = .237$ ) and measures



**Figure 4.** Four stages of implementation ('not yet started', 'in planning', 'in construction', 'completed') per cluster of water governance problems (cluster 1–4).

<sup>1</sup>In terms of measures 'completed', the non-significant results based on the Levene-test and the significant results of the ANOVA beyond a .05 error level are due to interpretation. Literature suggests, however, using a .01 error level in the ANOVA in order to identify significance in case of non-significant results of the Levene-test.

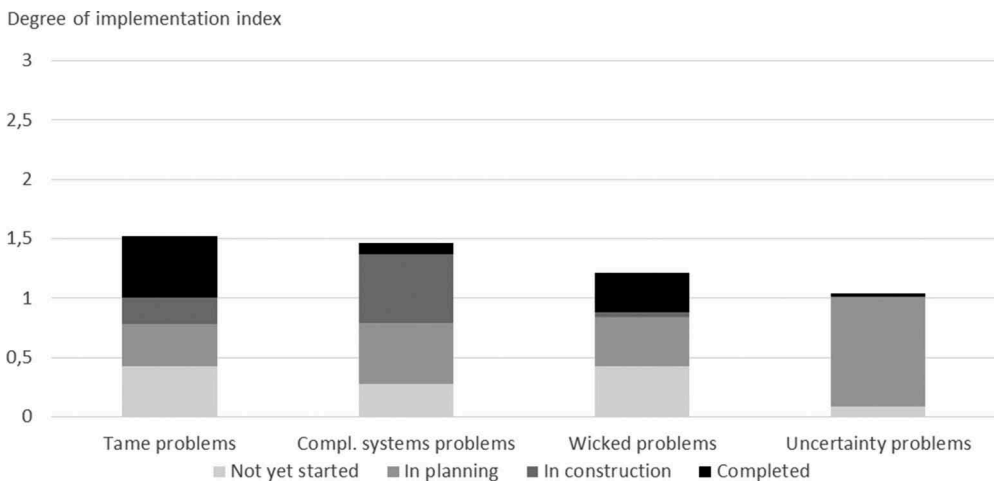
‘completed’ ( $\eta^2 = .236$ ), indicating that about 20% of the identified variance can be traced back to clusters of water governance problems. Additionally, the effect size is rather low for measures ‘not yet started’ ( $\eta^2 = .061$ ), indicating that about 6% of the identified variance can be traced back to clusters of water governance problems.

### *Degree of implementation index*

Based on a data set of 34 problems, Figure 5 indicates that the degree of implementation index varies only slightly between clusters. The Levene-test substantiates this first impression. We find non-significant results for the degree of implementation index ( $p = .536$ ), indicating variance homogeneity between the clusters. The ANOVA further confirms this, given that variance caused by the clusters is only about one time higher than variance caused by unknown effects ( $F = 1.225$ ). These results are also non-significant ( $p = .318$ ). The post-hoc tests further substantiate that variance between the clusters is non-significant. The effect size as indicated by Eta-squared is rather low ( $\eta^2 = .109$ ), indicating that about 10% of the identified variety can be traced back to clusters of water governance problems.

## Discussion and conclusion

Public policy scholars have increasingly argued for diverse types of problems and effects on policy delivery along the concept of wickedness. So far, however, research on wicked problems has been mainly theoretical or based on single case study approaches, hindering an empirical substantiating of different types and effects of problems. We provide here an *explorative* study, using cluster analysis as a starting point to identify types and effects of water governance problems. This explorative approach has first revealed a variety of water governance problems and effects on policy delivery. There are clearly four clusters of water governance problems (complex systems, uncertainty, tame and wicked problems), based on variations of three factors (goals, uncertainty and system complexity). These clusters of problems also vary in their effects on different



**Figure 5.** Degree of implementation index per cluster of water governance problems (cluster 1–4).

dimensions of policy delivery (goal formulation, stages and degrees of implementation), with significant effects on goal formulation and the number of measures ‘in construction’.

These results empirically substantiate current discourses on types of problems in public policy analysis. Public policy scholars increasingly call for differentiating wicked problems from other types of ‘difficult’ problems, based on perceptions by academics and practitioners (e.g. Peters, 2017). They particularly argue to go beyond simple dichotomies of wicked and tame problems, e.g. based on three dimensions of wickedness (e.g. Alford and Head, 2017; Head, 2008). So far, however, these operationalisations of wickedness have not been substantiated empirically. Our analysis first substantiates these claims based on a larger scale empirical analysis of water-related problems. The significant correlation between dimensions of complexity is, however, surprising, given strong reasons for separate impacts of variables, dynamics and interconnections. The significant correlations might be traced back to the role of natural scientific factors in our specific case, as compared with other areas of public policy such as social policy. Another reason might be the generally higher number of variables in public policy as compared with cases in psychological research on complex problem-solving. The higher the number, the more likely are findings of dynamics and interconnections, which could result in equal rankings of these dimensions even though there is, in fact, variety. Irrespective of the reasons for this correlation, we see the empirical substantiation of the dimension of complexity as an important contribution to the theoretical arguments made by Head (2008). This empirical substantiation suggests applying this operationalisation to further cases as well, which do not relate to Germany and the Water Framework Directive.

Turning to the effects of clusters, our results substantiate the mostly implicit assumption that clusters of wickedness public policy problems matter for policy delivery. Policy scholars often argue that types of public policy problems affect solutions. We firstly show that this is, in fact, the case for the delivery of policies. Three sorts of effects of problems are particularly important here. The first one is the effect of wicked or tame types of problems on the one hand and more diverse types of problems on the other hand. Literature on wicked and complex problem-solving continuously suggests that addressing wicked problems is particularly challenging. Our results, however, question this assumption. Clusters 3 and 4, which represent problems of particularly low and high degrees of wickedness, are rather similar in their effects of goal formulation and implementation. Moreover, clusters 1 and 2, which rather represent intermediate forms between tame and wicked problems, have particularly significant impacts on policy delivery. These results may hint to more complex effects of problem types on solutions beyond simple dichotomies of success and failure of wicked and tame problems.

Furthermore, we observe more significant results on goal formulation than on implementation, in the sense that if problems are particularly wicked or tame, problem solvers would rather formulate goals to address these problems. In terms of tame problems, this is rather plausible. In terms of wicked problems, we need an explanation. In case of high pressure, for instance, problem solvers may put wicked problems on the agenda without weighing arguments. For instance, psychology research suggests that problem solvers are more likely to take quick and extreme decisions if they experience both difficulty to address complexity and pressure to act (Dörner, 1980, 1996).

Similarly, from a public policy perspective, policy makers have been found to (quickly) produce decisions if faced with high problem complexity and societal pressure (Newig, 2007). Both psychology and public policy scholars emphasise, however, that such quick decisions are likely to remain ineffective or merely symbolic (Dörner, 1980, 1996; Head, 2008; Newig, 2007).

Significant variances in terms of measures ‘in construction’ may be best explained by considering the differences between clusters 1 and 2. Compared with cluster 1, problems in cluster 2 have a particularly low system complexity and goal conflicts and a particularly high degree of informational uncertainty. Compared with cluster 1, these characteristics delay the implementation of measures, meaning that related measures are rather ‘not yet started’ or ‘in planning’ than ‘in construction’. Whereas there are several structural differences between problems in cluster 1 and 2, it is rather reasonable to assume that the high ‘informational uncertainty’ in clusters 2 hinders – whatever polluter group – the quick implementation of measures. This is also in line with the fact that uncertainty generally correlates negatively with the implementation of measures (Kirschke et al., 2017b). However, it may also be possible that the policy field of mining has specific effects on policy delivery, given that most of the problems in cluster 1 relate to mining.

How may these results benefit governance strategies to address the wicked problem of poor water quality? Based on our analysis, it is reasonable to consider how different governance strategies facilitate or impede addressing different types of water governance problems. In the context of the European Water Framework Directive, the participation of stakeholders has been continuously suggested to address the complex problem of poor water quality, and diffuse pollution, in particular. Based on our results, however, we suggest to considering specific forms of participation such as participatory modelling (modelling by scientists and practitioners, Gaddis, Falk, Ginger, & Voinov, 2010) that systematically address certain features of water governance problems such as system complexity. This may help to overcome potential failures of evidence-based policy-making in the light of general tendencies to wicked problems (Newman & Head, 2017).

Beyond the field of water governance, we believe that our findings offer new perspectives to the scholarship on the governance of public policy problems more generally. This first regards the existence of clusters. Can we find, in other policy fields, similar types of clusters? Or are types of clusters such as ‘complex systems’ or ‘uncertainty’ clusters specific to individual policy fields such as social policy or environmental policy, e.g. in contrast to other policy fields such as transport policy? And can we identify in other policy fields new types of clusters such as problems with particularly high goal conflicts and low system complexity and uncertainty?

Based on such considerations, our research results may pave the way for further comparative analysis on the effects of clusters of public problems on policy delivery. Do we find, in other policy fields, the same type of effects of clusters on policy delivery? Or do the effects differ, due to other influencing factors such as social complexity or the numbers of actors involved (e.g. Peters, 2017) which are excluded in our understanding of wickedness? Such analyses would clarify to which degree these three dimensions of wickedness account for effects.

Such analyses may also help to systematically test the role of governance strategies for addressing public policy problems, instead of suggesting ‘one-size-fits-all’ models to

address wicked in problems in general – which have recently been questioned by wicked problem scholars (Alford and Head, 2017). If we find, for instance, clusters of problems related to different policy fields, the role of governance strategies can be tested along such clusters, opening up for going beyond policy field-related governance analyses. We may test, for instance, specific participatory modes of governance to address ‘complex systems’ problems (e.g. different forms of participatory modelling) regardless if they are more related to education, health or the environment. By the same token, the role of specific participatory modes of governance (e.g. different types of actors, involved to different degrees, at various stages of the problem-solving process) can be tested along different types of clusters such as ‘uncertainty’ and ‘complex systems’ problems.

We suggest such future analyses to be based on a higher number of problems, which may also be based on a higher number of assessments by policy experts. A higher number of problems may help to identify more fine-tuned sets of problem clusters. Building on more experts helps to validate the results provided in this study, since the degree of wickedness is likely to depend on the uncertainty related to the problem area. Moreover, future analysis could deepen the comparative analysis provided in this paper in terms of temporal and regional scales. In this research, we provided a snapshot of wicked problems in Germany. Building on these results, future research could analyse how problem wickedness changes over time or in different regional contexts. In which way does, for instance, the wickedness of micropollution changes over time, e.g. due to new knowledge on the effects of pharmaceuticals in socio-ecological systems? And are, for instance, micropollution and leaching in agriculture also wicked problems in other countries than Germany, e.g. in developing countries which apparently do not face such a high risk of pharmaceuticals in wastewater or an excessive application of nitrogen in agriculture?

Furthermore, in terms of policy delivery, more comprehensive understandings of policy delivery that go beyond our quantitative understanding are of relevance for future research. One important step forward may be here a combined approach with qualitative measurements of solutions in small n-comparative case study designs. Moreover, one important way forward is to understand the effects of problem types in relation to other influencing factors of policy delivery such as trigger events (e.g. floods resulting in enhanced pollution levels due to combined sewer overflows), influence of interest groups to put particular issues on the agenda (e.g. pesticides in agriculture) or governance strategies to implement measures (e.g. hard law, incentives, persuasion). Following these suggestions, analysing clusters of public policy problems is likely to be an advantageous starting point for identifying governance strategies beyond predefined policy fields and scales.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Notes on contributors

*Sabrina Kirschke* is a senior research associate at the United Nations University - Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES). As a political scientist, she is engaged in research, academic and capacity development activities in water resources management within the water-soil-waste nexus.

*Christian Franke* is a mathematician and has a PhD in economics. He has a specialisation in econometrics and multivariate data analysis related to international agricultural development. Before retirement, he was formerly a senior research fellow at the Humboldt-University of Berlin.

*Jens Newig* holds the chair of governance and sustainability at Leuphana University Lüneburg, Germany. He has led projects and published widely on topics of public policy, multi-level, collaborative and participatory governance, institutional change and policy failure, and global environmental governance. Areas of application include sustainable water governance, food and agriculture, and energy transition.

*Dietrich Borchardt* holds the Chair of Aquatic Ecosystem Analysis and Management in a joint appointment of the Helmholtz Centre for Environmental Research-UFZ with TU Dresden, Germany. He has led projects and published widely on human impacts on aquatic ecology, water quality and water security. Areas of application include sustainable water governance and Integrated Water Resources Management.

## ORCID

Sabrina Kirschke  <http://orcid.org/0000-0003-1036-3756>

## References

- Alford, J., & Head, B. W. (2017). Wicked and less wicked problems: A typology and contingency framework. *Policy & Society*, 36(3), 397–413.
- Batie, S. S. (2008). Wicked problems and applied economics. *American Journal of Agricultural Economics*, 90(5), 1176–1191.
- BMU (Ed.) (2010). *Water framework directive*. The way towards healthy waters. Retrieved from <https://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/4021.pdf>
- BMU (Ed.) (2013). *Water framework directive*. Implementation of WFD programmes of measures – interim results 2012. Retrieved from [https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/water\\_framework\\_direktive\\_2012\\_broschuere\\_wrrl\\_en\\_bf.pdf](https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/water_framework_direktive_2012_broschuere_wrrl_en_bf.pdf)
- BMUB/UBA (2016). Water framework directive – The status of German waters 2015. Retrieved from [https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/wrrl\\_englische\\_version\\_dez\\_2016.pdf](https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/wrrl_englische_version_dez_2016.pdf)
- Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA) (2013, August). Anlage. Fortschreibung LAWA-Maßnahmenkatalog (WRRL, HWRM-RL). Beschlossen auf der 146. LAWA-VV am 26./27. September 2013 in Tangermünde. LAWA-Arbeitsprogramm Flussgebietsbewirtschaftung. Produktdatenblatt WRRL-2.3.3. Stand 23. Retrieved from [http://www.wasserblick.net/servlet/is/142651/WRRL\\_2.3.3\\_Massnahmenkatalog\\_Anlage\\_24.01.2014.pdf?command=downloadContent&filename=WRRL\\_2.3.3\\_Massnahmenkatalog\\_Anlage\\_24.01.2014.pdf](http://www.wasserblick.net/servlet/is/142651/WRRL_2.3.3_Massnahmenkatalog_Anlage_24.01.2014.pdf?command=downloadContent&filename=WRRL_2.3.3_Massnahmenkatalog_Anlage_24.01.2014.pdf)
- Churchman, C. W. (1967). Wicked problems. *Management Science*, 14(4), B141–B142.
- Cilliers, P., Biggs, H. C., Blignaut, S., Choles, A. G., Hofmeyr, J. S., Jewitt, G. P. W., & Roux, D. J. (2013). Complexity, modeling, and natural resource management. *Ecology and Society*, 18(3), 1.
- Commission of the European Communities (COM). (2007). *Communication from the commission to the European Parliament and the council*. Towards sustainable water management in the European Union – First stage in the implementation of the Water Framework Directive 2000/60/EC, Brussels, Belgium.
- Cronin, M. A., Gonzalez, C., & Sterman, J. D. (2009). Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. *Organizational Behavior and Human Decision Processes*, 108(1), 116–130.
- DeFries, R., & Nagendra, H. (2017). Ecosystem management as a wicked problem. *Science*, 356(6335), 265–270.



- Dörner, D. (1980). On the difficulties people have in dealing with complexity. *Simulation & Gaming*, 11(1), 87–106.
- Dörner, D. (1996). *The logic of failure: Recognizing and avoiding error in complex situations*. New York: Basic Books.
- Duckett, D., Feliciano, D., Martin-Ortega, J., & Muñoz-Rojas, J. (2016). Tackling wicked environmental problems: The discourse and its influence on praxis in Scotland. *Landscape and Urban Planning*, 154, 44–56.
- Durant, R. F., & Legge, J. S. (2006). “Wicked problems,” public policy, and administrative theory. Lessons from the GM food regulatory arena. *Administration & Society*, 38(3), 309–334.
- Ferlie, E., Fitzgerald, L., McGivern, G., Dopson, S., & Bennett, C. (2011). Public policy networks and ‘wicked problems’: A nascent solution? *Public Administration*, 89(2), 307–324.
- FritzGibbon, J., & Mensah, K. O. (2012). Climate change as a wicked problem. *Sage Open*, 2, 1–14.
- Funke, J. (2012). Complex problem solving. In N. Seel (Ed.), *Encyclopedia of the sciences of learning* (pp. 682–685). New York: Springer.
- Gaddis, E. J. B., Falk, H. H., Ginger, C., & Voinov, A. (2010). Effectiveness of a participatory modeling effort to identify and advance community water resource goals in St. Albans, Vermont. *Environmental Modelling & Software*, 25(11), 1428–1438.
- Head, B. W. (2008). Wicked problems in public policy. *Public Policy*, 3(2), 101–118.
- Head, B. W., & Alford, J. (2013). Wicked problems: Implications for public policy and management. *Administration & Society*, 47(6), 711–739.
- Head, B. W., & Xiang, W. N. (2016). Why is an APT approach to wicked problems important? *Landscape and Urban Planning*, 154, 4–7.
- Hoppe, R. (2011). *The governance of problems: Puzzling, powering and participation*. Bristol: Policy Press.
- Howlett, M., & Lejano, R. P. (2013). Tales from the crypt: The rise and fall (and rebirth?) of policy design. *Administration & Society*, 45(3), 357–381.
- Howlett, M., Mukherjee, I., & Woo, J. J. (2015). From tools to toolkits in policy design studies: The new design orientation towards policy formulation research. *Policy & Politics*, 43(2), 291–311.
- Huntjens, P., Lebel, L., Pahl-Wostl, C., Camkin, J., Schulze, R., & Kranz, N. (2012). Institutional design propositions for the governance of adaptation to climate change in the water sector. *Global Environmental Change*, 22, 67–81.
- Ingraham, W. (1987). Toward more systematic consideration of policy design. *Policy Studies Journal*, 15(4), 611–628.
- Jentoft, S., & Chuenpagdee, R. (2009). Fisheries and coastal governance as a wicked problem. *Marine Policy*, 33, 553–560.
- Kirschke, S., Borchardt, D., & Newig, J. (2017a). Mapping complexity in environmental governance: A comparative analysis of 37 priority issues in German water management. *Environmental Policy and Governance*, 27(6), 534–559.
- Kirschke, S., & Newig, J. (2017). Addressing complexity in environmental management and governance. *Sustainability*, 9, 983.
- Kirschke, S., Newig, J., Völker, J., & Borchardt, D. (2017b). Does problem complexity matter for environmental policy delivery? How public authorities address problems of water governance. *Journal of Environmental Management*, 196, 1–7.
- Lach, D., Rayner, S., & Ingram, H. (2005). Taming the waters: Strategies to domesticate the wicked problems of water resource management. *International Journal of Water*, 3(1), 1–17.
- Levin, K., Cashore, B., Bernstein, S., & Auld, G. (2012). Overcoming the tragedy of super wicked problems: Constraining our future selves to ameliorate global climate change. *Policy Sciences*, 45(2), 123–152.
- Loorbach, D. (2010). Transition management for sustainable development: A prescriptive, complexity-based governance framework. *Governance*, 23(1), 161–183.



- Metz, F., & Ingold, K. (2014). Sustainable wastewater management: Is it possible to regulate micropollution in the future by learning from the past? A policy analysis. *Sustainability*, 6(4), 1992–2012.
- Newig, J. (2007). Symbolic environmental legislation and societal self-deception. *Environmental Politics*, 16(2), 276–296.
- Newig, J., & Koontz, T. M. (2014). Multi-level governance, policy implementation and participation: The EU's mandated participatory planning approach to implementing environmental policy. *Journal of European Public Policy*, 21(2), 248–267.
- Newman, J., & Head, B. W. (2017). Wicked tendencies in policy problems: Rethinking the distinction between social and technical problems. *Policy & Society*, 36(3), 414–429.
- Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: Towards adaptive water governance in river basins. *Environmental Science & Policy*, 23, 24–34.
- Patterson, J. J., Smith, C., & Bellamy, J. (2013). Understanding enabling capacities for managing the 'wicked problem' of nonpoint source water pollution in catchments: A conceptual framework. *Journal of Environmental Management*, 128, 441–452.
- Peters, B. G., & Pierre, J. (2015). Governance and policy problems: Instruments as unitary and mixed modes of policy intervention. *Asia Pacific Journal of Public Administration*, 37(4), 224–235.
- Peters, G. B. (2005). The problem of policy problems. *Journal of Comparative Policy Analysis*, 7(4), 349–370.
- Peters, G. B. (2017). What is so wicked about wicked problems? A conceptual analysis and a research program. *Policy and Society*, 36(3), 385–396.
- Rittel, H. W. J., & Webber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4, 155–169.
- Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review*, 16(4), 249–286.
- Termeer, C. J., Dewulf, A., Breeman, G., & Stiller, S. J. (2015). Governance capabilities for dealing wisely with wicked problems. *Administration & Society*, 47(6), 680–710.
- van Meter, D. S., & van Horn, C. E. (1975). The policy implementation process. A conceptual framework. *Administration & Society*, 6(4), 445–488.
- Voss, J.-P., & Kemp, R. (2006). Sustainability and reflexive governance: Introduction. In J.-P. Voss, D. Bauknecht, & R. Kemp (Eds.), *Reflexive governance for sustainable development* (pp. 3–28). Cheltenham: Edward Elgar Publishing.
- Voss, J.-P., Newig, J., Kastens, B., Monstadt, J., & Nölting, B. (2007). Steering for sustainable development: A typology of problems and strategies with respect to ambivalence, uncertainty and distributed power. *Journal of Environmental Policy & Planning*, 9(3–4), 193–212.
- Weber, E. P., & Khademian, A. M. (2008). Wicked problems, knowledge challenges, and collaborative capacity builders in network settings. *Public Administration Review*, 68(2), 334–349.
- Xiang, W.-N. (2013). Working with wicked problems in socio-ecological systems: Awareness, acceptance, and adaptation. *Landscape and Urban Planning*, 110, 1–4.

## Annex

**Table A1.** Correlations between five dimensions of wickedness. Depicted are parametric correlation coefficients (Pearson) and error probabilities.

Dimensions of Complexity		Goals	Variables	Dynamics	Connections	Uncertainty
Goals	<i>p</i>	1.000	.162	.068	.031	.306
	<i>P</i>	.	.339	.691	.854	.065
Variables	<i>p</i>	.162	1.000	.562**	.636**	.264
	<i>P</i>	.339	.	.	.	.118
Dynamics	<i>p</i>	.068	.562**	1.000	.648**	.232
	<i>P</i>	.691	.000	.	.	.167
Interconnections	<i>p</i>	.031	.636**	.648**	1.000	.227
	<i>P</i>	.854	.	.	.	.176
Uncertainty	<i>p</i>	.306	.262	.232	.227	1.000
	<i>P</i>	.065	.118	.167	.176	.

\*\*The correlation is significant at the 0.01 level (two-tailed).

**Table A2.** Rotated component matrix.

Dimensions of Wickedness	Factor 1 'System complexity'	Factor 2 'Goals'	Factor 3 'Uncertainty'
Goals	.041	<b>.982</b>	.151
Variables	<b>.834</b>	.171	.097
Dynamics	<b>.847</b>	-.009	.111
Interconnections	<b>.885</b>	-.048	.102
Uncertainty	.156	.157	<b>.975</b>

**Table A3.** Clusters of wicked problems. The table shows mean values, ranges and standard deviations and *F*-values for three factors and four clusters.

Cluster	<i>N</i>	Factor	Mean value	Range	Standard deviation	<i>F</i>
1	6	1	1.3223788	.67594	.23200940	.054
		2	-.7559019	.85221	.33896954	.115
		3	-.7335673	1.01955	.37753328	.143
2	10	1	-.0687962	2.93299	.96413648	.930
		2	-.5285016	2.61843	.69548835	.484
		3	1.2524608	2.11129	.74958390	.562
3	14	1	-.7529936	1.75771	.49296794	.243
		2	-.1132070	2.22902	.57192585	.327
		3	-.6868413	1.71188	.43209004	.187
4	7	1	.4708000	2.69052	.83432569	.696
		2	1.6293322	1.49471	.55316095	.306
		3	.2132249	1.68741	.57231413	.328

**Table A4.** Distribution of types of sources, waters, and polluters along four clusters of wicked problems. each type of problem (water, sources, and polluters) has a total sum of 37 problems.<sup>a</sup>

Cluster	Type of water		Type of source		Type of polluter							
	SW	GW	DS	PS	AGR	MIN	AS	CA	UW	STW	IND	OTH
1	3	3	4	2		4	1					1
2	6	4	5	5	3	2	2				2	1
3	13	1	4	10	3				7	3	1	
4	4	3	6	1	4			2	1			

<sup>a</sup>SW = Surface waters, GW = Groundwater, DS = Diffuse sources, PS = Point sources, AGR = Agriculture, MIN = Mining, AS = Abandoned Sites, CA = Constructed Areas, UW = Urban wastewater, STW = Storm water, IND = Industry, OTH = Others.

**Table A5.** Mean values and standard deviation for different phases of policy delivery per cluster of problems.<sup>a</sup>

Policy delivery	N	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
		M	SD	M	SD	M	SD	M	SD
Goal formulation (problems defined)	37	8.00	9.21	110.20	225.70	512.29	503.50	410.14	655.39
Goal formulation (problems treated)	34	9.60	9.32	110.20	225.70	551.69	501.08	478.50	690.06
Measures ‘Not yet started’	34	8.72	13.88	27.60	35.29	31.18	30.65	28.23	34.08
Measures ‘In planning’	34	39.61	43.17	53.47	42.64	16.12	21.52	35.72	35.81
Measures ‘In construction’	34	48.15	43.41	6.42	9.43	21.67	23.58	22.58	27.21
Measures ‘Completed’	34	3.53	7.89	12.50	21.09	31.03	23.18	13.46	15.41
Degree of Implementation index	34	1.46	.38	1.04	.55	1.53	.77	1.21	.62

<sup>a</sup>M = Mean value, SD = Standard deviation. Rounded to two decimal places.