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Article

Bayesian Network Modeling to Improve Water Pricing Practices in Northwest China

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Abstract: Water pricing is regarded as the most important and simplest economic instrument to encourage more efficient use of irrigation water in crop production. In the extremely water-scarce Tarim River basin in northwest China, improving water use efficiency has high relevance for research and policy. A Bayesian network modeling approach was applied, which is especially suitable under data-scarce conditions and the complex geo-hydrological, socioeconomic, and institutional settings of the study region, as it allows the integration of data from various types of sources. The transdisciplinary approach aimed at understanding the actual water pricing practices, the shortcomings of the current system, and possible ways of improvement. In an iterative procedure of expert interviews and group workshops, the key factors related to water pricing and water use efficiency were identified. The interactions among specific factors were defined by the respective experts, generating a causal network, which describes all relevant aspects of the investigated system. This network was finally populated with probabilistic relationships through a second round of expert interviews and group discussions. The Bayesian modeling exercise was then conducted using Netica software. The modeling results show that the mere increase of water price does not lead to significant increases in water use efficiency in crop production. Additionally, the model suggests a shift to volumetric water pricing, subsidization of water saving irrigation technology, and advancing agricultural extension to enable the farmer to efficiently react to increased costs for water. The applied participatory modeling approach helped to stimulate communication among relevant stakeholders from different domains in the region, which is necessary to create mutual understanding and joint targeted action. Finally, the challenges related to the applied transdisciplinary Bayesian modeling approach are discussed in the Chinese context.

Keywords: water pricing; water use efficiency; Bayesian network modeling; causal networks; transdisciplinary research

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1. Introduction

The Tarim River is located in the southern part of Xinjiang Uyghur Autonomous Region (XUAR) in northwest China. The Tarim River Basin is one of the driest areas in the world, with annual precipitation of less than 50 mm and potential evaporation of more than 2000 mm [1,2]. The snow and glacier melt from the surrounding mountains is the main water resource of the Tarim River (Figure 1). Because of the low precipitation, all human activities and natural ecosystems depend on the water from the Tarim River [3,4].

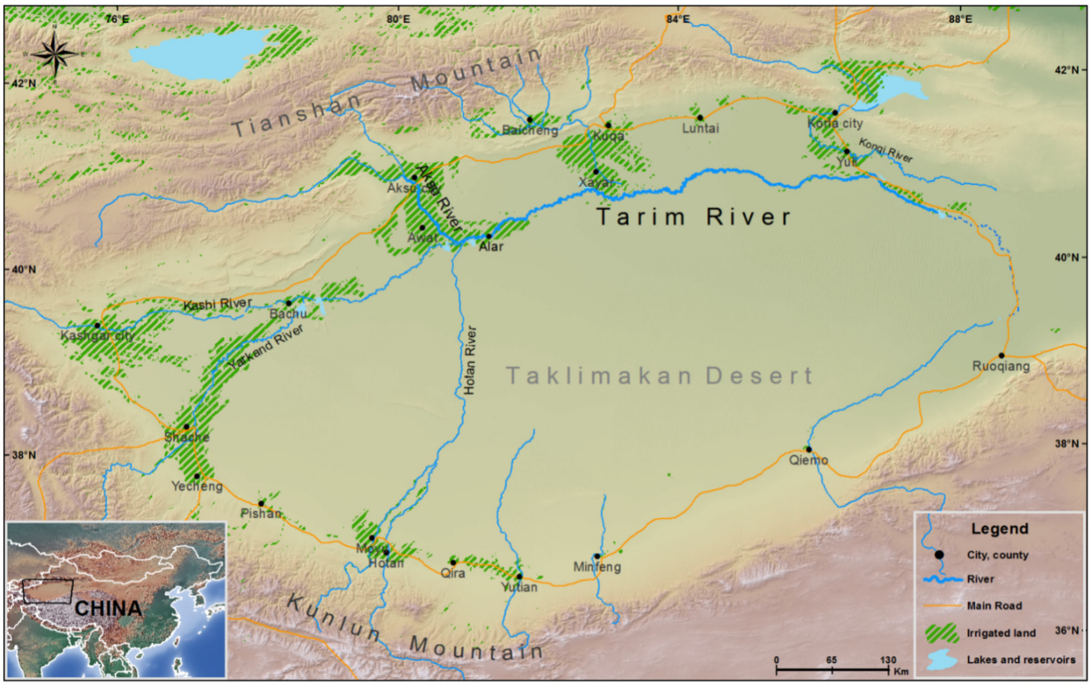

Figure 1. Map of the study region.

The Tarim River Basin is an important cotton, grain, and fruit production base in China. Low precipitation and rich sunshine offer favorable crop production conditions, especially for producing high-quality cotton. According to the Chinese statistical yearbook, regional cotton production in 2012 contributed to more than 50% of Chinese national cotton production and accounted for about 15% of world cotton production [5].

However, intensive agricultural production is the main consumer of water in this arid region, accounting for more than 90% of total fresh water consumption along the Tarim River [6]. Over the last decades there has been strong intensification of agricultural activities and consecutive overutilization of water resources, which resulted in severe environmental problems in the region [7–10]. Furthermore, the diversion of more and more water to agricultural production in the upper stream and middle stream of the river has led to increased conflicts among the farmers, resulting in yield losses [3]. In addition, current irrigation water pricing is believed to be too low to cover the full supply cost. According to the XUAR Provincial Department of Water Resources, irrigation water pricing in 2010 was 0.019 RMB/m^3, only covering 37% of the full supply cost [11]. Underpricing is recognized as one of the major causes of overutilization of water resources, low water use efficiency (WUE), and aging infrastructure along the Tarim River Basin [12]. It is recognized that effective allocation and conservation of water resources has become a major issue in sustainable development along the Tarim River [13,14]. As an important policy option, irrigation water pricing was integrated into the agenda of the government's future plan targeting water saving, sustainable water use, and increasing WUE. According to the XUAR People's Government, full supply cost recovery levels should reach 70% at the end of 2015 and 100% at the end of 2020 [15].

Irrigation water pricing is regarded as the most important and simplest economic instrument for promoting WUE [16]. Irrigation water pricing is believed to have two major roles in terms of promoting WUE. Firstly, it provides funds to sustain the supply system by guaranteeing the cost recovery from the water users [17]. Secondly, it gives incentives to use water resources more wisely by encouraging people to use advanced irrigation methods and technologies. Water pricing furthermore encourages them to choose crops that generate higher returns and require less water, and to improve farm management practices with the aim of reducing water losses [18–20]. However, there is a lot of debate about the externality and uncertainty of raising irrigation water pricing. Tardieu and Prefol [21] and Liao *et al.* [22] argue that besides leading to a reduction in agricultural production, raising irrigation water pricing also counteracts the sustainability of rural development by increasing rural poverty [23]. In addition, some case studies showed that increasing water pricing did not result in stopping overutilization of water resources and related environmental problems [24,25]. Furthermore, Liao *et al.* [22] added that irrigation water pricing is not effective without additional agricultural policy interventions. Such ineffectiveness of water pricing can largely be explained by water being a rather inelastic production factor, *i.e.*, an increase in water price by a certain percentage will not lead to a reduction in water consumption at a similar rate. As farmers in arid and semi-arid regions essentially rely on water for growing crops, they might not easily reduce their consumption amount [26,27].

Various methods have been applied to find the impacts of water pricing on WUE including mathematical programming [28–32], econometric analysis of survey data [33,34], and various other modeling approaches [35,36]. However, those approaches mainly simulate the impact of changed water pricing practices on the farm level. As such, the institutional aspects related to agricultural water policies, which are of utmost importance for successful policy design, can only be considered insufficiently.

Therefore, Bayesian Networks (BN) modeling was employed in the present study, which is better able to consider the crucial institutional aspects of agricultural water policy design. BN modeling is a popular tool, especially when dealing with decision-making in the face of uncertainty and limited data availability [37]. It has been widely used in environmental sciences and natural resources management with a focus on ecosystem service modeling [38,39], climate change impact assessment [40,41], watershed management [42–44], and ground water protection [45,46]. Its ability to clearly explain complex relations, easily compare alternative management scenarios, and determine the important driving factors makes BN modeling an extremely useful approach to support natural resources management under complex settings [47]. Another important advantage of BN modeling is its flexibility with regards to data sources. Especially under data-limited conditions, as is the case with the present study in the Tarim Basin, its potential to meaningfully integrate data from different sources, including stakeholder and expert knowledge, empirical data, and data from the literature, is of vital importance [37,48].

There has been extensive research on the Tarim River focusing on water resource variations [49–52], land use and land cover change [53,54], climate change impact [55–57], and the ecological restoration efforts along the lower reaches of the river [58–60]. However, very little research has been conducted on the role of water pricing for sustainable water use in the Tarim River up to now. Thus, there is an urgent need to determine the effects of water pricing on WUE along the Tarim River.

Therefore, the overall objective of this paper is to find out whether increasing water pricing will lead to more efficient water use along the Tarim River. The specific objectives are: (1) to develop a model to determine the effects of water pricing policies on increasing WUE; (2) to improve current water pricing practices; (3) to evaluate the effects of alternative measures on increasing water use efficiency; and (4) to develop policy recommendations aimed at more effective water pricing policies.

2. Materials and Methods

2.1. Bayesian Networks

BN, also called Bayesian belief networks, form the conditional probability model, which can be described as a directed acyclic graph consisting of a series of variables and their conditional dependencies [61]. Each BN is composed of three elements: nodes, directed edges or links between nodes, and a conditional probability table (CPT). Nodes represent the variables in the graph, while directed edges or links visualize the casual relations between these nodes. The CPT is used for defining the conditional probability of the casual relations. The conditional probability relies on Bayes's theorem, for which the mathematical equation can be written as:

$$\boldsymbol{P}(\boldsymbol{i}|\boldsymbol{j}) = \frac{\boldsymbol{P}(\boldsymbol{i})\boldsymbol{P}(\boldsymbol{j}|\boldsymbol{i})}{\boldsymbol{P}(\boldsymbol{j})},$$

where "$\boldsymbol{i}$" and "$\boldsymbol{j}$" are the two random events, "$\mathbf{P}(\boldsymbol{i})$" represents the probability of event $\boldsymbol{i}$, and "$\mathbf{P}(\boldsymbol{j})$" represents the probability of event $\boldsymbol{j}$. "$\mathbf{P}(\boldsymbol{i}|\boldsymbol{j})$" is the conditional probability of event $\boldsymbol{i}$ under the condition that event $\boldsymbol{j}$ occurs [62–64].

A number of commercial and open source software packages are available for BN modeling. In this study the most commonly used software package, "Netica," was employed, which has all necessary features, flexibility, and a user-friendly interface.

2.2. Model Development Process

A number of guidelines are available for developing BN (e.g., [65–67]). For this study, the seven-step guideline developed by Bromley [67] was applied for establishing the BN model. Detailed information on the applied process including the modeling process, objectives, research activity dates, research activity format, research participants, number of participants, and the collected data type is shown in Table 1.

Table 1. Bayesian network modeling process to evaluate the impacts of water pricing on water use efficiency.

Modeling Process	Objectives	Date	Format	Participants	No. Participants	Data Type
Define the problem and context	(a) Define the problem and objectives (b) Identify and select potential participants and stakeholders	July 2011	Group discussions	Research team	3	Expert knowledge
Identify the variables and indicators	(a) Identify all relevant variables and key indicators (b) Identify the possible scenarios	August 2011	Workshop	Local experts	13	Expert knowledge
Design the preliminary network	(a) Construct the pilot network, insert links and variables (b) Generalize/finalize the network for consistency, logic, and focus	August 2012	Face-to-face interview and workshop	Local experts	6 + 15	Expert knowledge
Gather relevant data	Collect and analyze the relevant data from all sources	March 2013	Face-to-face interview	Local experts, water authorities	17	Expert knowledge, empirical data
Construct and populate the CPT	(a) Enter the interview data manually (b) Enter the empirical data by parameter learning	April 2013	--	--	--	--
Evaluate and validate the network	(a) Present the final results (b) Evaluate the model process and final results of the model	April 2013	Workshop	Local experts, water authorities	19	Expert knowledge

2.3. Construction of Networks

The construction of the causal networks was conducted in an iterative procedure following three major steps. After the definition of research objectives, a first group workshop with previously identified key stakeholders was held. Possible scenarios for future agricultural water resource management were discussed and the related variables and key indicators were identified. In the second step, interactions between all relevant factors were defined via one-to-one discussions with experts in the fields of water infrastructure, crop irrigation, and agricultural extension. Partial interaction graphs of specific parts of the system were defined by the respective experts. The research team then integrated the partial interaction graphs to generate a single pilot causal network that represents the major relevant aspects related to water pricing and water use efficiency in the region. In this process regional senior researchers from the field of water resource management were consulted to help refine the pilot causal network accordingly. In the final step, a consultation workshop was arranged with the same local experts. In several parallel group discussions, experts were asked to evaluate the pilot network and add, remove, or change the variables included in networks or modify the relationships according to their perception. The recommended adjustments proclaimed by the different groups were finally discussed to achieve consensus on the major aspects of the network. Following the workshop, specific variables of limited importance and relevance were removed from the network, and some variables that were missing thus far but considered important were added. In the pilot network there were 25 nodes (variables) and 36 links, while in the finalized network there were nine nodes and 12 links. In addition, the number of nodes was kept at a maximum of three in order to guarantee the accuracy and optimum size of the model as suggested by Cain [65]. The finalized causal network and a detailed description of the variables and their states are shown in Figure 2 and Table 2, and explained in detail below.

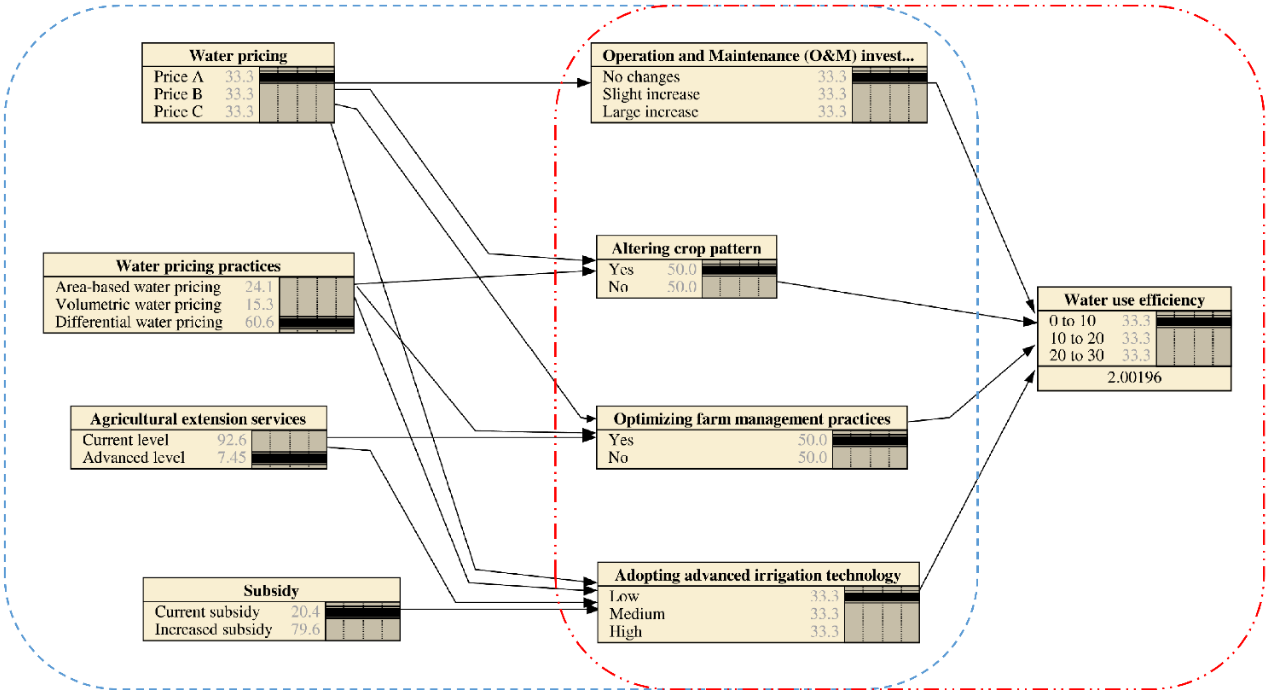

Figure 2. Causal networks for modeling the impact of water pricing on water use efficiency.

Water pricing practices determine the methods for charging water fees. There are three basic water pricing practices: Area-based water pricing (ABWP), volumetric water pricing (VWP), and differential water pricing (DWP). ABWP charges the water fee according to each unit of irrigated area. ABWP is a popular and widely used method because it is easy to implement and administer. Moreover, it entails rather low implementation costs. However, ABWP does not prevent overutilization of water resources, because there is no direct link between water charges and thee amount of water actually used for irrigation [68]. VWP charges the water fee according to each unit of volume water used [69]. VWP encourages users to save water and reduce consumption, because the charged water fee is directly linked to the amount of water consumed. However, VWP generally entails higher costs compared to ABWP because specific measuring equipment needs to be installed at the level of the final user [68,70]. VWP for agricultural water use is common in some states of the U.S. and some regions of Spain [71]. Finally, DWP considers a standard (rather low) price below a certain threshold of water consumption, and a significantly higher WP when the threshold is exceeded. DWP can be adjusted to local crop water requirements under good agricultural practice, and can therefore better address the aspect of farmer's affordability [70]. In Israel and Jordan DWP is reported as existing water pricing practice [20,72].

Table 2. Variables, variable states, and detailed description of the variables in the Bayesian networks (1 RMB = 0.16 US$).

Variables	States	Description
Water pricing	Price A (1500 RMB/ha; 0.18 RMB/m^3; 0.18 RMB/m^3 for standard consumption, 0.36 RMB/m^3 for surplus consumption)	Increased water price levels based on the government's policy documents. Prices listed as follows (area-based water price; volumetric water price; differential water price); Price A equals an increase of 25%, Price B of 50%, Price C of 100%, all compared to current prices.
	Price B (1800 RMB/ha; 0.22 RMB/m^3; 0.22 RMB/m^3 for standard consumption, 0.44 RMB/m^3 for surplus consumption)	
	Price C (2400 RMB/ha; 0.3 RMB/m^3; 0.3 RMB/m^3 for standard consumption, 0.6 RMB/m^3 for surplus consumption)	
Water pricing practices	Area-based water pricing (ABWP)	Water pricing practices determine the methods of charging the water fee; ABWP: per unit irrigated area; VWP: per volume of water used; DWP considers a low price below a certain threshold of water consumption, and a significantly higher WP when the threshold is exceeded.
	Volumetric water pricing (VWP)	
	Differential water pricing (DWP)	
Agricultural extension services	Current level	Training farmers with regards to good crop management practices and advanced technologies to improve yield levels, resource use efficiency and profits.
	Advanced level	
Subsidy	Current subsidy	Subsidizing agricultural producers for implementing advanced irrigation technology and converting from flood irrigation to sprinkler irrigation or drip irrigation.
	Increased subsidy	
Operation and Maintenance (O & M) investment	No change	Investments for running the water supply system including planning, construction, monitoring, and repair of water storage and distribution infrastructure as well as planning and distribution of water resources.
	Slight increase	
	Large increase	
Altering crop pattern	Yes	Shifting towards crops with higher water productivity.
	No	
Optimizing farm management practices	Yes	Improving farm management practices to increase yields and minimize water losses.
	No	
Adopting advanced irrigation technology	Low	Adapting advanced irrigation technology such as sprinkler irrigation or drip irrigation.
	Medium	
	High	
Water use efficiency	Increased by 0%–10%	WUE in agriculture is defined as the economic yield of crops produced per unit of water; the three states correspond to low, medium, and high levels of increase in WUE.
	Increased by 10%–20%	
	Increased by 20%–30%	

Along the Tarim River ABWP is commonly used in the agricultural sector, while in the industrial and domestic sectors VWP is applied. The farm household survey conducted in the study region in 2012 revealed an average water fee that farmers pay to the water authorities of approximately 1200 RMB/ha and year. According to the average water amounts consumed for crop production by farmers in the region, as determined from the farm survey data, farmers currently pay an approximate volumetric water price of 0.14 RMB/m^3. This water price determined from primary farm data is significantly higher than the water price officially announced at the county level by the XUAR Provincial Department of Water Resources in 2010. Obviously the final water price paid by the farmers entails additional costs arising from water allocation on the town and village level. Those include costs for construction and maintenance of local water infrastructure, as well as administrative costs.

2.4. Data Collection

For the development of the BN model, data from purposefully selected sources such as expert interviews, expert workshops, policy documents, scientific literature, and official statistics was collected, analyzed, and integrated. For the core part of the BN model development, which is populating the CPTs, mainly expert knowledge and empirical data from Xinjiang Production and Construction Corps (XPCC) statistical yearbooks [73] was used. Experts from major research institutions including universities and academies that specialize in water resources management, water conservation, agricultural economics, ecology, and forestry were interviewed face to face. In addition, experts from major water management agencies including the Xinjiang Uyghur Autonomous Region Provincial Department of Water Resources, the Tarim River Basin Management Bureau, and the Tarim River Basin Aksu River Management Bureau were also interrogated within the frame of the current study (Table 3).

Table 3. Detailed information regarding the interviewed local experts and water authorities who helped to populate the conditional probability table.

Institutions	Institution Type	No. of Participants
Xinjiang Uyghur Autonomous Region Provincial Department of Water Resources	Regional Government	2
Xinjiang Institute of Ecology and Geography	Research Institution	1
Xinjiang Institute of Water Resources and Hydropower Research	Research Institution	1
Xinjiang Academy of Forestry Sciences	Research Institution	1
Xinjiang University	University	2
Xinjiang Agricultural University	University	4
Xinjiang Financial University	University	1
Tarim River Basin Management Bureau	River Basin Authority	2
Tarim River Basin Aksu River Management Bureau	River Basin Authority	2
Xinjiang Tarim University	University	3

Elicited expert knowledge from face-to-face interviews was used to estimate probabilistic relationships among specific variables of the causal network in the blue rectangle in Figure 2. In the beginning of the interview, the probabilistic concept of Bayesian modeling and the previous construction of the finalized causal networks were explained carefully. Building on a simple example, the procedure of populating the causal network with respective CPTs was illustrated to help local experts understand conditional reasoning. In the final step, the experts were asked to fill in conditional probability tables according to their knowledge and expert judgment. The collected data were ultimately integrated by the research team and entered into the model using Netica software.

Additionally, empirical data was used to estimate the probabilistic relationships of specific parts of the causal networks in the red rectangle in Figure 2. The data collected and analyzed from XPCC statistical yearbooks included data from 2000 to 2012 on area of irrigated land, area of micro-irrigated land, total investment for water conservation, area of major crops (e.g., cotton, fruit trees, and vegetables), main inputs for farming (e.g., fertilizer, pesticides, and labor), total output value from farming, and the total amount of water consumption for farming. After data collection, the following steps were applied to estimate the probabilities. First, all related variables were converted manually to discrete variables according to the state of the previously finalized nodes. Then, possible combinations of the states in the parent nodes were listed, and the frequencies of the occurrence of the states of child nodes were counted. In the end, the final probability was estimated by dividing the frequencies of the occurrence of the states of the child nodes by the total number of each parent states' combination. This estimation procedure was completed using the Bayesian learning algorithm featured in the Netica software package.

2.5. Scenario Management

Thirty-six scenarios were developed in order to evaluate the impact of water pricing and other relevant adjustments and agricultural policy interventions on WUE (*cf.* Table 4). Scenario 0, which constitutes the baseline scenario, simulates the impacts of increasing water price at a rather low level, while scenarios 1 and 2 simulate the impacts of increasing water price at a medium and high level without considering any other changes or policy interventions. Scenarios 4–8 consider increasing water prices at a different level in combination with changes in water pricing practices towards volumetric and differential water pricing. In 2009, the XUAR Provincial Department of Finance began to subsidize drip irrigation by 1500 RMB/ha to promote advanced water-saving irrigation. The subsidy for drip irrigation officially increased to 4500 RMB/ha in 2011, which almost covers the cost of drip irrigation [74,75]. However, the farm survey conducted in 2012 revealed a much lower financial support for advanced irrigation technology of approximately 1500 RMB/ha. Additionally to the high investment costs, farmers also stated that they lacked knowledge of how to install and operate such irrigation systems, which deterred them from adopting water-saving irrigation. Therefore, scenarios 9–11 were used to test a combination of increasing water pricing and the policy intervention of advancing agricultural extension services. Moreover, scenarios 12–14 consider a combination of increasing water pricing and the policy intervention of increasing subsidies for drip irrigation. Scenarios 15–17 test a combination of increasing water pricing and both policy interventions, advancing agricultural extension services and increasing subsidies. Finally, scenarios 18–35 deal with multiple combinations of water pricing, water pricing practices, and both policy interventions.

Table 4. Probability value of increases in WUE under different water pricing scenarios.

Scenario	Water Pricing	Water Pricing Practices	Subsidy	Agricultural Extension Services	Probability Value for Increase in WUE			Probability Change for Increase in WUE		
					0%–10%	10%–20%	20%–30%	0%–10%	10%–20%	20%–30%
Scenario 0	Price A	ABWP	Current subsidy	Current level	39.49	30.69	29.82	--	--	--
Scenario 1	Price B	ABWP	Current subsidy	Current level	34.20	33.73	32.07	−5.29	3.04	2.25
Scenario 2	Price C	ABWP	Current subsidy	Current level	31.19	34.70	34.11	−8.3	4.01	4.29
Scenario 3	Price A	VWP	Current subsidy	Current level	37.93	31.46	30.61	−1.56	0.77	0.79
Scenario 4	Price B	VWP	Current subsidy	Current level	33.27	33.96	32.77	−6.22	3.27	2.95
Scenario 5	Price C	VWP	Current subsidy	Current level	30.80	34.68	34.52	−8.69	3.99	4.7
Scenario 6	Price A	DWP	Current subsidy	Current level	37.33	31.87	30.80	−2.16	1.18	0.98
Scenario 7	Price B	DWP	Current subsidy	Current level	32.90	33.99	33.11	−6.59	3.3	3.29
Scenario 8	Price C	DWP	Current subsidy	Current level	29.83	34.96	35.21	−9.66	4.27	5.39
Scenario 9	Price A	ABWP	Current subsidy	Advanced level	37.67	31.84	30.49	−1.82	1.15	0.67
Scenario 10	Price B	ABWP	Current subsidy	Advanced level	33.44	34.03	32.53	−6.05	3.34	2.71
Scenario 11	Price C	ABWP	Current subsidy	Advanced level	30.84	34.96	34.20	−8.65	4.27	4.38
Scenario 12	Price A	ABWP	Increased subsidy	Current level	35.49	33.33	31.18	−4	2.64	1.36
Scenario 13	Price B	ABWP	Increased subsidy	Current level	32.53	34.60	32.87	−6.96	3.91	3.05
Scenario 14	Price C	ABWP	Increased subsidy	Current level	30.67	34.90	34.43	−8.82	4.21	4.61
Scenario 15	Price A	ABWP	Increased subsidy	Advanced level	34.71	33.67	31.62	−4.78	2.98	1.8
Scenario 16	Price B	ABWP	Increased subsidy	Advanced level	31.98	34.73	33.29	−7.51	4.04	3.47
Scenario 17	Price C	ABWP	Increased subsidy	Advanced level	30.18	34.92	34.90	−9.31	4.23	5.08
Scenario 18	Price A	VWP	Current subsidy	Advanced level	36.58	32.30	31.12	−2.91	1.61	1.3
Scenario 19	Price B	VWP	Current subsidy	Advanced level	32.82	34.15	33.03	−6.67	3.46	3.21
Scenario 20	Price C	VWP	Current subsidy	Advanced level	30.53	34.74	34.73	−8.96	4.05	4.91
Scenario 21	Price A	VWP	Increased subsidy	Current level	34.96	33.44	31.60	−4.53	2.75	1.78
Scenario 22	Price B	VWP	Increased subsidy	Current level	32.07	34.57	33.36	−7.42	3.88	3.54
Scenario 23	Price C	VWP	Increased subsidy	Current level	30.31	34.88	34.81	−9.18	4.19	4.99
Scenario 24	Price A	VWP	Increased subsidy	Advanced level	34.50	33.61	31.89	−4.99	2.92	2.07
Scenario 25	Price B	VWP	Increased subsidy	Advanced level	31.85	34.58	33.57	−7.64	3.89	3.75

Table 4. *Cont.*

Scenario	Water Pricing	Water Pricing Practices	Subsidy	Agricultural Extension Services	Probability Value for Increase in WUE			Probability Change for Increase in WUE		
					0%–10%	10%–20%	20%–30%	0%–10%	10%–20%	20%–30%
Scenario 26	Price C	VWP	Increased subsidy	Advanced level	30.14	34.87	34.99	−9.35	4.18	5.17
Scenario 27	Price A	DWP	Current subsidy	Advanced level	36.23	32.56	31.21	−3.26	1.87	1.39
Scenario 28	Price B	DWP	Current subsidy	Advanced level	32.60	34.08	33.32	−6.89	3.39	3.5
Scenario 29	Price C	DWP	Current subsidy	Advanced level	29.68	34.96	35.36	−9.81	4.27	5.54
Scenario 30	Price A	DWP	Increased subsidy	Current level	34.18	33.81	32.01	−5.31	3.12	2.19
Scenario 31	Price B	DWP	Increased subsidy	Current level	31.77	34.51	33.72	−7.72	3.82	3.9
Scenario 32	Price C	DWP	Increased subsidy	Current level	29.57	35.01	35.42	−9.92	4.32	5.6
Scenario 33	Price A	DWP	Increased subsidy	Advanced level	33.95	33.77	32.28	−5.54	3.08	2.46
Scenario 34	Price B	DWP	Increased subsidy	Advanced level	31.65	34.49	33.86	−7.84	3.8	4.04
Scenario 35	Price C	DWP	Increased subsidy	Advanced level	29.41	34.98	35.61	−10.08	4.29	5.79

2.6 Validation of the Model

For most modeling exercises a validation of simulation results should generally be conducted to ensure model accuracy and reliability. However, in the present study a validation of the developed BN model is not feasible at this stage, as the model investigates potential future impacts of different management actions that are not yet implemented. Therefore, the judgment of local experts and water authorities was used to validate the model. A workshop with local experts and water authorities was carried out to evaluate the plausibility and acceptability of the modeling results. Additionally, the modeling results were checked with respective scientific findings from literature to ensure consistency and identify potential implausibilities.

3. Results and Discussion

Table 4 illustrates the probability values of an increase in WUE under different water pricing and other management scenarios. To access the impact of the other management actions and agricultural policies, and to determine the best scenario that leads to the highest WUE, a change in the probability value of WUE in the 35 scenarios is compared to the basic scenario (scenario 0), in which water prices only increase at a low level. The magnitude of the probability changes represents the strength of the impact of different scenarios.

3.1. Impacts of Water Pricing on WUE (*Scenarios 0–2*)

When looking at the baseline scenario (scenario 0) (Price A) with a slightly increased water price and *ceteris paribus* conditions, the results show that there is a high chance (39.49%) of increasing WUE by 0%–10%. In Scenario 1 (Price B) the WUE still has a higher chance (34.20%) of increasing by 0%–10%. The results indicate that water pricing may not lead to a significant increase in WUE when irrigation water pricing varies between the current water price (1200 RMB/ha) and the increased level Price B (1500 RMB/ha). There is strong evidence that this level of water price increase is still not sufficient to affect users' behavior and improve the capacity of the supply system. Those results corroborate the findings of Amayreh *et al.* [76] and Vasileiou *et al.* [77], who found that the price for irrigation water is rather inelastic, which means that there is no significant agricultural water demand reduction with a slightly increased price. In contrast, there is a higher chance (34.70%) of WUE increasing by 10%–20% under Scenario 2 (Price C). This shows that a significant increase in water price (by 100%) may lead to higher WUE. However, stronger increases in water price may also lead to a significant reduction in crop production and farm income [21]. Thus, economic consequences and external effects need to be assessed with great care before the implementation of such significant increases in irrigation water price.

3.2. Impacts of Water Pricing and Changes in Water Pricing Practices on WUE (*Scenarios 3–8*)

In scenarios 3 (Price A + Volumetric water pricing) and scenario 6 (Price A + Differential water pricing), WUE still has a higher chance (37.93% and 37.33%) of increasing by 0%–10%. However, the probability shows a slight decrease (1.56% and 2.16%) compared to the base case. Under scenario 4 (Price B + Volumetric water pricing), scenario 5 (Price C + Volumetric water pricing and scenario 7

(Price B + Differential water pricing), WUE has a higher chance (33.96%, 34.68% and 33.99%) of increasing by 10%–20%, while Scenario 8 results in a significant increase in water WUE, meaning that WUE has a higher chance (35.21%) of increasing by 20%–30%. The results of these scenarios indicate the importance of changing the water pricing system to volumetrically measured systems such as volumetric water pricing and differential water pricing. They also indicate that the impacts of differential water pricing are much stronger than volumetric water pricing, which leads to a significant increase in WUE. Water users have no incentive to save water when the water price is determined on a non-volumetric basis. Therefore the volumetric water pricing system clearly is the preferable option when advancing water pricing policies in the region [70,78]. Still, a mere adjustment of water pricing practices will most likely not lead to a substantial increase in water use efficiency, as identified by several case studies (e.g., [24,25,33]). If farmers have no capacities (financial, technological, know-how) to adjust their crop management to efficiently react to the increased cost of water, the proposed policies will most likely not lead to the desired water conservation, but instead have a substantial negative impact on rural development [21]. It is therefore crucial to integrate additional (supportive) agricultural policies to improve the effectiveness of water pricing, as the results below show.

3.3. Impacts of Water Pricing and Agricultural Policy Intervention on WUE (*Scenarios 9–14*)

3.3.1. Impacts of Advancing Agricultural Extension Services (Scenarios 9–11)

Under scenario 9 (Price A + Advanced agricultural extension), WUE has a higher chance (37.67%) of increasing by 0%–10% compared to baseline conditions. Similarly, the probability decreased slightly (−1.82%) compared to the baseline. Under scenarios 10 (Price B + Advanced agricultural extension) and 11 (Price C + Advanced agricultural extension), there is a higher chance (34.03% and 34.96%) of WUE increasing by 10%–20%. The results show that advancing the agricultural extension system has a positive effect on WUE improvement. A major global challenge in advancing agricultural production is that research findings and new technologies are not effectively transferred to farmers [79], which causes an increasing gap between actual agricultural practices and the potentials of modern agriculture. In this respect, advancing agricultural extension services may constitute a key trigger to improving farmers' WUE and overall agricultural productivity.

3.3.2. Impacts of Increasing Subsidies (Scenarios 12–14)

Under scenario 12 (Price A + Increased subsidy), WUE has a higher chance (35.49%) of increasing by 0%–10% compared to the baseline. Under scenarios 13 (Price B + Increased subsidy) and 14 (Price C + Increased subsidy), there is a higher chance (34.60% and 34.90%) of WUE increasing by 10%–20% compared to the baseline. The results show that fully increased subsidies for advanced irrigation technology lead to a strong increase in WUE. Under the non-volumetric water pricing system, farmers are obviously less willing to conduct the necessary investments for advanced irrigation technologies, as they do not benefit directly from saving water. Also, the subsidization of advanced irrigation technology will be more effective under the volumetric pricing mechanisms presented by VWP and DWP [20].

3.4. Comparison of Baseline and Most Promising Scenario (*Scenarios 0 & 35*)

The results show that scenario 35, which is a combination of increasing water pricing at a high level, changing the water pricing system to differential water pricing, increasing subsidies for advanced irrigation technology, and advancing agricultural extension services, is the most effective scenario, leading to the highest WUE. Scenario 35 suggests remarkable changes in the probability of WUE compared to the baseline scenario 0 (*cf.* Figure 3). These results demonstrate that adoptions in water pricing mechanisms need to be supported by additional adjustments and agricultural policies to achieve significant increases in WUE.

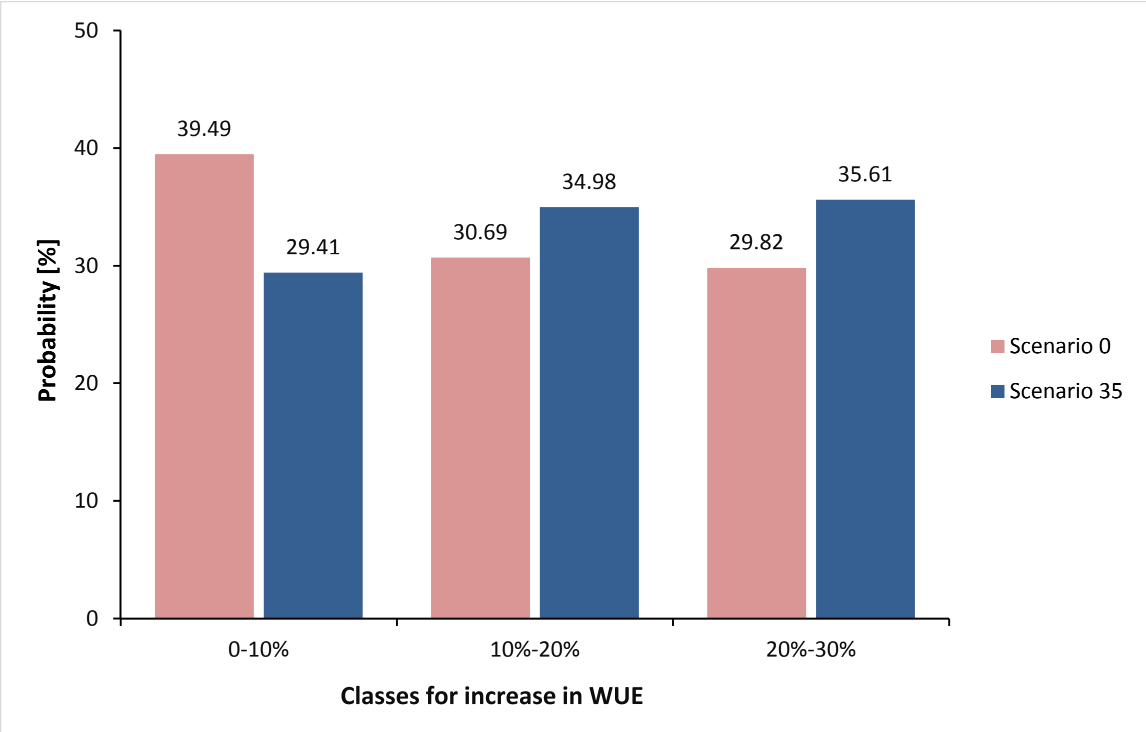

Figure 3. Probability value of the increase in WUE under baseline conditions (scenario 0) and the best combination of policy measures (scenario 35).

3.5. Challenges and Limitations of the Participatory BN Modeling Approach

Despite the obvious advantages of BN modeling, including its ability to integrate data from different disciplines and sources and its potential to clearly visualize complex interrelations, the approach also has several limitations. For instance, the participatory BN modeling approach is very time- and energy-consuming, and the outcome of each individual expert interview, including its viability and usefulness for the overall research procedure, cannot be planned in advance. A high rate of flexibility and persistence is crucial to keep the involved stakeholders motivated throughout the participatory exercises. In this regard, the methodological complexity of Bayesian modeling constitutes a specific challenge, with the local Chinese experts being rather inflexible to leave their trained domain and get involved with systems thinking.

Furthermore, a general reluctance of local Chinese experts to express their personal perception of potentially critical issues (in our case water scarcity) to members of foreign institutions needs to be recognized. Similar challenges were also faced by other foreign research groups conducting participatory research in China, as described by Siew and Döll [80] and van den Hoek *et al.* [81]. It is therefore critical to establish sufficient trust between the research team and the local experts to avoid a pure repetition of official opinion during interviews. Besides, the participatory process requires substantial time investments by the participating local experts, which they have to arrange under the condition of completing their actual tasks and responsibilities. Under these conditions, it is essential to convince the participants of the importance of the research topic and the usefulness of the research method.

Furthermore, the trade-off between completeness of the factors to be considered in the causal networks and manageability of the causal networks requires careful consideration and target-oriented communication with the involved experts during group discussions. Intensive mediation is also crucial, when a minimum consensus is required among members of different domains (e.g., ecological and agricultural experts) regarding the causal and probabilistic relationships among factors.

A specific limitation of the applied approach lies in its limited capability to consider the spatial and temporal variation of the water resource status within the study region. In the study region the water resource situation varies along the 1321-km Tarim River, with water quantity and quality generally degrading downstream and fluctuating seasonally [9]. Specific approaches exist in BN modeling to cope with such spatial and temporal dynamics. They may either be considered by an additional node [82], or separate casual networks can be prepared for each temporal and spatial state [83], which is tedious [38] and adds additional complexity in the participatory process. Similarly, the potential integration of empirical models into BN modeling, as suggested by Castelletti and Soncini-Sessa [84], was considered improper in the present study, due to increasing complexity being undesirable for the participatory approach applied.

4. Conclusions

A Bayesian network model was developed to determine the effects of water pricing policy on WUE along the Tarim River. Together with local experts from different relevant domains, the key factors of the current agricultural water management system were identified, their relationships determined, and their probabilistic interdependencies quantified. Through the participatory modeling approach, expert knowledge and empirical data could be integrated and a clearer picture of the current situation and the opportunities related to improving WUE in the Tarim region could be drawn. For conducting the participatory approach it was crucial to develop sufficient trust between the local experts and the research team to be able to make the experts' knowledge and perceptions operational. The complexity of the probabilistic concept of BN modeling furthermore required strong effort and persistence from the research team to keep participants motivated throughout the iterative participatory approach.

The BN model results show that a mere increase in water price, even to a high level, would have only a limited positive impact on regional WUE. Moreover, the results show that additional adjustments and supportive agricultural policies such as adoption of volumetric water pricing, increasing subsidies for advanced irrigation technology, and advancing agricultural extension services are necessary to significantly improve WUE. The model finally suggests that a strong increase in water price combined with differential water pricing, increased subsidization for irrigation technology, and improved agricultural extension services proved the best scenario, leading to the highest increase in

WUE. Such adjustments in the current agricultural water management system would require substantial efforts from both the agricultural and the water-related administrative bodies in the Tarim region. As such, the participatory modeling exercise realized joint communication, understanding, and mutual learning among different stakeholders for better decision-making.

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Author Contributions

Yusuyunjiang Mamitimin, Til Feike and Reiner Doluschitz participated in the design of the study. Yusuyunjiang Mamitimin performed the data collection, analysis, and preparation of the first draft of the manuscript. Til Feike and Reiner Doluschitz supervised the data collection and analysis, and Til Feike helped with the preparation of the final manuscript. All authors reviewed the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Huang, X.; Chen, Y.; Ma, J.; Hao, X. Research of the sustainable development of Tarim River based on ecosystem service function. *Procedia Environ. Sci.* **2011**, *10*, 239–246.
2. Han, S.; Hu, H.; Yang, D.; Liu, Q. Differences in changes of potential evaporation in the mountainous and oasis regions of the Tarim basin, northwest China. *Sci. China Ser. E Technol. Sci.* **2009**, *52*, 1981–1989.
3. Thevs, N. Water scarcity and allocation in the Tarim Basin: Decision structures and adaptations on the local level. *J. Curr. Chin. Aff.* **2011**, *40*, 113–137.
4. De La Paix, M.J.; Lanhai, L.I.; Jiwen, G.E.; de Dieu, H.J.; Theoneste, N. Analysis of snowmelt model for flood forecast for water in arid zone: Case of Tarim River in Northwest China. *Environ. Earth Sci.* **2012**, *66*, 1423–1429.
5. National Bureau of Statistics of China. *China's Statistical Yearbook*; China Statistical Press: Beijing, China, 2013.
6. Feike, T.; Mamitimin, Y.; Li, L.; Doluschitz, R. Development of agricultural land and water use and its driving forces along the Aksu and Tarim River, P.R. China. *Environ. Earth Sci.* **2014**, *73*, 517–531.
7. Leiwen, J.; Yufen, T.; Zhijie, Z.; Tianhong, L.; Jianhua, L. Water resources, land exploration and population dynamics in arid areas—The case of the Tarim River Basin in Xinjiang of China. *Popul. Environ.* **2005**, *26*, 471–503.

8. Zhao, R.; Chen, Y.; Zhou, H.; Li, Y.; Qian, Y.; Zhang, L. Assessment of wetland fragmentation in the Tarim River basin, western China. *Environ. Geol.* **2009**, *57*, 455–464.
9. Rumbaur, C.; Thevs, N.; Disse, M.; Ahlheim, M.; Brieden, A.; Cyffka, B.; Doluschitz, R.; Duethmann, D.; Feike, T.; Frör, O.; *et al.* Sustainable management of river oases along the Tarim River in North-Western China under conditions of climate change. *Earth Syst. Dynam. Discuss.* **2014**, *5*, 1221–1273.
10. Peng, H.; Thevs, N.; Ott, K. Water Distribution in the Perspectives of Stakeholders and Water Users in the Tarim River Catchment, Xinjiang, China. *JWARP* **2014**, *6*, 543–555.
11. Nian, Z. *Water Supply Cost Calculation Results and Analysis of Xinjiang Water Conservancy Project in 2010*; Xinjiang Uyghur Autonomous Region Provincial Department of Water Resources: Urumqi, China, 2012.
12. Xinjiang Uygur Autonomous Region Management Method of Water Supply Price in the Water Conservancy Project, 2002. Available online: http://www.xjdrc.gov.cn/copy_4_copy_10_second.jsp?urltype=news.NewsContentUrl&wbtreeid=11305&wbnewsid=203718 (accessed on 10 December 2014).
13. Chen, Y.; Xu, C.; Chen, Y.; Liu, Y.; Li, W. Progress, challenges and prospects of Eco-hydrological studies in the Tarim river basin of Xinjiang, China. *Environ. Manag.* **2013**, *51*, 138–153.
14. Hailiang, X.; Mao, Y.; Yudong, S. The dynamic variation of water resources and its tendency in the Tarim River Basin. *J. Geogr. Sci.* **2005**, *15*, 467–474.
15. XUAR People's Government's Comments on Promoting the Development of Water Conservation Reform, 2013. Available online: http://www.xjslt.gov.cn/zwgk/flfg/gfxwj/2013/28079.htm (accessed on 10 December 2014).
16. Tsur, Y.; Dinar, A. The relative efficiency and implementation costs of alternative methods for pricing irrigation water. *World Bank Econ. Rev.* **1997**, *11*, 243–262.
17. Abu-Zeid, M.A. Water pricing in irrigated agriculture. *Int. J. Water Resour. Dev.* **2001**, *17*, 527–538.
18. Dinar, A.; Subramanian, A. Policy implications from water pricing experiences in various countries. *Water Policy* **1998**, *1*, 239–250.
19. Schoengold, K.; Sunding, D.L.; Moreno, G. Price elasticity reconsidered: Panel estimation of an agricultural water demand function. *Water Resour. Res.* **2006**, *42*.
20. Molle, F.; Venot, J.P.; Hassan, Y. Irrigation in the Jordan Valley: Are water pricing policies overly optimistic? *Agric. Water Manag.* **2008**, *95*, 427–438.
21. Tardieu, H.; Préfol, B. Full cost or "sustainability cost" pricing in irrigated agriculture. Charging for water can be effective, but is it sufficient? *Irrig. Drain.* **2002**, *51*, 97–107.
22. Liao, Y.; Giordano, M.F.; de Fraiture, C. An empirical analysis of the impacts of irrigation pricing reforms in China. *Water Policy* **2007**, *9*, 45–60.
23. Lohmar, B.; Wang, J.; Rozelle, S.; Huang, J.; Dawe, D. *China's Agricultural Water Policy Reforms: Increasing Investment, Resolving Conflicts, and Revising Incentives*; United States Department of Agriculture, Economic Research Service: Washington, DC, USA, 2003.
24. Schuck, E.C.; Green, G.P. Conserving one water source at the expense of another: The role of surface water price in adoption of wells in a conjunctive use system. *Int. J. Water Resour. Dev.* **2003**, *19*, 55–66.

25. Liao, Y.; Gao, Z.; Bao, Z.; Huang, Q.; Feng, G.; Xu, D.; Cai, J.; Han, H.; Wu, W. *China's Water Pricing Reforms for Irrigation: Effectiveness and Impact*; International Water Management Institute (IWMI): Colombo, Sri Lanka, 2008.
26. Moore, M.R.; Gollehon, N.R.; Carey, M.B. Multicrop Production Decisions in Western Irrigated Agriculture: The Role of Water Price. *Am. J. Agric. Econ.* **1994**, *76*, 859–874.
27. Scheierling, S.M.; Young, R.A.; Cardon, G.E. Determining the price-responsiveness of demands for irrigation water deliveries versus consumptive use. *J. Agric. Resour. Econ.* **2004**, 328–345.
28. Albiac, J.; Playán, E.; Martínez, Y. Instruments for water quantity and quality management in the agriculture of Aragon. *Water Resour. Dev.* **2007**, *23*, 147–164.
29. Berbel, J.; Gómez-Limón, J.A. The impact of water-pricing policy in Spain: An analysis of three irrigated areas. *Agric. Water Manag.* **2000**, *43*, 219–238.
30. Doppler, W.; Salman, A.Z.; Al-Karablieh, E.K.; Wolff, H.P. The impact of water price strategies on the allocation of irrigation water: The case of the Jordan Valley. *Agric. Water Manag.* **2002**, *55*, 171–182.
31. Frija, A.; Wossink, A.; Buysse, J.; Speelman, S.; van Huylenbroeck, G. Pricing policies and impact on water demand in Tunisia: A DEA-based methodology for estimation of individual input demand functions. *J. Environ. Manag.* **2011**, *92*, 2109–2118.
32. Stijn, S.; Jeroen, B.; Stefano, F.; Aymen, F.; Marijke, D.; Luc, D. Estimating the impacts of water pricing on smallholder irrigators in North West Province, South Africa. *Agric. Water Manag.* **2009**, *96*, 1560–1566.
33. Mamitimin, Y.; Feike, T.; Seifert, I.; Doluschitz, R. Irrigation in the Tarim Basin, China: Farmers' response to changes in water pricing practices. *Environ. Earth Sci.* **2014**, *73*, 559–569.
34. Abu-Madi, M.O. Farm-level perspectives regarding irrigation water prices in the Tulkarm district, Palestine. *Agric. Water Manag.* **2009**, *96*, 1344–1350.
35. Chellattan Veettil, P.; Speelman, S.; Frija, A.; Buysse, J.; Mondelaers, K.; van Huylenbroeck, G. Price Sensitivity of Farmer Preferences for Irrigation Water-Pricing Method: Evidence from a Choice Model Analysis in Krishna River Basin, India. *J. Water Resour. Plan. Manag.* **2011**, *137*, 205–214.
36. Garcia, S.; Reynaud, A. Estimating the benefits of efficient water pricing in France. *Resour. Energy Econ.* **2004**, *26*, 1–25.
37. Uusitalo, L. Advantages and challenges of Bayesian networks in environmental modelling. *Ecol. Model.* **2007**, *203*, 312–318.
38. Grêt-Regamey, A.; Brunner, S.H.; Altwegg, J.; Bebi, P. Facing uncertainty in ecosystem services-based resource management. *J. Environ. Manag.* **2013**, *127*, S145–S154.
39. Rositano, F.; Ferraro, D.O. Ecosystem services provided by agroecosystems: A qualitative and quantitative assessment of this relationship in the Pampa Region, Argentina. *Environ. Manag.* **2014**, *53*, 606–619.
40. Richards, R.G.; Sanò, M.; Roiko, A.H.; Carter, R.W.; Bussey, M.; Matthews, J.; Smith, T. Bayesian belief modeling of climate change impacts for informing regional adaptation options. *Environ. Model. Softw.* **2013**, *44*, 113–121.

41. Mantyka-Pringle, C.S.; Martin, T.G.; Moffatt, D.B.; Linke, S.; Rhodes, J.R. Understanding and predicting the combined effects of climate change and land-use change on freshwater macroinvertebrates and fish. *J. Appl. Ecol.* **2014**, *51*, 572–581.
42. Keshtkar, A.R.; Salajegheh, A.; Sadoddin, A.; Allan, M.G. Application of Bayesian networks for sustainability assessment in catchment modeling and management (Case study: The Hablehrood river catchment). *Ecol. Model.* **2013**, *268*, 48–54.
43. Barton, D.N.; Saloranta, T.M.; Moe, S.J.; Eggestad, H.O.; Kuikka, S. Bayesian belief networks as a meta-modelling tool in integrated river basin management—Pros and cons in evaluating nutrient abatement decisions under uncertainty in a Norwegian river basin. *Ecol. Econ.* **2008**, *66*, 91–104.
44. Shenton, W.; Hart, B.T.; Chan, T. A Bayesian network approach to support environmental flow restoration decisions in the Yarra River, Australia. *Stoch. Environ. Res. Risk Assess.* **2014**, *28*, 57–65.
45. Farmani, R.; Henriksen, H.J.; Savić, D.A. An evolutionary Bayesian belief network methodology for optimum management of groundwater contamination. *Environ. Model. Softw.* **2009**, *24*, 303–310.
46. Portoghese, I.; D'Agostino, D.R.; Giordano, R.; Scardigno, A.; Apollonio, C.; Vurro, M. An integrated modelling tool to evaluate the acceptability of irrigation constraint measures for groundwater protection. *Environ. Model. Softw.* **2013**, *46*, 90–103.
47. McCann, R.K.; Marcot, B.G.; Ellis, R. Bayesian belief networks: Applications in ecology and natural resource management. *Can. J. For. Res.* **2006**, *36*, 3053–3062.
48. Landuyt, D.; Broekx, S.; D'Hondt, R.; Engelen, G.B.; Aertsens, J.; Goethals, P.L. A review of Bayesian belief networks in ecosystem service modelling. *Environ. Model. Softw.* **2013**, *46*, 1–11.
49. Ye, M.; Xu, H.; Song, Y. The utilization of water resources and its variation tendency in Tarim River Basin. *Chin. Sci. Bull.* **2006**, *51*, 16–24.
50. Song, Y.; Wang, R.; Peng, Y. Water resources and ecological conditions in the Tarim Basin. *Sci. China Ser. D Earth Sci.* **2002**, *45*, 11–17.
51. Sun, P.; Zhang, Q.; Lu, X.; Bai, Y. Changing properties of low flow of the Tarim River basin: Possible causes and implications. *Quat. Int.* **2012**, *282*, 78–86.
52. Xu, J.; Chen, Y.; Li, W.; Dong, S. Long-term trend and fractal of annual runoff process in mainstream of Tarim River. *Chin. Geogr. Sci.* **2008**, *18*, 77–84.
53. Zhao, R.; Chen, Y.; Shi, P.; Zhang, L.; Pan, J.; Zhao, H. Land use and land cover change and driving mechanism in the arid inland river basin: A case study of Tarim River, Xinjiang, China. *Environ. Earth Sci.* **2013**, *68*, 591–604.
54. Shi, Y.; Wang, R.; Fan, L.; Li, J.; Yang, D. Analysis on land-use change and its demographic factors in the original-stream watershed of Tarim river based on GIS and statistic. *Environ. Earth Sci.* **2010**, *2*, 175–184.
55. Xu, C.; Chen, Y.; Chen, Y.; Zhao, R.; Ding, H. Responses of surface runoff to climate change and human activities in the arid region of Central Asia: A case study in the Tarim River Basin, China. *Environ. Manag.* **2013**, *51*, 926–938.
56. Zhang, Q.; Xu, C.; Tao, H.; Jiang, T.; Chen, Y. Climate changes and their impacts on water resources in the arid regions: A case study of the Tarim River basin, China. *Stoch. Environ. Res. Risk Assess.* **2010**, *24*, 349–358.
57. Zhou, H.; Zhang, X.; Xu, H.; Ling, H.; Yu, P. Influences of climate change and human activities on Tarim River runoffs in China over the past half century. *Environ. Earth Sci.* **2012**, *67*, 231–241.

58. Sun, Z.; Chang, N.; Opp, C.; Hennig, T.A. Evaluation of ecological restoration through vegetation patterns in the lower Tarim River, China with MODIS NDVI data. *Ecol. Inform.* **2011**, *6*, 156–163.
59. Chen, Y.; Chen, Y.; Xu, C.; Ye, Z.; Li, Z.; Zhul, C.; Ma, X. Effects of ecological water conveyance on groundwater dynamics and riparian vegetation in the lower reaches of Tarim River, China. *Hydrol. Process.* **2010**, *24*, 170–177.
60. Xu, H.; Ye, M.; Li, J. The water transfer effects on agricultural development in the lower Tarim River, Xinjiang of China. *Agric. Water Manag.* **2008**, *95*, 59–68.
61. Nielsen, T.D.; Jensen, F.V. *Bayesian Networks and Decision Graphs*; Springer Science & Business Media: New York, NY, USA, 2009.
62. Pearl, J. *Probabilistic Reasoning in Intelligent Systems*: *Networks of Plausible Inference*, 2nd ed.; Morgan Kaufmann: San Francisco, CA, USA, 1998.
63. Koski, T.; Noble, J.M. *Bayesian Networks*: *An Introduction*; Wiley: West Sussex, UK, 2009.
64. Blitzstein, J.K.; Hwang, J. *Introduction to Probability*; CRC Press/Taylor & Francis Group: Boca Raton, FL, USA, 2015.
65. Cain, J. *Planning Improvements in Natural Resources Management: Guidelines for Using Bayesian Networks to Support the Planning Management of Development Programmes in the Water Sector and beyond*; Centre for Ecology and Hydrology: Wallingford, UK, 2001.
66. Marcot, B.G.; Steventon, J.D.; Sutherland, G.D.; McCann, R.K. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. *Can. J. For. Res.* **2006**, *36*, 3063–3074.
67. Bromley, J. *Guidelines for the Use of Bayesian Networks as a Participatory Tool for Water Resource Management*; Centre for Ecology and Hydrology: Wallingford, UK, 2005.
68. Tsur, Y. Economic Aspects of Irrigation Water Pricing. *Can. Water Resour. J.* **2005**, *30*, 31–46.
69. Easter, K.W. *Irrigation Investment, Technology and Management Strategies for Development*; Westview Press: Boulder, CO, USA, 1986.
70. Easter, K.W.; Liu, Y. *Cost Recovery and Water Pricing for Irrigation and Drainage Projects*; World Bank: Washington, DC, USA, 2005.
71. Molle, F. Water scarcity, prices and quotas: A review of evidence on irrigation volumetric pricing. *Irrig. Drain. Syst.* **2009**, *23*, 43–58.
72. Just, R.E.; Netanyahu, S.; Horowitz, J.K. Water pricing and water allocation in Israel. *J. Policy Reform* **1999**, *3*, 97–119.
73. National Bureau of Statistics of China. *XPCC Statistical Yearbook* (*2001–2012*); China Statistical Press: Beijing, China, 2001–2012.
74. Ministry of Water Resources, China. *China Water Conservancy Statistical Yearbook 2010–2012*; China Water Conservancy and Hydropower Press: Beijing, China, 2010–2012.
75. Li, H.; Li, G.; Tian, C. The research on stint drip irrigation underside film for cotton production in the middle-lower reach of the Tarim river and the Peacock river. *Agric. Res. Arid Areas* **2006**, *24*, 82–84.
76. Amayreh, J.A.; Abdulla, F.A.; Al-Ja'afreh, H. Impact of different water price levels on irrigated agriculture in Northern Jordan Valley. *Irrig. Drain. Syst.* **2011**, *25*, 307–321.

77. Vasileiou, K.Z.; Mitropoulos, P.; Mitropoulos, I. Optimizing the performance of irrigated agriculture in eastern England under different water pricing and regulation strategies. *Nat. Resour. Model.* **2014**, *27*, 128–150.
78. Singh, K. Rational pricing of water as an instrument of improving water use efficiency in the agricultural sector: A case study in Gujarat, India. *Int. J. Water Resour. Dev.* **2007**, *23*, 679–690.
79. Von Wirén-Lehr, S. Sustainability in agriculture—An evaluation of principal goal-oriented concepts to close the gap between theory and practice. *Agric. Ecosyst. Environ.* **2001**, *84*, 115–129.
80. Siew, T.-F.; Döll, P. Transdisciplinary research for supporting the inte-gration of ecosystem services into land and water management in the Tarim River Basin, Xinjiang, China. *J. Arid Land* **2012**, *4*, 196–210.
81. Van den Hoek, J.; Baumgartner, J.; Doucet-Beer, E.; Hildebrandt, T.; Robinson, B.E.; Zinda, J.A. Understanding the challenges and rewards of social-ecological research in China: Society & Natural Resources. *Soc. Nat. Resour.* **2012**, *25*, 1324–1329.
82. Pollino, C.A.; Henderson, C. *Bayesian Networks: A Guide for Their Application in Natural Resource Management and Policy*; Landscape Logic: Tasmania, Australia, 2010; Volume 14.
83. Duespohl, M.; Frank, S.; Döll, P. A review of Bayesian networks as a participatory modeling approach in support of sustainable environmental management. *J. Sustain. Dev.* **2012**, *5*, doi:10.5539/jsd.v5n12p1.
84. Castelletti, A.; Soncini-Sessa, R. Bayesian networks and participatory modelling in water resource management: Bayesian networks in water resource modelling and management. *Environ. Model. Softw.* **2007**, *22*, 1075–1088.

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