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Managing Scarce water resources for socially acceptable solutions, through hydrological and econometric modeling

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Abstract

Covering increasing water demand for competitive uses with limited resources is becoming one of the most challenging water management issues. The effects are more evident in arid areas, where conflicts are more likely to occur. Such an example is Urumqi County, China; Urumqi River is the main water supply source, and in order to balance the upstream agricultural water demand and the downstream urban water demand, the government imposed fallow measures. The region is traditionally a rural area with high production expectations, however, urban water demand is continuously increasing over the last decades, following the population and urbanization trends. Irrigation needs are covered from the river, during the summer period, creating seasonal demand peaks. The fallow measures aim to sustain agriculture and the government defines which farmers will fallow each year. This study uses a questionnaire survey to examine the farmers' willingness to continue fallow, and the fallow period preference; both examined for the first time so far. The driving factors are used as variables to analyze and describe the preferences through regression models. A non-negligible portion of farmers highly depend on agriculture and want to cultivate. The feasibility of satisfying their needs through better water management is examined through a coupled WEAP (Water Evaluation And Planning) model. Combining econometric and hydrological tools is a novel element. The results are encouraging, with significant insights on the current water management policy, the potential of diversified fallow systems, and the achievement of sustainable and socially acceptable planning.

Keywords: Urumqi River Basin, water scarcity conflicts, willingness to fallow, econometrics, hydrology.

Paper type: Research article.

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1. Introduction

Water in arid regions is essential for the development of oasis agriculture and a source of life for the local residents' productive activities and prosperity(Lei et al., 2020) Urbanization and population growth in big cities cause increased water and food demand(Chen et al., 2017; Du et al., 2014). The increased expectations from agricultural productivity further stress freshwater abstraction, causing competition among water uses(Alamanos et al., 2020; Li, 2003). Disturbance of local economies, environmental degradation, pollution, and depletion of water resources are the consequences, that often lead to conflicts(Paisley, 2018).

The area of Urumqi River in Xinjiang province, China, faces all the above challenges. The river originates from the seasonal melt of a glacier, the physical supply is limited and the competition among users is intense. The upstream Urumqi County is a region that traditionally relies on agriculture for living, while Urumqi City in the downstream, is the biggest city of Xinjiang Uygur Autonomous Region, and consumes only about 1/4 of the national average water per capita, according to the Xinjiang Statistical Yearbook (2018). In order to balance the upstream and downstream uses, avoid water resources overexploitation and extinction of agriculture, the Urumqi Municipal Government imposes obligatory fallowing measures to certain farmers each year (based on the supply and demand estimation of urban water resources). At this point, a research question arises: is this policy acceptable and sustainable for the majority of the farmers, and if it is not, is it possible to manage water resources in a way that will satisfy their needs?

The willingness of farmers to fallow and to receive compensation is believed to be highly dependent on their non-agricultural income, the quality of the land(Zeng et al., 2018), the differences between rural or urban residents(Zhang et al., 2017), while the fallow compensation standard has found to be related to farmers' willingness to pay(Xie et al., 2017; Zeng et al., 2018) find that farmers' perception on the quality of cultivated land has a negative impact on the willingness to fallow, while education, labor, farmer-worker days, total family labor, per capita cultivated land area, and fallow attitude have a positive influence on the willingness to fallow. Most studies have mainly explored the impact mechanism and compensation standards. Still to our knowledge, no study has examined the farmers' willingness to continue fallowing, and for how long, connecting their perceptions to potential water resources management options.

Integrated modeling has been a promising solution for complex water management problems with social characteristics(MacEwan et al., 2017; Peña-Haro et al., 2009). However, its disadvantages are the difficulty to apply, detailed data requirements, and the fact that subjects to the weaknesses of both hydrologic and economic models, while it is difficult to incorporate the social and economic aspect of the system(Alamanos et al., 2016, 2019). This work uses integrated modeling to cope with the above challenges: a framework easy to use, with limited data, combining hydrologic and econometric tools, is presented for the first time in Urumqi River Basin (URB). In terms of water resources modeling, the experience is also limited in the study area. The few studies have mainly focused on the glacier's dynamics, where the flow of Urumqi River starts(Deng et al., 2011; Zhang et al., 2016), and its natural runoff processes(Fu et al., 2017; Wang et al., 2018). However, no study was found on water resources management and allocation.

In this work, integrated modeling is used, combining a socio-economic (econometric) and a water resources management model, as connecting expertise is a very promising path to achieve sustainability(Sehring, 2015). A survey is used to depict the factors that affect farmers' perceptions on the continuation of fallow, for how long, and the results are analyzed through different regression models. Moreover, the overall water demand (as sum of urban, industrial, livestock and agricultural) is estimated through a coupled WEAP (WEAP, 2001), CROPWAT (FAO, 2015) and MS Excel model. Alternative management and allocation options are also simulated, in order to examine if more farmers could cultivate, and the potential to develop a future diversified fallow system. Overall, the study's integrated character in an area with no relevant experience is its novel element. Although it is a preliminary attempt to depict the situation, because of the limited available data, it successfully illustrates the current conditions both socio-economically and hydrologically, and examines future paths to reduce conflicts, increase productivity, support local economy, and set the bases for more systematic research in the area.

2. Study area

Xinjiang is in the arid and inland region of northwest China, characterized by limited rainfall, large evaporation, and severe water shortage. The climate is dry, with hot summers and cold winters(Thevs et al.,2017). Urumqi River is the most important water supply source; The river's flow originates from mountainous glaciers in the Southern part of the County (Figure 1) and it is distributed to the different water uses through a system of three main reservoirs (with limited or no available data regarding their inflows, outflows, and volumes). Daxigou, the main reservoir, supplies the other two reservoirs: Wulabo supplies Urumqi City, and Hongyanchi, which was used for urban and industrial supply until 2014, when it started supplying only Urumqi City (Figure 2).

The exponential increment of Urumqi City's population the last decades has brought conflicts between the upstream (agricultural areas that are blamed for causing water deficit) and the downstream (urban water use). The upstream agriculture is characterized by poor infrastructure and management, contributing to water inefficient use, i.e. high irrigation losses because of methods such as open channel irrigation(Y. Li et al., 2020). The main crops are vegetables, alfalfa, rapeseeds, potato, and wheat; the crop choices are limited and subject to the area's dry climatic and sandy soil characteristics(Yang et al., 2019).

The insufficient water resources have led to long-term pumping, resulting in reduced flows of Urumqi River, drawdown of the Lake Chaiwopu's level, shrinking of the surrounding wetlands, and ecosystem deterioration(Ye et al., 2017).

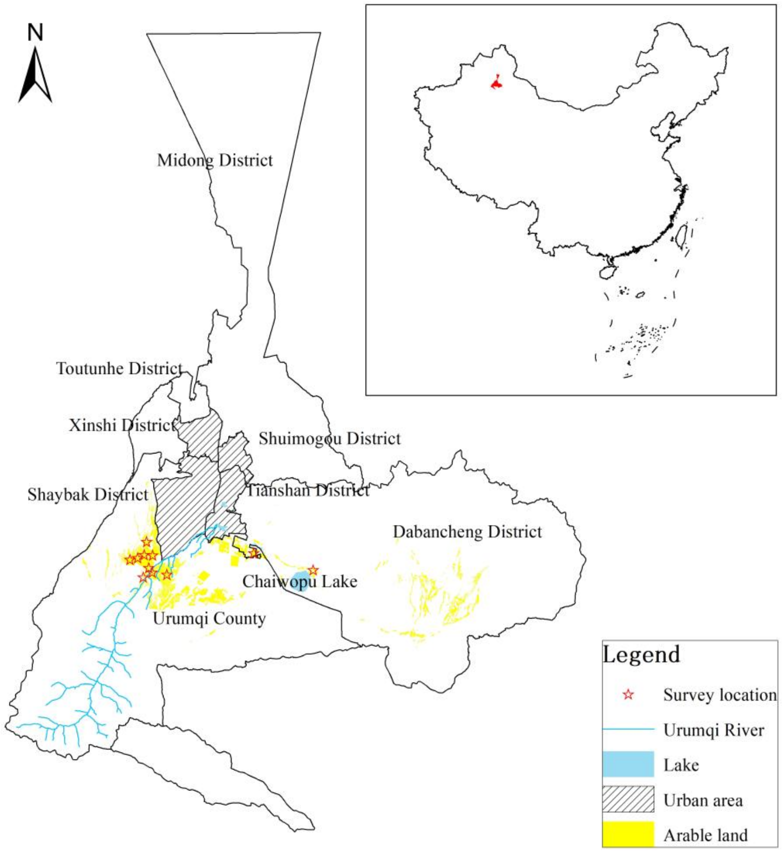

Figure 1. The Study Area

In order to cover the increasing urban water demand in the downstream, the local government applied the scheme “reduce grain and save water” in 2012, which means to “reduce water for crops and supply to cities”, and also restore the area’s surface water levels(Yang, 2018). Practically, the Urumqi Municipal Government determines a fallow level based on estimated water availability, which is imposed to the farmers. Then the respective (village) leaders sign informal fallow contracts with farmers. The fallow area mainly involves the towns of Banfanggou, Yongfeng, Saldaban, Chaiwopu, and Xigou. Through rural surveys, it is found that the farmers who are selected to fallow will receive a compensation of 480 RMB/Mu (0.72 RMB/m^2) of cultivated land. In 2012, 14974 hectares (ha) were fallowed, and by 2016 27439 ha were fallowed, resulting in total water savings of around 120 hm^3 (data released only for 2012-2016 by Statistics Bureau of Urumqi County.).

The way that this policy was implemented obviously lacks equity and does not fully consider the willingness of farmers to fallow, or to continue fallowing, or for how long they wish to do it. These factors are analyzed and presented in the next sections. Furthermore, the long-term fallow gradually caused soil desertification, soils lost their fertility, deteriorating also the surrounding ecological environment(Ramachandran, 2017). Considering these consequences, the government reduced the fallow area from 27439 hectares to 16593 hectares in 2017. From 2018, the water-saving goal from fallowing is 20 hm^3/year (re-cultivation policy).

The potential of a wiser water resources management is also examined in the following sections, considering both socio-economic and environmental factors, to explore more sustainable and socially acceptable paths.

3. Methodology

Initially, a questionnaire survey was designed to map the socio-economic, demographic background, and the preferences of farmers of the County (Fig.1). For the sample selection the random sampling method was followed among the towns that have already implemented the fallow measure. 430 face-to-face interviews took place in September-October 2018. Invalid questionnaires (unclear text recognition, incomplete information) were eliminated, and 395 valid questionnaires were finally obtained (effective rate 91.86%). The dependent variable, as designed in the interviews, was the behavioral decision-making of fallow farmers, which is divided into **the willingness to continue fallow (WCF)** and **the fallow period preference (FPP)**, i.e. short-term (a season) or long-term (for more than one season). The independent variables were (Table 1):

- Age(AGE) – older farmers are engaged in agricultural activities (around 50 years old), reflecting China's urbanization, with a large number of young laborers moving to big cities.
- Education level(EDU) – relatively low, mainly primary and junior high schools (46.58%).
- Health status(HEA) – relatively good, with “average” health status accounting for the largest proportion (58.48%).
- Proportion of labor(LAB) – share among family members and workers.
- Irrigation reliability(IRR) – This refers to the conditions of farmland irrigation, from good to bad, divided into “completely guaranteed” irrigation (irrigation canal, continuous water supply), basically guaranteed irrigation (irrigation canal, occasional water cut) and not guaranteed irrigation (no irrigation canal). The latter case is the dominant for the fallowed areas.
- Fertility status(FER) – The classification of farmland fertility levels in three levels from the best (first-class) to the worst (third-class). The study area is dominated by the second- and third-class.
- Understanding of re-cultivation policy(POL) – Most of the interviewed farmers only have a preliminary understanding of the re-cultivation policy.
- Acceptance of compensation(COM) – Most of the farmers are basically satisfied with the fallow compensation amount.
- Employment opportunities(EMP) – 63.29% of the interviewed farmers think it is difficult to find another job after fallow.
- Changes in household income(INC) – 29.87% of the farmers claimed that their family income has decreased.

After the statistical analysis of the variables (as above and in Table 1), regression (econometric) models were used to scrutinize the relations of the studied factors regarding willingness to fallow for certain periods.

Table I. Descriptive statistical analysis of the survey's variables.

	Variable	Variable description	Mean	St. Deviation	Minimum	Maximum
Dependent variable	WCF	1=Yes 0=No	0.691	0.463	0	1
	FPP	1=No fallow (0 years) 2=Short-term (1-2 years) 3=Long-term (3-5 years)	2.22	0.89	1	3
	AGE	1=under 40 years old; 2=40-50 years old; 3=50-60 years old; 4=over 60 years old	2.932	0.978	1	4
	EDU	1= never go school; 2=Elementary school; 3=Junior school; 4=High school; 5=College and above	2.478	0.913	1	5
	HEA	1=bad 2=fair 3=good	2.428	0.748	1	3
	LAB	Labor/family population	0.637	0.317	0	1
Explanatory variables	POL	1=Don't understand 2=General 3=Understand	1.977	0.838	1	3
	COM	1=Not accepted 2=General 3=Fully accepted	1.932	0.851	1	3
	IRR	1=not guaranteed irrigation; 2=basically guaranteed irrigation; 3=completely guaranteed irrigation	1.732	0.74	1	3
	FER	1= first-class; 2=second-class; 3= third-class	2.19	0.674	1	3
	EMP	1=bad 2=fair 3=good	1.466	0.669	1	3
	INC	1=decrease 2=unchanged 3=increased	2.091	0.826	1	3

Since farmers' willingness to participate in fallow is a binary discrete variable, the binary Logit model (Eq.1) is used to conduct the empirical analysis on the factors affecting farmers' willingness to fallow(Martey et al., 2014):

$$Logit(P) = ln\frac{P}{1-P} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n + \varepsilon_i \qquad (1)$$

In the formula, P represents probability of farming fallow, X_i are the independent variables to continue participating in fallow, α is the constant, β are their regression coefficients, and ε_i are the random disturbance terms.

The fallow period preference is a disordered multi-categorical variable. It does not satisfy the model's proportional advantage assumption (namely the P value of the parallelism test is greater than 0.05), so the Multinomial Logit regression model (Eq.2, 3) was deemed most suitable to analyze the farmers' preference for the fallow period(Haan & Uhlendorff, 2006):

$$Logit = (P_{2/1}) = \ln\left[\frac{P(Y=2\mid X)}{P(Y=1\mid X)}\right] = \alpha_2 + \beta_{21}X_1 + \beta_{22}X_2 + \cdots + \beta_{2K}X_K = g_2(X) \quad (2)$$

$$Logit = (P_{3/1}) = \ln\left[\frac{P(Y=3\mid X)}{P(Y=1\mid X)}\right] = \alpha_3 + \beta_{31}X_1 + \beta_{32}X_2 + \cdots + \beta_{3K}X_K = g_3(X) \quad (3)$$

Y represents the explained variable (*Y*=1 for baseline group, i.e. not continued fallow), *X* are explanatory variables, *K* is the number of *X's*, β their regression coefficients, and α the constant terms. Eq.2 expresses the ratio of short-term fallow to no continued fallow. Eq.3 shows the ratio of long-term fallow to no continued fallow. The probability of event (y=j) occurring is:

$$P(y \geq j \mid x) = \frac{1}{1 + \exp(-\alpha_j + \sum_{j=1}^{n} \beta_j x_i)} \quad (4)$$

The relative risk ratio (RRR) refers to the ratio of the probability of occurrence of other selection preferences to the baseline group (Eq.5):

$$RRR = \frac{P(Y=j)}{P(Y=1)} \quad (5)$$

The sample's analysis shows that a portion of farmers want or will need to cultivate, and in order to examine if there can be any alternative management option, we simulated the demand of all the competitive water uses (Urban, Industrial, Agricultural, Livestock) and the reservoirs' system that supplies them. A WEAP model (Fig.2) was developed, considering the areas of each use, specific consumptions (following equations), while for the irrigation water requirements per crop, a CROPWAT model (Fig.2) was developed considering climate, soil, and cropping parameters (data retrieved from Urumqi's meteorological station, the Statistics Bureau of Urumqi County(2018), and cropping data from field surveys).

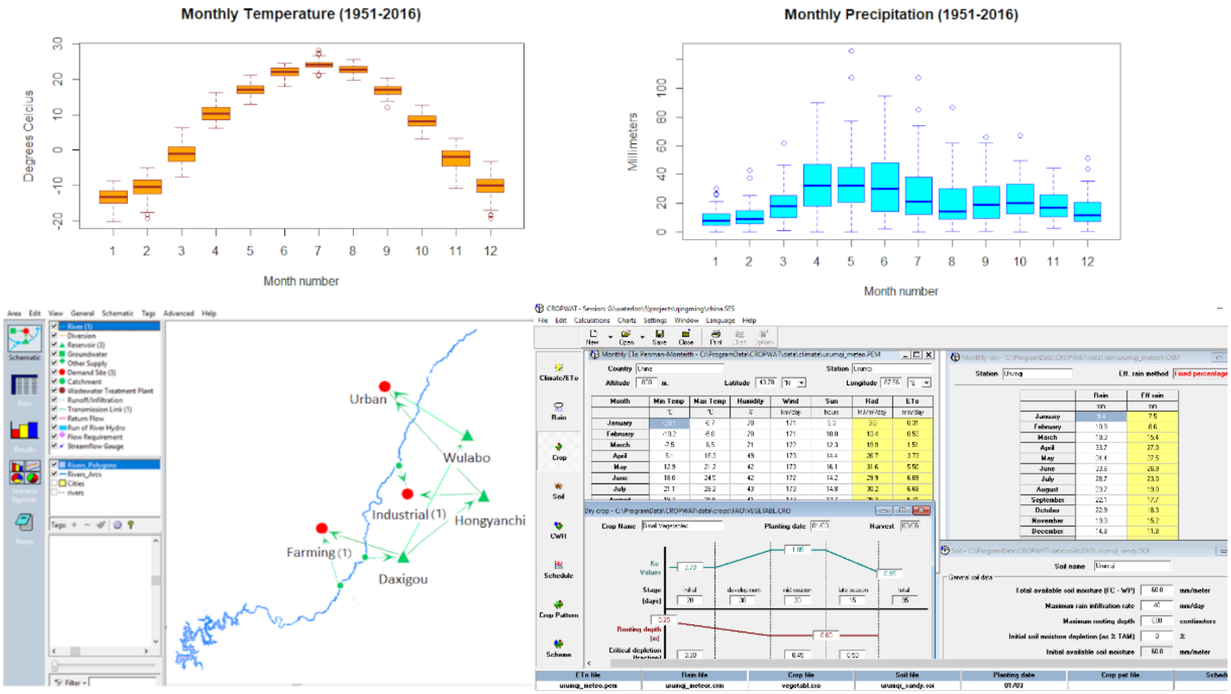

Figure 2. The climate of the study area, the WEAP model schematic representation, and the CROPWAT model.

Urban water demand was set as 1^{st} priority, (to be supplied), and the other water uses will use the remaining water supply from the respective reservoirs. The urban water demand Q_{ur} (m^3) occurs from the specific consumption q_s (m^3/pe/month), multiplied with the serviced population E, increased by the network losses, L (Eq.6). Similarly, regarding livestock water demand, using the existing animal recordings and typical values of their daily water consumption (q_{an}), the total monthly water needs were estimated (Q_{an}). The main types (i) in the area are cattle, swine, beef, poultry, horse-type animals (Eq.8).

$$Q_{ur} = q_s \cdot E + \mathrm{L} \qquad (6)$$

$$Q_{an} = \sum_i q_{an(i)} \cdot \mathrm{Type_i} \qquad (7)$$

$$Q_{ind} = \sum_{ind} q_{in(i)} \cdot \mathrm{Type_{ind}} \qquad (8)$$

The area's industries counted to 32 categories (include mining, oil and gas extraction, food and beverage manufactures, clothing, textile, wood, pharmaceutical, plastic, electricity and more industries) ($\mathrm{Types_{ind}}$). Using typical consumption values (q_{ind}) from official data, per units of produced products (Xinjiang Statistical Yearbook, 2018) the total consumption was estimated similarly (Q_{in}). The monthly variation was considered constant (Eq.8).

Urban and industrial water use are supplied mainly from the same supply sources (Fig.2); livestock and irrigation water demand are covered from the same supply sources, and in the schematic of Figure 2 they are combined in the same demand site ("Farming").

The monthly irrigation requirements from each crop were estimated from the CROPWAT model, using the modified Blanney-Criddle method (Blanney-Criddle, 1962). The method estimates the EvapoTranspiration of a reference crop (PET_o) based in three coefficients (a, b, f) which are functions of meteorological factors (average day-hours, temperature, humidity, wind speed). Temperature and rainfall data are also inserted into the CROPWAT model, together with soil-type and cropping data (cultivation periods and cropping coefficients k_c) to estimate the actual crop Evapotranspiration (ET_c). The method compares the effective rainfall (P_{eff}) with the ET_c (losses); the difference is each crop's irrigation water requirements (NIR) (Eq.9). The final NIR is increased by the total losses' coefficient E_{tot} (Eq.10). This considers the losses of the network based on the areas serviced by groundwater or surface network, and their condition (i.e. performance E_f) and the losses from each irrigation method, based on the areas serviced by surface, sprinkler, or drip irrigation method (given their standard performances, E_d).

$$NIR = ET_c - P_{eff}/n_d \tag{9}$$

$$E_{tot} = \frac{1}{E_f\, E_d} \tag{10}$$

n_d is the number of days for each month (for unit conversion purposes).

The above were simulated for the baseline do-nothing (BAU scenario), and for a Demand Management Scenario (DM Sc.), that considers the following measures' combination:

- Maintenance of surface network (cleaning, pipelines, etc.). This will reduce the network losses (increase performance coefficient E_f), and the L of Eq.1,
- More efficient irrigation methods (e.g. drip irrigation), increasing thus the irrigation method's performance coefficient E_d,
- Use Hongyanchi reservoir again for industrial water supply, instead of Urumqi River, in order to increase the river's ecological flows (i.e. environmental and ecosystem sustainability).

All measures aim to increase the water use efficiency, environmental sustainability, reducing conflicts, and are actual plans discussed by the local government as potential options. The results will explore the factors driving the farmers to their decisions regarding fallowing and for what periods. 30.89% is not willing to continue fallowing, and the 16.20% of those who want to continue, prefers the short-term period (64 farmers). Although the majority is more inclined to continue (long-term) fallowing, the portion of those who do not agree is believed to be a manageable portion that could be serviced from the savings of the DM Sc.

4. Results and discussion

The factors affecting the willingness of farmers to continue to fallow were estimated using the software Stata14.0, and the maximum likelihood estimation method. After testing, the Binary Logistic Regression model is overall significant (Table 2).

Table II. Factors affecting farmers' willingness to continue fallow (WCF model).

Variable	Coefficients	Robust standard error	Z value	Sig	Odds ratio
AGE	0.156	0.175	1.040	0.299	1.168
EDU	-0.122	0.139	-0.780	0.436	0.885
HEA	-0.568***	0.107	-3.010	0.003	0.567
LAB	-1.454***	0.105	-3.240	0.001	0.234
POL	-0.254*	0.118	-1.670	0.094	0.776
COM	0.567***	0.282	3.550	0.000	1.763
IRR	-0.415**	0.114	-2.390	0.017	0.660
FER	-0.169	0.165	-0.870	0.385	0.844
EMP	0.409**	0.314	1.960	0.050	1.506
INC	0.707***	0.331	4.340	0.000	2.029
Log-likelihood	-198.181				
Wald Chi-square	92.00				
Observations	395				

Note： ***,**,* is significance at 1%, 5%, and 10% respectively.

In order to clarify the factors influencing the categorical variable “fallow period preference” is used as the explained variable, and the selection of no continued fallow as the baseline group. The results of the Multinomial Logit model are presented in Table 3.

Table III. Factors influencing farmer' choice for fallow period (FPP model).

Variable	Short-term（baseline group *Y*=1）			Long-term (baseline group *Y*=1)		
	Coefficients	S.D.	RRR	Coefficients	Stand. deviation	RRR
AGE	-0.177	0.195	0.837	0.299*	0.162	1.348
EDU	-0.0633	0.204	0.939	-0.148	0.165	0.863
HEA	-0.563**	0.24	0.570	-0.565***	0.199	0.568
LAB	-1.036*	0.573	0.355	-1.585***	0.471	0.205
POL	-0.12	0.197	0.887	-0.306*	0.161	0.737
COM	0.716***	0.209	2.047	0.500***	0.170	1.649
IRR	-0.355	0.226	0.701	-0.448**	0.185	0.639
FER	-0.0276	0.253	0.973	-0.223	0.207	0.800
EMP	0.22	0.274	1.246	0.492**	0.220	1.635
INC	0.236	0.215	1.267	0.899***	0.176	2.458
Log-likelihood	-332.063					
LR chi^2	121.58					
Observation	395					

Note： ***,**,* is significance at 1%, 5%, and 10% respectively.

The findings of both models are insightful, and are summarized and discussed in Table 4, for each variable.

Table IV. Interpretation of each variable's role for both models.

Xi	**Willingness to Continue Fallow**	**Fallow Period Preference**
AGE	No significant effect, but older farmers are more willing to continue fallowing.	No significant effect on the selection of short-term fallow, but it is significant at the level of 5% for the selection of long-term fallow. The older the fallow-farmers are, they prefer a long-term fallow. Possibly because as farmers grow older, it is tougher to work. Also, they do not have many alternative employment opportunities.
EDU	Higher-educated farmers want to cultivate.	Higher-educated farmers prefer short-term fallow.
HEA	Significant at 1%, with negative impact. Healthier farmers are more willing to cultivate, which makes sense, given their increased physical ability.	Significant effect on both short-term and long-term fallow, with negative impact. This is consistent with the WCF model, and with past research findings, as mentioned in the introduction.
LAB	Significant at 1%, with negative effect. The per capita arable land is relatively large, and agricultural production activities require a large amount of labor. Thus, farmers with less family labor capacity are willing to continue fallow, in contrast with those who have labor 'surplus'.	Significant effects on both short-term and long-term fallow, with negative effect. This is in line with the WCF model, and with previous research, cited in the introduction section.
POL	Significant negative impact at 10%. Farmers who do not understand the re-cultivation policy find the continuation of fallowing a good idea.	Similarly, farmers who have limited knowledge on the re-cultivation policy are more willing to choose long-term fallow. They seem to ignore the increased costs of recultivating long-term fallowed land (because of the damages to irrigation systems and soil degradation), and possible subsidy policies that they can get for re-cultivation.
COM	Significant positive impact at the 1% level. Higher acceptance of compensation means continuation of fallowing. Possibly because it is difficult for those farmers to obtain higher benefits from agricultural production, so the compensation can make up, and they can obtain more income through other sources.	Significant positive effect on both short-term and long-term fallow. This is consistent with the previous model, and in agreement the previous studies mentioned in the introduction section.
IRR	Significant at 5% with negative impact on the willingness to continue fallow. Obviously, irrigation water in arid areas is a very important measure of security for farmers' perception of the fallow policy. Lands lacking irrigation water are more likely to be used for fallow.	No significant effect on the selection of short-term fallow, and negatively significant at 5% on the selection of long-term fallow. In line with the previous model, land with higher irrigation chances has higher productivity and is prioritized for cultivation, and vice versa.
FER	No significant impact on WCF or FPP. The area's land is mainly second- and third-class (low fertility). The difference between those two is not very obvious after long-term cultivation, so it is not the main factor that affects the farmers' preferences.	
EMP	Positively significant at 5%. Those farmers who are more likely to find another job are more willing to choose continuous fallow. Some farmers do obtain stable non-agricultural income from other activities.	Employment opportunities have no significant impact on choosing short-term fallow, but have a significant positive effect on choosing long-term fallow. It is a measure of dependency on cultivation (as in the previous model).

INC	If the proportion of agricultural income in the total family income has decreased, the respondents want to increase it by re-cultivation. Similarly, those who saw an increased agricultural income are more willing to continue fallowing. Thus, changes in household income are positively significant at 1% level.	No significant impact on choosing short-term fallow, but there is a positive significant effect on choosing long-term fallow. Economically motivated farmers to cultivate (or not) are defined by this variable's result. If there are other income sources and after fallowing the income has increased, long-term fallow seems to be a better option.

The majority that wants to continue fallowing (especially long-term) tend to quit farming, while there is a non-negligible portion that highly depends on agriculture but are restricted because of the competition for the limited water resources. The results of the alternative water resources management (as described above) could save significant amount of water, allowing those farmers to re-cultivate:

More specifically, the DM Sc. increases water use efficiency, the overall demand is reduced, with a higher impact on the irrigation water demand (Fig.3) and reservoirs' balances (Fig.4). Hongyanchi reservoir can reduce the river's pumping for industrial supply significantly, while contributing to the urban water use. The river's pumping is reduced, while the ecological flow deficit is restored under to DM Sc. Thus, economic-agricultural needs can be covered, meeting also environmental objectives, and socially acceptable policy.

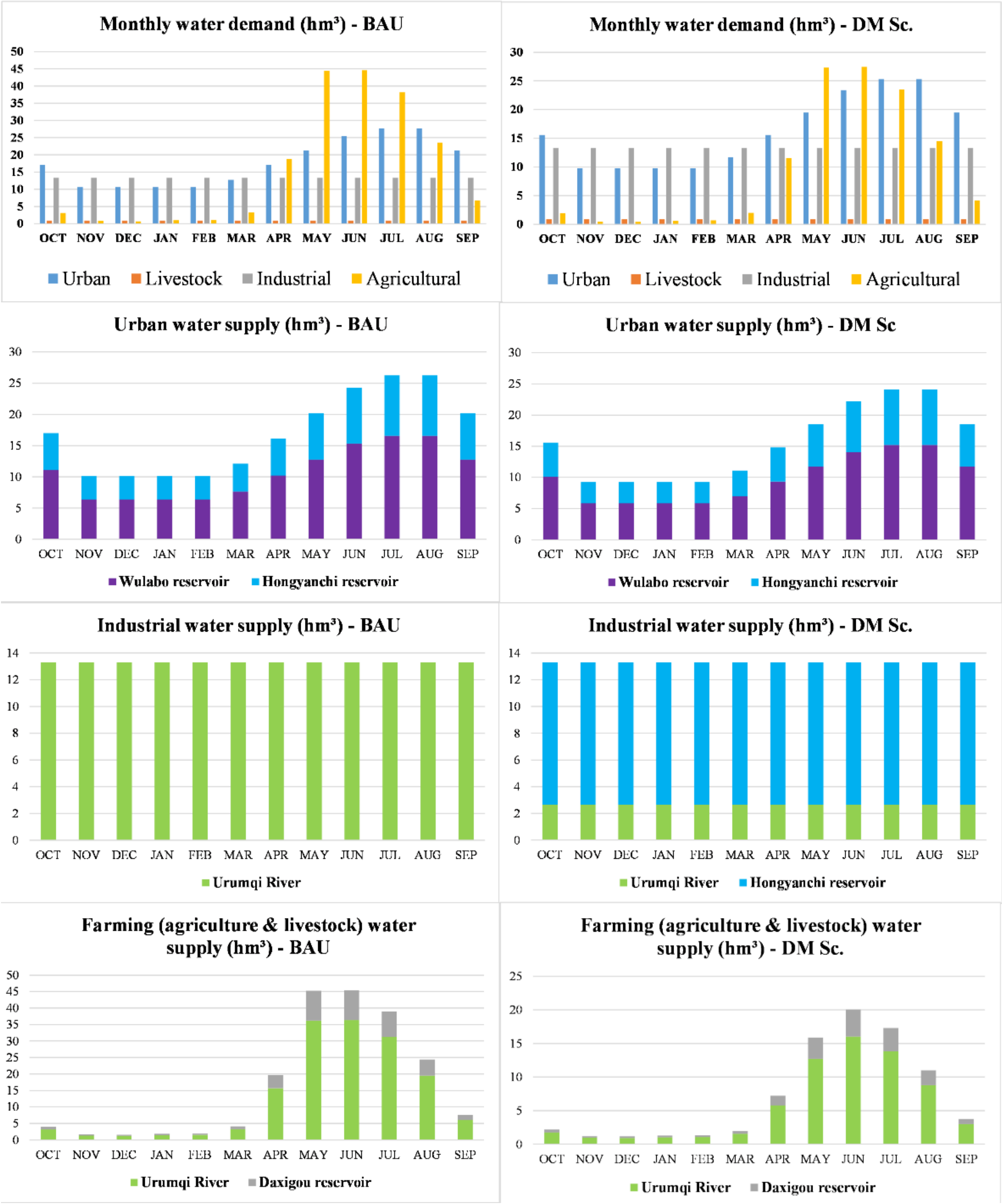

Figure 3. Water demand for each use per supply source, for the BAU and the DM Scenarios.

Currently there were no available supply data to estimate a water balance, however, the coverage of the same needs without deficits, is an important insight supporting the aforementioned finding. Regarding the reservoirs, no data were available, hence we could not include their volume components to compare their performances (e.g. water levels, storage, pumping capacities, evaporation, spills, releases). So only the inflows (per source) and the outflows (to sites) were simulated for each reservoir (Fig.4), based on the water amount required to cover the demands. Daxigou reservoir, which is the largest and the main one had the highest deficit, but initial conditions (e.g. storage-level-area curves were unknown). under the

DM Sc. all deficits are reduced and combined with the initial storages, we can assume that the balances will be positive.

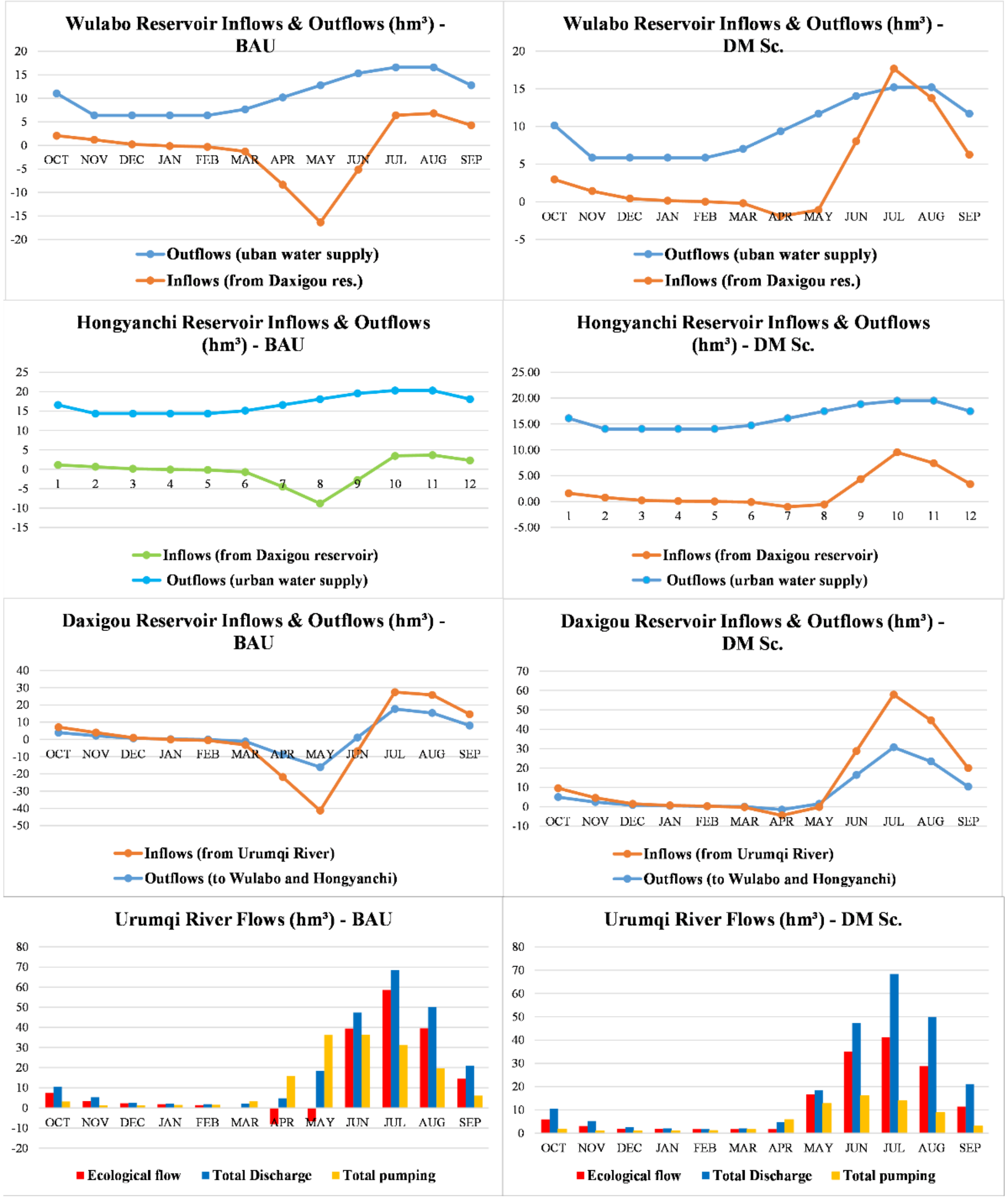

Figure 4. Reservoirs' required inflows and outflows, and Urumqi River's flows, for the BAU and the DM Scenarios.

The DM Sc. reduced water demand by 38.1% (70.8 hm^3/year) compared to the current BAU scenario, and the biggest effect was on farming water use. Clearly, this strategy is much more effective than the current policy's annual water-saving goal (20 hm^3/year). If, however, that is the desirable target, then the remaining 50 hm^3/year can still be used for agricultural activities, enhancing thus the local socio-economic growth and satisfaction.

These estimations are conservative because of data limitations: More land can be cultivated if the current water storages of the reservoirs are considered, and additional water conservation can be achieved if certain wells are used for irrigation, if necessary (additional groundwater supply), while more paths can be found even through bottom-up approaches(Niyazmetov et al., 2019).

The compensation amount that currently goes to farmers is around 119.5 million RMB [480 RMB/Mu times the 248895 fallowed Mu (16593 hectares)]. The implementation cost of just the DM Sc. considered is believed to be lower [experts' judgment based on similar works per typical unit-costs (mu or m^3), and ad-hoc calculations]. Furthermore, such investments will pay-off in the future (social welfare, equity, increased productivity, soil and environmental benefits).

5. Conclusion

A novel combination of econometric modeling for the farmers’ behavioral preferences, followed by a hydrological model for more efficient water use, was developed and successfully applied. To our knowledge, this was the first time that the local population commented on the fallow-policy schemes, revealing their preferences:

Most farmers want to continue fallowing, preferably for long-term, although they do not understand this policy completely. Health status, labor capacity, guaranteed irrigation and understanding of the re-cultivation policy have a significant negative impact on the willingness of farmers to continue fallow; compensations, employment status, and income changes have a significant positive impact. Overall, those who are not completely dependent on agriculture or cannot physically continue to cultivate, prefer long-term fallow. On the other hand, a considerable part (30.89%) wants to cultivate, mainly for livelihood reasons, which was proved to be feasible (and potentially more profitable) under a wiser water resources management (DM Sc.).

The main limitation of the study is the lack of data on the actual water supply, which prevents the calculation of a water balance, allowing only demand-based estimations. However, that was enough to show the potential of a more rational water management, which is a significant and practically useful finding. Further research is needed to cover the limitations, and more scenarios (or combinations of options) can be examined. In the future, any option must be also tested under varying climate conditions (drier hydrological years using historic timeseries, or future climate and population growth projections) to ensure satisfactory performances. Then the options (scenarios) can be further expanded and enriched with supply management to address the respective challenges.

At this point, this study proved to be an important first step with very encouraging results. The fallow policy is necessary at the moment, but it can be implemented in a better way, to sustain farming instead of eliminating it. It is possible to save more water than planned, use it for re-cultivating the land according to the population needs, and increase river flows, enhancing the ecosystem’s functions. On this basis, future fallow plans need to pay more attention to the farmers' needs and consider factors such as their health status, their household labor abilities, and the irrigation reliability to determine a fairer fallowing distribution.

Furthermore, the compensation rates can be regularly adjusted according to the local economic development level and the agricultural product prices, to avoid a reduction of the living standards of those who fallow. At the same time, scientific support is strongly recommended for integrated monitoring, modeling, analysis of the social aspects, and training fallow-farmers to re-cultivate. A rotated "fallow-return to farming" scheme seems to be a good option in terms of increasing land fertility, which will increase productivity and economic growth. In any case, the publicity of such measures must be supported, as increasing the awareness and the understanding of the policies and their purposes, are fundamental for the successful implementation of any policy.

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