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Decoding the Wickedness of Resource Nexus Problems—Examples from Water-Soil Nexus Problems in China

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Abstract: Managing environmental resources in a nexus manner is typically denoted as a highly wicked problem. Such denotations are, however, barely based on clearly defined dimensions and degrees of wickedness. This hinders the application of effective policy and governance strategies to address nexus problems in practice. This study provides a conceptually thorough analysis of the wickedness of resource nexus problems, taking specific water-soil nexus problems in the Loess plateau in China as an example. Analyses are based on a clear operationalization of wicked problems, as provided in the literature on public policies, the nexus, and the case study area. Results show that resource nexus problems generally fulfill the theoretical criteria of wicked problems, namely the existence of highly conflicting goals, high system complexity, and high informational uncertainty. Consequently, traditional policy and governance strategies to address wicked problems such as participatory modes of governance may be fruitful in order to deal with resource nexus problems in general and in the Loess plateau, more particularly.

Keywords: conflicts; complexity; uncertainty; soil and water management; wicked problems

1. Introduction

Nexus problems such as the water-energy nexus or the nexus of water, energy and food are traditionally labelled as being complex or wicked [1–6]. This also corresponds to closely-related environmental resource concepts and problems such as ecosystem management [7], an Integrated Water Resources Management [8], or diffuse pollution of waters [9,10]. The label of wicked problems generally hints at the challenges of defining and solving a problem, given the existence of diverse interests and values of stakeholders, as well as numerous interconnected factors that, if not sufficiently taken into account, may result in various negative side-effects of actions. One prime example is the diffuse pollution of water resources by agricultural practices. To address this issue, there are different types of stakeholders involved such as farmers, consumers, and environmental non-governmental organizations. These stakeholders may have diverging interests such as ecological or economic benefits. Moreover, addressing pollution may have various impacts on the complex social-ecological system in the short and long term.

To better define and address such problems, research recommends specific policies and governance strategies. In environmental management, the complexity of the issue often results in recommendations to apply transdisciplinary research as well as adaptive learning and participatory modes of governance. The basic idea here is that the continuous participation of various actors, such as citizens or politicians, in research and planning processes helps to define and address complex resource management

problems more comprehensively and effectively [7,8,11]. In the example of diffuse pollution by agriculture, this would mean, for instance, the involvement of farmers' organizations or individual farmers in the process of defining and addressing the pollution problem.

Assumptions on the wickedness of problems are, however, hardly based on a clear-cut operationalization of wicked problems. Most importantly, it remains unclear which dimensions and factors substantiate the wickedness of nexus problems. Are conflicting goals related to the use of resources particularly challenging? Or is it the number of interconnected factors or the lack of data and information? And do mainly natural factors contribute to the complexity of the problem or do socio-economic and political dimensions also play an important role?

Such a lack of understanding ultimately hinders the identification of effective policy and governance strategies to address wicked nexus problems in theory and practice. Research has suggested, for instance, partly effective participatory modes of governance to address conflicting goals or a lack of data [12–16]. But how can we know which participatory modes of governance are most effective in a specific case, considering the vague nature of problem descriptions? Take, for instance, the recurrent suggestion of involving citizens in complex problem solving. The relevance of their involvement may significantly depend on problem features and needs. If there is great uncertainty with regards to citizens' interests, involving citizens in the process may be of value. If, however, technical knowledge is required, it may be more beneficial to involve scientists.

Against this background, this study aims to apply recognized concepts of wickedness to clarify the wickedness of natural resource management problems. It further illustrates the wickedness of nexus complexities along an example of a soil–water nexus problem in China. Nexus problems encompass a broad spectrum of different types of challenges [17]. This paper focusses on resource nexus problems in general and an integrated management of water and soil in particular. These problems refer to sustainability challenges at different scales, that involve more than one resource (e.g., water, soil, and waste), that are not addressed coherently (in terms of policy and governance strategies), thereby hindering sustainable development (in terms of bio-physical, social, and economic dimensions) [18]. Understanding the wickedness of these problems is particularly helpful, since it can support the design of policy and governance strategies that allow for a coherent and holistic assessment of nexus problems in the future [19–21].

In order to achieve this goal, Section 2 discusses basic concepts for the wickedness analysis. In a first step, this section provides a clear operationalization of wicked problems, drawing on analyses in public policy and environmental management. We particularly refer to existing operationalizations of wicked problems which differentiate various dimensions and degrees. In a second step, this section also expands on our understanding of resource nexus problems in general and the specific China case in the Loess plateau more particularly. Based on these clarifications of basic concepts, Section 3 delineates the methodology used to define wicked problems. This section shows how we arrived at the assessment of wickedness using a questionnaire to determine the wickedness of the nexus problem (see Supplementary Materials Annex 1) and the methodological approach to categorize whether answers to the questions indicate low, middle, or high degrees of wickedness (see Supplementary Materials Annex 2). The questionnaire was answered by the authors based on three focus group discussions and an analysis of relevant literature, drawing on both policy field and case-related literature. In Section 4, the results are presented, describing typical goal conflicts, system complexities, and informational uncertainties, from both a natural science and a social science perspective. Sections 5 and 6 discuss and conclude on the relevance of the results for identifying policy and governance strategies to address nexus problems in the future.

2. Basic Concepts

2.1. Wicked Problems

In nexus research [1,3,5], wickedness generally serves as a label for a sum of challenges in addressing nexus problems in practice. These challenges refer to the high number of interdependent

factors such as natural and socio-economic conditions as well as diverse political contexts. Their identification leads to new management and governance strategies such as adaptive management or participatory forms of governance to address wicked problems in practice: If a problem is highly complex, the involvement of actors in decision-making processes is particularly relevant; if it concerns a rather tame problem, top down modes of governance seem more convenient [11].

Adding to this research, we argue for a specific description of nexus problems along dimensions and degrees of wickedness. This mainly goes back to the issue of conceptual stretching: If a term is not clearly defined, the concept is not very useful for describing problems in a comparative way. If, for instance, some researchers use the concept to highlight varying perspectives of stakeholders whereas others refer to interlinkages of natural factors, the use of the term does not say a lot about similarities and differences of problems. This also influences the identification of governance strategies to address problems in practice. Whereas deliberation may be particularly helpful to address various perspectives of stakeholders, an expert's modeling efforts are recommended to address natural interlinkages [16].

Fortunately, public policy analyses provide an important operationalization of wicked problems, which can be applied to resource nexus problems. First, research on wicked problems generally emphasizes that there are several dimensions, such as goal diversity, non-solvability, or delayed side-effects of actions [13,22–25]. For the purpose of this analysis, the conceptualization of Head [22] is followed, differentiating three dimensions, namely divergence, complexity, and uncertainty. This differentiation clearly separates underlying structures of problems from their effects such as difficulties in addressing problems. It also focusses on core dimensions that probably affect the possibility and choice of solutions and governance strategies. Moreover, empirical analyses in the field of water management have substantiated the relevance of these three dimensions [26]. We believe, therefore, that they can also be applied to nexus problems that involve more than one resource.

Turning to the degrees of wickedness, public policy analysis provides, again, various conceptualizations, such as numerical scales from 0 to 1, or binary concepts in which tame and wicked problems are contrasted [22–24,27,28]. We will draw on Head [22] who convincingly differentiates low, medium, and high values of the three dimensions. Such an operationalization goes beyond studies that contrast (super-) wicked from tame problems. This is particularly important since empirical evidence has shown that resource management problems can have various degrees of wickedness [29]. On the other hand, differentiating these three degrees allows for the identification of solutions and governance strategies to problems, e.g., in contrast to conceptualizations providing gradual variations on a scale from more simple or tame to more complex or wicked.

Against this background, we refer wickedness to the three dimensions of goal conflicts (or divergence), system complexity and informational uncertainty and specify that these three dimensions can have low, medium and high values. In doing so, the concept of wickedness is greatly congruent with the operationalization of complex problems in psychology and environmental governance research, which differentiate three to five dimensions of complex problems, amongst them conflicts, uncertainty and interconnected systems [26,29,30]:

1. Goals, including their number and relationship with each other, varying from 'goal singularity' to a 'plurality of prioritized goals' up to a 'plurality and non-prioritized goals';
2. System complexity, referring to the number of dynamic and interdependent factors that characterize problems, varying from a 'low and manageable number' to a 'challenging number' up to an 'overcharging number of dynamic and interrelated variables';
3. Informational uncertainty, referring to how much information is missing for problem solving, varying from 'informational certainty' to 'manageable uncertainty' up to 'an important, non-manageable lack of information';

In the following, it is shown how these dimensions can be analyzed in practice.

2.2. The Resource Nexus Problem

Describing the wickedness of resource nexus problems requires a clear definition of such problems first. Although resource problems can take various forms, three core components exist: First, more than one environmental resource is at stake in practical management, for instance, water (quantity and quality of surface waters and groundwater), soil (quantity and quality), and waste (such as wastewater which may be used for irrigation). The consideration of these resources defines clear resource-related boundaries that influence policy design and development. Resource nexus approaches thus also have a different focus than sectoral nexus approaches. Whereas the sectoral nexus focuses on sectoral needs and thus the provision of essential services, the resource nexus focuses on the natural elements supporting sectoral development. For human beings, the sector thus constitutes a link to the service that a resource provides [18,20,31]. Second, the resources involved are not managed coherently, meaning that synergies and trade-offs are not managed at the same time. In practice, this means, for instance, that soil is managed without taking into consideration water-related aspects, or vice versa, that water is used without considering potential impacts on soil quality. Third, incoherent management is likely to negatively impact sustainable development in its environmental, social, and economic dimensions (see Table 1).

To illustrate the wickedness of resource nexus problems, an example of water and soil resource management in the Loess Plateau in Northwest China is provided. The Loess Plateau (640,000 km²) is an economically underdeveloped region in comparison to the eastern and southern parts of China. The average annual GDP is only 50% of the more developed regions of China [32]. Major constraints to advance regional social and economic development are the unfavorable natural conditions, including water scarcity and soil erosion. Limited water availability due to low precipitation increases water competition among different users, while long-term cultivation activities on deep loess deposits without appropriate soil management measures result in severe soil erosion. Nutrient loss from soil erosion further contaminates water and puts more stress on the water shortage situation in the region.

To improve the natural condition and to control soil erosion, China has taken a series of actions to restore its degraded environment over the past two decades. Among these actions, the Sloping Land Conversion Program (SLCP) is the world's largest forest restoration program and the Loess Plateau is the main area for its implementation. Severe soil erosion often takes place at degraded slope farmland and on marginal slopes without land cover. The SLCP aims to convert these lands to forestland to reduce soil erosion. Moreover, SLCP intends not only to improve the environmental circumstances but also to diversify the rural income through payment. It employs public payments to millions of rural households for its implementation [33]. The SLCP chose afforestation as the main measure, as forests can improve the soil structure and increase the land surface roughness and is thus effective in fixing the surface soil and in mitigating soil erosion. However, forest uses more water than other vegetation for growth. In areas with water stress, such as the Loess Plateau, tree-driven evapotranspiration can remove more water from deep soils, lowering local groundwater recharge and water supply for downstream areas, thereby intensifying water shortage in dryland areas [34–36]. The expected ecological and social “win-win” outcomes have not emerged due to degraded water resources as a result of afforestation [37].

The case study of the Loess Plateau in China represents a specific example of the general nexus problem definition. First, two resources are involved, namely water and soil. These two resources need to be managed simultaneously but trade-offs are inevitably involved between these two resources due to vegetation restoration in an ecological fragile dryland area. Second, one resource (i.e., soil) is more effectively managed than another (i.e., water), meaning that Chinese soil and water-related policy actions do not fully account for all synergies and trade-offs involved and therefore lack coherence. Third, the incoherent management results in water scarcity and soil degradation, which also has negative socio-economic consequences for the population (see Table 1).

Table 1. Three components of a resource nexus problem in general and in the Loess plateau in China.

Resource Nexus Problems	Loess Plateau Case
Several environmental resources are at stake, such as water, soil, and waste	Two resources are of concern, namely water and soil
No effective management of environmental resources, no policy coherence, no understanding of synergies and trade-offs, externalities are largely ignored	Non-coordinated management of the two resources, policies focus on a single resource
Negative impact on sustainable development in ecological, social, and economic terms	Incoherent management results in water scarcity impacting social and economic processes

3. Methodology: Understanding the Wickedness of Resource Nexus Problems

To get an understanding of the wickedness of these resource nexus problems, a questionnaire has been developed and applied (see Supplementary Materials Annex 1).

The questionnaire first asks for a general description of the resource nexus problem (TOP 1). It then applies an adapted version of the operationalization of Kirschke et al. [29]. In terms of application, the questionnaire includes questions on all elements of the original operationalization of complexity, resulting in 13 questions aimed at defining the wickedness of problems (questions related to TOP 2, 3, and 4 of the questionnaire). In terms of adaption, these questions were assigned to three dimensions of wickedness. In relation to ‘goal diversity’, the first dimension of wickedness, the questions as depicted in TOP 2 of the questionnaire directly refer to the dimension of goals as described in the original operationalization. In terms of ‘system complexity’, the second dimension of wickedness, the questions as depicted in TOP 3 of the questionnaire refer to the dimensions ‘variables’, ‘dynamics’, and ‘interconnections’ of the original operationalization. Finally, in terms of ‘informational uncertainty’, the third dimension of wickedness, the questions as depicted in TOP 4 of the questionnaire directly refer to the dimension of informational uncertainty as depicted in the original operationalization. Finally, and in addition to the questions on the three dimensions of wickedness, this questionnaire also includes an additional set of questions (TOP 5), particularly aiming at identifying potential weightings between the dimensions.

The questionnaire guided focus group discussions among the three authors of this manuscript and an analysis of additional literature. In terms of the focus group discussions, the authors discussed and agreed upon answers to the questionnaire in three consecutive meetings, referring to the three dimensions of wickedness. The first author was taking extensive notes during these discussions. These notes were the basis for summaries of the discussions which were then reviewed, reflected based on literature, and discussed by the authors of this paper, resulting in answers to questions all authors agreed upon.

To quantify the three dimensions, the answers to the questions were compared with the assignment of degrees of complexity as depicted in the original operationalization. To facilitate this process, and to increase the traceability of this assignment, Annex 2 in Supplementary Materials shows which type of answer to each single question of the questionnaire (2.1–4.3) indicates which degree of wickedness (low, middle, or high). The table shows that the questions partly build upon each other and are partly independent. If the questions build upon each other, the assessment of the degree of wickedness is defined based on the exclusion principle. If there are several questions indicating certain degrees, the assessment of the degree of wickedness is based on dominant answers, resulting in answers such as ‘rather wicked’. If there is no dominant answer, mixed forms are possible such as ‘middle to high degrees of wickedness’.

An example relates to the dimension of goals. Question 1.1. follows the exclusion principle, asking if there are any conflicting interests between actors related to the problem. If there are no such conflicting interests, the problem is clearly a simple problem. If there are, however, conflicting interests, follow up questions 1.2 and 1.3 help to identify if these conflicting interests indicate a middle or high degree of wickedness. If the answers to questions 1.2 and 1.3 both indicate a middle degree

of wickedness, the problem is defined as having a middle degree. If the answers to questions 1.2 and 1.3 both indicate a high degree of wickedness, the problem is defined as having a high degree. If the answers to questions 1.2 and 1.3 differ, indicating a middle and a high degree of wickedness, the problem is defined as having a middle to a high degree. The same logic applies to all remaining questions of the questionnaire.

This approach allows to systematically compare problems in terms of different dimensions and degrees of wickedness. The next section further develops the wickedness of resource nexus problems, based on this approach.

4. Results: The Wickedness of Resource Nexus Problems

This section describes the wickedness of resource nexus problems, based on our definition described in Section 2 and the methodological approach outlined in Section 3. Here, the general degree of wickedness is referred to, taking into account that the wickedness of real-world problems can differ in practice due to various context factors such as the type of resources involved and the state of the development of countries. The definition of the general degree of wickedness is based on the answers to the questionnaire as depicted in Supplementary Materials Annex 1, that was given by the authors based on three focus group discussions and an analysis of relevant literature. These answers were contrasted with the general operationalization of low, medium, and high degrees of wickedness as described in Section 2 and in the related literature [29].

In sum, resource nexus problems and the management of land and water in the Loess plateau in China are rather wicked problems. In terms of goal conflicts, this is based on conflicts related to resource allocation and management in the context of various overarching goals. High system complexity comes from the high number of dynamic and interconnected social and natural factors. Informational uncertainty is high due to a lack of adequate, reliable, and timely data with regards to these natural and social factors (see Table 2).

Table 2. The wickedness of resource nexus problems.

Dimension of Wickedness	Factors Substantiating Wickedness	Degree of Wickedness
Goal conflicts	Conflicts related to resource allocation and management in the context of various overarching goals; in theory no prioritization of resources; the need for negotiation	High
System complexity	A large amount of highly dynamic and strongly interconnected factors, including solution options (e.g., technical, management) as well as social (e.g., governance, actors, interests) and bio-physical conditions (e.g., climate, quantity and quality of resources)	High
Uncertainty	Lack of adequate, reliable and timely data with regards to solution options, as well as bio-physical and social factors; limited means to gather/share information	High

4.1. Goal Conflicts

‘Goal conflicts’ is the first dimension of wickedness. In sum, the analysis suggests that resource nexus problems are characterized by high degrees of goal conflicts. Nexus problems typically encompass several conflicts that relate to how a resource is allocated and managed (e.g., addressing the mismatch of supply and demand) in the context of various overarching goals (e.g., ecological, societal and economic), of different types of users (e.g., industry, agriculture, forestry), and at different scales (e.g., local, basin, national).

Conflicts generally refer to the allocation and management of resources and emerge in connection with different ecological, societal and economic goals. In the case of semi-arid and arid areas in China, conflicting goals between water needs for ecological restoration and social and economic development cause tension [38]. Conflicts typically take place between different resource users, such as agriculture, forestry, rural or urban residents. To give a general example, forestry and agricultural development

can compete for land/soil and green water resources (defined as the part of the water used by plants) while there is also a need to produce goods and blue water (defined as the water in rivers, lakes, and groundwater) for human use. A possible conflict may arise here: if forestry and agriculture consume a higher amount of (green) water, less (blue) water will be available for human consumption. A similar conflict in the Loess plateau arises along with soil erosion control through afforestation in a water-scarce area. Such measures lower the available land area for agriculture. To increase the yields, agricultural practices must be intensified. High intensified agricultural practices can, however, lead to excessive inputs of chemical fertilizers such as nitrogen and phosphor, which ultimately results in deteriorated quantity and quality of groundwater [39]. This creates a soil resources competition/conflict between forestry and agricultural sectors and a water resources competition/conflict between the ecological and the social systems.

These conflicts can take place at various scales such as the local, regional, or national scale. They can also take place between upstream and downstream areas, or between communities. In the Loess plateau, the upstream soil conservation measures reduce the on-site soil loss and sediment load in the river system. Yet, higher water consumption of trees than of other land covers lower streamflow in the downstream river network [40]. This has negative impacts on local and regional water supply for socio-ecological development due to water shortage and demonstrates how an on-site/local solution can create negative side-effects in terms of an off-site/regional conflict.

Moreover, applying a nexus approach means, in theory, no prioritization of one specific resource or specific interest of sector over another, further hinting to high degrees of wickedness. Resources such as soil, water, and waste are, as well as the interests of related sectors and their stakeholders, equally important. There is no hierarchy between them, and all shall be benefited [21,31,41]. Treating all resources/sectors with equal importance, where neither is superior to the other(s), is an essential characteristic of the nexus approach [42]. The idea is that only if policy-makers break out of hierarchical, siloed thinking it becomes possible to identify synergies, reduce trade-offs, and to create win-win situations between resources and sectors [19,21,31]. This is also an important difference to concepts that focus on one resource or sector only. An example is an Integrated Water Resources Management which, in theory, clearly prioritizes achieving water-related goals (water-centric approach) [43].

In practice, however, nexus approaches often show a hierarchy from a political, social, and bio-physical perspective. Most importantly, many governments prioritize some uses over others. Moreover, managing the inherent trade-offs between resources and turning them into synergies is a great challenge. Thus, nexus problems typically encompass several conflicts that relate to how a resource is allocated and managed (addressing the mismatch of supply and demand) [44–46]. In semi-arid and arid areas in China, for instance, there is a tendency to prioritize soil over water in some regions [37]. Consequently, farmers are compensated for their loss of land for soil conservation. Such prioritizations depend on several aspects such as the bargaining power, available resources, or the imminence of the problem in question. It also depends on the administrative structures and responsible actors. There may be a difference if soil and water-related issues are dealt with under one or two separate ministries, and if the responsible actors prioritize ecological or economic goals.

In order to address these conflicts, there is a need for coordination and negotiation between various stakeholders at different levels, also indicating high degrees of wickedness. Often, these efforts are to address uneven bargaining powers between stakeholders. The implementation of negotiation and coordination practices differs, however, depending on the regional context and the respective governance system, among others. Democratic systems such as the European Union may provide some more possibilities for coordination and negotiation than more authoritarian systems. In the China case, both negotiation between various parties and decisions that are made unilaterally by the government or responsible ministries take place. Decisions for ecological restoration (e.g., forest development program) in China are commonly made through a typical top-down approach. Relevant households are rarely consulted and involved in negotiation before decisions are implemented. By doing so, conflicts of interests between officials and stakeholders and visions of participants are not considered

in the program, which increases the risks of program unsustainability, as participants may apply the measures and decisions as far as they receive a benefit (e.g., subsidy, compensation) and will return to old practices when the benefits disappear during the post-program period [37].

4.2. System Complexity

'System complexity' is the second dimension of wickedness. The analysis suggests that resource nexus problems are characterized by a high system complexity. Such typically encompass a large number of factors that must be taken into account when addressing problems in practice. Most importantly, no blueprint exists, but there are several options to address a problem. These options can refer to various technical and management solutions, but also to changes in consumer behavior, among others. The choice of options typically depends on a large set of context factors, meaning that a multitude of boundary conditions are to be considered to identify the right measures to address a problem. These context factors relate to both bio-physical and social conditions.

In terms of bio-physical conditions, various natural factors must be taken into account, such as the qualitative and quantitative status of the resources water, soil, and waste, as well as the impacts of climate change or biodiversity. In some regions, there may be natural constraints, such as water scarcity in an arid environment, which restricts the regional ecological and social development. Changes in land cover, for example, convert seasonal or annual plants to perennial plants, which may easily exceed the vegetation load that local natural conditions can support, leading to declining water resources availability [47]. Resource management options in such areas need to consider the causality and capacity of the environment to support certain ecosystems [41]. In the Loess plateau, expanding forest cover in relatively dry environments has alleviated the soil loss from erosion. However, insufficient knowledge about a suitable coverage of forest led to overloaded carrying capacity of regional water resources. High water use by forest decreased soil, water, and groundwater levels and further intensified water shortage in the region [48]. Even worse, exotic tree species were selected for afforestation. The fast growth of exotic trees depletes deep soil water and creates permanent dry soil layers in some cases [47]. In such conditions, there is not sufficient water to support the long-term forest growth, causing a high mortality of young trees, which ultimately results in unsustainable forest development.

In terms of social conditions, actors, and their interests, responsibilities as well as governance and other framework conditions must be considered. In particular, an examination of the resource using sectors (e.g., agriculture, forestry, and energy), of resource users, including their socio-economic circumstances and impacts of human-environment interactions, and of fiscal processes that influence the choice of interventions needs to be carried out [18]. The analysis should also address the varying interests and powers of affected sectors and users. Moreover, these groups are not always homogeneous, and their interests may differ depending on the context. In the China case, the interests of smaller communities, and especially of minorities, as well as of rural and urban or rich and poor areas are of particular relevance.

Further important social factors are the distribution of responsibilities, institutional capacities, governance conditions, and frameworks, as well as other social and economic conditions. Existing institutional arrangements and forms of interaction (e.g., horizontal and vertical interactions and coordination mechanisms, the interplay of administrative boundaries and ecosystem boundaries) or usual forms of participatory governance (e.g., an implementation of the subsidiary principle, especially the role of local governments) must be considered. These conditions can differ tremendously depending on the context, which emphasizes the importance of determining boundary conditions as the first step in a nexus analysis. In China, for instance, if a top-down mode of governance is applied, regional differences in terms of socio-economic conditions are rarely considered. As in other cases, it seems problematic that the institutional and individual capacity to identify solutions is rather low.

In practice, understanding and considering all these context factors can be very challenging. In the case of China, solutions are rarely contextualized. In fact, there are criteria on where and how to implement management options, but these only provide general guidance. One example regards

soil erosion protection on slopes. Currently, China applies a general rule—'slope inclination more than 25 degrees'—to decide on the location for conservation measures. However, this rule is too simple since it does not include other relevant factors, such as soil depth and moisture—if the soil is rather shallow or deep, dry or wet, more suitable for growing grass and shrubs or for planting trees. These factors could help practitioners to choose the most suitable plants and species to adapt to site-specific circumstances. However, by neglecting these contextual factors, the uses of unsuitable species (e.g., intrusive and fast-growing species) introduce unwanted water and biodiversity loss [49]. It would thus be useful to design management guidance documents in a way that such local factors are considered systematically.

The factors that influence solutions are generally dynamically evolving. This applies to management options, given continuous technological and scientific developments. It also applies to bio-physical conditions, with climate change having a particularly important impact on resource stocks and flows. Moreover, important dynamics in the social domain, such as urbanization, demographic changes (e.g., population growth), or varying interests of actors (e.g., changing priorities of new generations related to ecological and economic goals) must also be taken into account [50]. In the case of the Loess plateau, these dynamics are all present. Climate change has a particularly important impact here, since dry areas are getting much drier because of global warming [51]. Another particularly relevant dynamic is the increasing demand on resources (e.g., food demands, space), which is further exacerbated by population growth and urbanization. Such an increasing demand influences, for instance, the role of soil conservation in cities (e.g., sponge cities, storing all the rain water such as Singapore which recycles 100% of its rain water).

Moreover, these factors are interconnected and interdependent so that changes related to one variable influence other variables in the system. These interconnections regard both bio-physical factors (e.g., climate change, the status of resources) and social factors (e.g., actors, human well-being). Due to these interconnections, actions can have delayed positive or negative side-effects on bio-physical processes or on user practices of different groups. It is important to note however that omission (meaning non-action) can also have positive and negative effects. In the Loess plateau, an example for the effects of interconnections refers to changes from crop to forest land on the slopes. Such interventions decrease land owners' areas for agricultural practice. This, again, raises the need for increasing the yield in other areas. This forces several negative practices such as an increased use of fertilizers and pesticides under conditions of water stress. These practices degrade soil and groundwater resources in both quantitative and qualitative terms.

Given the high number of dynamically evolving and interconnected factors, resource nexus problems are particularly difficult to manage. There is thus a need for (integrated) models or decision-support tools to understand system complexity and to define management options. However, models are only useful if they consider all relevant factors, and if all relevant data and information are available. It is problematic that models often do not fulfill these requirements. Most importantly, numerical data are lacking, due to insufficient monitoring programs, or simply because relevant data is intangible, meaning that they cannot be expressed in numerical terms. This particularly applies to social factors such as the interests of actors. Moreover, even if all relevant data do exist, data must be updated continuously due to fast changing drivers and pressures. Models also seldom couple natural and social aspects [52]. Further, often institutional and individual capacities and knowledge required to carry out such modeling activities are too low; and decision support tools are limited by user friendliness and accessibility [21]. This applies to resource nexus problems in general and to the case of the Loess plateau in China.

4.3. Informational Uncertainty

'Informational uncertainty' is the third dimension of wickedness. The analysis suggests that resource nexus problems are characterized by rather high degrees of informational uncertainty. There is usually a lack of adequate, reliable, and timely data and information for addressing nexus

problems [5,53]. This lack regards both social and bio-physical data, e.g., due to an absence of permanent physical stations. Moreover, data and information are sometimes available, but not accessible to problem solvers. This means that the data that are dispersed amongst the various data holders (e.g., ministries, departments, institutes) are not shared, resulting in data and information lacks and asymmetries [21]. There are several reasons for this status quo, amongst which a shortfall of financial means to purchase data, such as high-resolution GIS data or mistrust and power issues between data and information holders such as states and actors within states. Furthermore, data is sometimes both available and accessible, but cannot be used by problem solvers given insufficient individual and institutional capacities on the part of public authorities. In addition to that, policy-makers may not be used to rely on evidence for policy making but are driven by political negotiation. Sometimes, policy-makers even do not know that they need specific types of information (e.g., on social issues) to address the problem. Besides, the understanding of a problem and its solutions varies along scientific disciplines and actors [21].

Data gaps can usually be addressed from a financial point of view. This applies to developed countries, but also to developing and emerging countries, given funds of international development organizations for data gathering and sharing. The main conditioning factor here seems to be the political will to address the problem. This means that if the government is convinced that there is an important problem, they may also find the financial means to address data deficits. However, one exemption is the data that must be gathered by using sophisticated technology, since this can be very cost intensive. Moreover, even if data and information deficits can be addressed from a financial point of view, there are still issues of power, diverse interests, and mistrust as well as a lack of data comparability that pose an important barrier to data and information sharing; and lacking capacities of public authorities remains an obstacle in many regions, e.g., when authorities do not know where to put measuring stations or how to interpret data.

Coming back to the Chinese case study area, there is a clear lack of data and information for addressing the problem. This applies to both bio-physical data and social data. One reason is that the Chinese government did not fully consider the most relevant indicators, and thus underestimated the need for monitoring. Another reason is related to financial constraints for monitoring. There are also regional constraints, such as data gathering in remote areas that are particularly difficult to access. Addressing these data deficits seems to be particularly challenging. This also applies to financial support for data gathering, especially in low-income areas. Provinces are, however, not fully dependent on the central government and can thus spend their own money in addition to governmental funding, and they can also make a case if money provided by governments is to be increased.

5. Discussion

The main goal of this paper was to analyze the basic wickedness of resource nexus problems in a systematic way, as a foundation for subsequent analysis of governance strategies based on existing tools [16]. Public policy analyses provide some important conceptual starting points for analyzing wicked problems, clarifying dimensions (goal conflicts, system complexity, and informational uncertainty) and degrees of wickedness (low, middle, and high). This analysis shows that resource nexus problems in general, as well as an integrated management of water and soil in the Loess plateau are wicked in all three dimensions. They are characterized by high goal conflicts between different stakeholder groups (e.g., farmers, environmental actors) at different levels (e.g., local, regional and national levels); system complexity is present with regards to both natural and social-related variables; and there are also important informational uncertainties related to this problem (e.g., lack of data and data sharing). We thus clarified the wickedness of resource nexus problems as compared with more general statements in the nexus debate [1–6].

What are the implications for the management of these problems? Research suggests that highly wicked problems come along with specific challenges for management. Based on Kirschke and Newig [16] and psychological literature on complex problem solving [30,54], these challenges refer

to the need for solving conflicts, gathering and sharing information, modeling, prioritizing, deciding under uncertainty, and being adaptive and flexible. In addressing problems, relevant actors must come to terms with these specific needs of wicked problem-solving. In terms of conflict solving, they have to address varying values and interests, including often diverging perceptions of problems. Further, financial, technical, and political means should be established to gather and share data as well as to model respective complexities. Given that there is no possibility to gather all relevant data, managers must prioritize their data generating efforts. This results in a need to decide under uncertainty, and thus also to adapt flexibly to changing conditions such as climate and demographic changes.

Governance research provides several useful tools to address these management challenges of wicked resource nexus problems: Based on widespread discussions in public policy analysis, participatory approaches—broadly defined—including networking activities, the involvement of practitioners, cooperation between science and policy, as well as approaches of social learning, play a particularly important role [55]. Decoding the wickedness of problems helps to identify very specific participatory strategies within this set of participatory strategies to address specific management challenges. First, different types of stakeholders may be involved (both scientific actors and/or practitioners) for identifying and addressing diverse perspectives and needs of stakeholders (goal diversity), developing complex models to understand system complexity, or to gather social and natural scientific data and information. Practitioners may, for instance be involved to address goal conflicts or to gather social data. Scientists, on the other hand, may be more helpful in designing complex models to gather data on the respective ecosystem. Second, these different types of actors may interact in different ways depending on the dimension of wicked problems. If, for instance, informational uncertainty is high, deliberation between different types of actors seems to be a useful strategy to gather information. If, however, there are high goal conflicts, negotiation may be a more appropriate interaction strategy. Third, governance tools to address wicked problems sometimes refer to the role of precise and obligatory rules that guide participatory processes. The basic assumption is here that obligatory and precise rules are particularly helpful to foster information gathering and conflict solving. However, lower degrees of obligation and precision may also be helpful to foster decision-making under uncertainty [56,57]. It follows that decoding the wickedness of problems helps to identify very specific governance strategies for addressing problems in a systematic way.

What does this mean for practical problem-solving processes? Resource problems have long been understood as problems that can be fixed in a technical, top-down manner. Given the wickedness of the issue, however, such an approach is no longer appropriate. One particularly important recommendation here is to include participatory modes of governance into environmental problem-solving processes. This does not mean, however, to flood such processes with large-scale, highly cost-intensive participation measures. Practitioners are advised to reflect on which type of participatory strategy (e.g., low or high degree of participation of a specific stakeholder group) is relevant to address which kind of challenge provided by wicked problems (e.g., addressing conflicting interests or modeling). Whereas a broad involvement of stakeholders may be helpful to address conflicting interests of stakeholders, for instance, scientific experts' involvement may be more helpful to understand natural complexities of the system [16,58].

In terms of the Chinese case, reflecting on the requirements of wicked problems might result in an important shift from focusing on short-term benefits, top-down modes of policy-making, to more participatory, collaborative, and evidence-based forms of governance aiming at addressing problems in a sustainable way in the long-term. In fact, the Chinese case is often described as an example of authoritarian environmental governance [59]. Recent research has shown, however, that Chinese environmental governance also incorporates important elements of liberalism (in this case understood as more participatory forms of governance) and evidence-based policy-making [60]. There is also a regular evaluation of policies (water and soil survey), providing room for adaptation of policies. These elements of liberal and evidence-based policy-making may be strengthened to address the specific requirements of wicked problems. Respective management processes must address the issue

of short-term planning. Whereas the Chinese government tends to focus on short-term benefits, such as fast economic development, more long-term strategies are likely to be more useful in order to address problems in a sustainable way. The nature of the Agenda 2030 and the Sustainable Development Goals (SDGs) may shift some of these priorities and allow nexus problems to be tackled more systematically. The added complexity resulting from interconnected goals and targets requires innovation in policy-making processes and implementation. The concept of wickedness as presented here could provide important stimulus and practical implementation approaches and methods for countries to achieve often competing and conflicting SDGs. The mapping of interactions, synergies, and trade-offs between resources and resource uses against the dimensions of wickedness would allow for greater clarity and understanding in how far different policy choices may impact on diverse, interdependent development goals.

While our analysis suggests that resource nexus problems are in general rather wicked, further research can carve out varieties of problems. There might, for instance, be differences between problems that relate to two resources only (e.g., soil, and water) or to three resources (e.g., water, soil and waste). Further, different regional contexts are associated with different local factors influencing solutions. There might be a difference, for instance, between national and transboundary levels [61] between developing, emerging and developed countries, given their specific levels of capacities for gathering and processing information [62]. The history of conflict in certain regions is also of importance here. Resource conflicts in conflict-laden regions such as in the Middle East are particularly challenging to address and will require special trust-building measures to foster cooperation between actors [63]. Respective varieties could influence the design of specific management and governance strategies to address these problems in practice. Thus, whereas all resource nexus problems are assumed to require management and governance strategies adapted to their general wickedness, there might be, due to slight differences in their wickedness, also slight differences in these strategies. If for instance, conflicting goals are particularly high or dominant, problem solvers might prioritize sets of management and governance strategies that address such conflicts rather than focusing on interlinked models to address the high complexity of the problem. Such a fine-tuned approach can be relevant within a general strategy to address the overall existing wickedness of the problem.

Future research could also develop the question of the best strategies to identify the wickedness of problems. In this paper, we follow the strategy of focus group discussions and the analysis of literature to describe problems. Following a different strategy, Kirschke et al. [29] conducted a large set of interviews with experts having an inter- and transdisciplinary background. To move one step further, researchers are advised to systematically compare the impact of different methodologies, such as focus group discussions and expert interviews, on the definition of the wickedness of a problem. Respective results could support policy-makers in finding the best-suited strategies to define problems, such as the involvement of specific types of experts from science and practice within a process of moderated discussion.

Finally, the goal of this research paper was to systematically describe resource nexus problems through the lens of wicked problems. We understand, however, that there are many different lenses through which such problems can be understood. Considering analyses in public policy, for instance, the concept of structured, moderately structured, and ill-structured problems may provide additional insight [12].

6. Conclusions

We provided a systematic analysis of the wickedness of resource nexus problems, taking a specific water–soil nexus problem in China as an example. Resource nexus problems generally fulfill the theoretical criteria of wicked problems, namely the existence of highly conflicting goals, high system complexity, and high informational uncertainty. Consequently, traditional policy and governance strategies to address wicked problems may be fruitful to deal with resource nexus problems in general and in the Loess plateau, more particularly. One important suggestion here is to systematically integrate specific participatory modes of governance to unlock conflicts, model system complexities,

and gather relevant information for addressing problems. Both scientific experts and practitioners can contribute based on their core competency (e.g., modeling or providing local knowledge). However, there is no blueprint for addressing nexus problems. Future research should quantify the degree of wickedness for each single nexus problem separately, considering differing context factors for problems and their solutions.

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