REFEREED ARTICLE

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Multi-year agro-economic modelling for predicting changes in irrigation water management indicators in the Tadla sub-basin

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ABSTRACT

The irrational use of irrigation water resources is a major constraint to agricultural development in the watersheds of Morocco, including the Tadla sub-basin. It is essential for these areas to have effective instruments for managing and organizing the control and distribution of water resources and to ensure their protection and conservation. Within this context, this study focused on the Tadla sub-basin, where there has been a marked decrease in the supply of irrigation water. Using a dynamic agro-economic model called 'TADMOD' (for TADla Basin MODel), which classifies agricultural units according to their different sources of irrigation water, the study's main purpose was to analyse the interannual variations in selected irrigation water management indicators. One of the most important indicators studied here was irrigation water shadow price between 2011 and 2020. The results of the analysis revealed important differences in this indicator value among the observed agricultural units. Its average value, calculated by TADMOD, was about 1.33 MAD[4] (Moroccan Dirham) per cubic metre of water. The model showed that, over the ten simulated years, reduced water supplies in the Tadla sub-basin would lead to an increase of 33.2%, on average, in the irrigation water shadow price and to a decline in the cultivated area and total consumption of irrigation water. The reduction in the cultivated area would lead to a slight fall in value-added, estimated at 3,180.78 million MAD per year in 2010-11, the first year of simulation.

KEYWORDS: Agro-economic modelling; water resources management; water access; water shadow price; agricultural profit; Agricultural Territorial Unit; Tadla Sub-Basin

1. Introduction

Morocco's water resources are influenced mainly by a strong spatial and temporal heterogeneity in water volume and by their scarcity, 22 billion m^3/year (CESE, 2014), the equivalent of 660 m^3/pers.year. On the basis of the water scarcity indicator, defined by Falkenmark (1989) as the volume of renewable water per capita, Morocco is facing a chronic water shortage. The management of the country's water resources is currently experiencing major problems, hindering the development of these resources in an integrated and consistent manner (MEMEE, 2010). These problems relate to watershed protection, water quality, population growth, climate change, water resources valuation and the rational use of water resources. Morocco's commitment to rationalizing the use of its water resources is crucial to ensuring their quantitative and qualitative sustainability. One of the most critical activities in this regard is agriculture.

Agriculture is a strategic sector in the socio-economic development of Morocco (Benabdelouahab *et al.*, 2015). Since the 1960s, the country has implemented various agricultural and rural development programmes and structural reforms (e.g., dam construction, agricultural structural adjustment programs and the Green Morocco Plan strategy) aimed at ensuring food security and economic growth (Desrues, 2005). Currently, the agricultural sector is of paramount importance in the national economy in terms of its contribution to the Gross Domestic Product (GDP), its role in employment (it accounts for 80% of rural employment) and its contribution to foreign trade (Toumi, 2008).

Morocco has recognized the need to upgrade, restructure and redefine its agricultural activities and revise its

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[4] At the time of writing (mid-March 2016), MAD1.00 was approximately £0.07, $US0.10 and €0.09.

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agricultural policy accordingly so that it is adapted to the global context of food security, climate change, rising prices of agricultural products and the fight against poverty. It has taken the first steps along this road with the development of the Green Morocco Plan, aimed at making agriculture the main growth engine of the national economy. Agriculture in Morocco depends on climatic conditions, however, and therefore water control is crucial to its socio-economic development. The climatic insecurity results in costly food insecurity in the country (massive food importation is needed in dry years) and greatly affects living conditions in rural areas, with repercussions on other economic activities. The main focus of the new agricultural policy has been on long-term and large-scale irrigation schemes, particularly in the Tadla plain. Irrigation efficiency is still poor, however, with the flood irrigation systems that dominate 90% of this area (according to the Regional Direction of Agriculture) having an efficiency rate of 50% or less. In addition, productivity per irrigated hectare is below its potential for some farms, economic efficiency is 69% on average and a cubic metre of water is not sufficiently valued in terms of high-value crops (Lionboui *et al.*, 2016). The incentives for effective water management are still limited in scope and the price of water does not reflect its scarcity. There is therefore a need to develop more efficient irrigation and agricultural production systems by promoting irrigation techniques and cropping systems based on a higher value of water. Water policy strategies need to be based on demand management, the development of participative management and a realistic socio-economic valuation of water. These strategies would enhance water resource mobilisation efforts by promoting its efficient use and would provide Morocco with the means to accommodate drought risk by having appropriate solutions for managing water shortages.

The non-rational allocation of irrigation water is a major obstacle to the development of vegetable production chains in the Tadla sub-basin. The adoption of efficient irrigation technologies would help to better manage this activity and improve production and profitability.

The agro-economic model TADMOD, for TADla basin MODel, (Lionboui *et al.*, 2014) was developed to identify irrigation efficiency issues in the Tadla sub-basin. In its static version, TADMOD does not predict interannual variations of water management indicators. This study focuses on the development of a dynamic agro-economic version of this model for the sub-basin of Tadla that enables interannual variations in water management and socioeconomic indicators to be predicted, taking into account the various development projects planned for this area. This tool has been achieved in order to help stakeholders to control water management and adopt the most appropriate agricultural policies.

2. Materials And Methods

Modelling water resources management at the sub-basin level

Water management has become a central topic in economic literature in recent decades. In many semi-arid regions of the world, addressing issues related to the scarcity of water resources is crucial to development (Cirilo, 2008). The high value of water in these areas can be a quantitative and qualitative constraint to its domestic, industrial and, in particular, agricultural use. At the international level, the focus initially was on a single source of water, either surface water or groundwater (e.g., Gisser and Sánchez (1980) and Feinerman and Knapp (1983), who discussed the economic aspects of groundwater management). In most watersheds, however, there is joint use of surface and groundwater for irrigation and increasing attention is therefore being paid to the joint management of these water resources (Buras, 1963; Burt, 1964), given that ''groundwater and surface are two components of a single system and must be managed jointly'' (Masahiko and Tsur, 2007, p 540). In a simple static model of the joint use of these water sources, Tsur (1990) identified a specific value of groundwater in the context of variability in surface water. Subsequently, Tsur and Graham-Tomasi (1991) calculated a different value for groundwater in a dynamic context, which they called the buffer value of groundwater. This groundwater value was also analysed by Masahiko and Tsur (2007). In an attempt to address the complexity of the joint management of water sources, an innovative approach was developed by Cai (1999) for the Syr Darya basin in central Asia. It was a dynamic interannual model that included hydrological, economic, agronomic and institutional components in the analysis of sustainability issues related to water resources management. In their model developed for the Maipo River basin in Chile, Rosegrant *et al.* (2000) included the sensitivity of water management to flow variations, the cost of improved irrigation techniques and the salinity problem. Later, Albek *et al.* (2004) integrated climate change simulations into their model and calibrated it on the basis of past data.

The assessment of agricultural development policies is a central issue in various watershed models that have been developed (Cai and Wang, 2006; Pulido-Velázquez *et al.*, 2006; Ward *et al.*, 2006). Cai *et al.* (2003) evaluated the role of investment and the impact of taxes and subsidies on water allocation, and also determined the sensitivity of water allocation to the increased demand for water and to changes in water prices. Several studies have looked at water management sensitivity to strategies based on sharing this resource (Draper *et al.*, 2003; Jakeman and Letcher, 2003; Jenkins *et al.*, 2004; Letcher *et al.*, 2004).

Most studies conducted in Morocco about watershed management have focused on four watersheds: the Loukkos and Tadla watersheds (Elame and Farah, 2008), the Draa watershed (Heidecke and Heckelei, 2010) and the Souss-Massa watershed. Only the model developed for the Draa watershed has the dynamic capacity to conduct long-term simulations. It is based, however, on an agricultural unit being a single farm, which could negatively influence results because in any agricultural unit there might be several modes of access to irrigation water, as well as differences in the degree of access. The models for the three other basins are still at the elementary stage, with production systems not explicitly introduced. It is also worth noting that regional agricultural policies have not been a factor in research conducted at the national level on water resources management.

The study described here focused on developing a model for the Tadla sub-basin that takes account of differences among farms in terms of mode of access to irrigation water, within the context of current agricultural policy in Morocco.

The Tadla sub-basin

The Tadla sub-basin covers an area of 320,000 ha. The usable agricultural part of this area is about 300,000 ha, including 124,600 ha under irrigation. The sub-basin is characterised by a semi-arid climate with a dry season from April to October and a wet season from November to March. The average temperature is 18 °C., with a maximum of 38 °C in August and a minimum of 3.5 °C in January. It is also characterised by irregular annual rainfall and very pronounced interannual variability. An analysis of rainfall in the Oum Erbia basin, which includes the Tadla sub-basin, showed a significant decline. In the 1935-80 period, annual rainfall ranged from 275 to 1,025 mm, but in the 1980-2008 period, it ranged from 175 to 625 mm (ABHOER, 2012). The water used for irrigation in the Tadla sub-basin comes mainly from surface water. The proportion of groundwater used in irrigation, however, is increasing in parallel with the overall decline in rainfall. Between 2003 and 2010, it increased by 6.28%, from 446 million m3 to 474 million m3 (ABHOER, 2012). The main river in the Tadla sub-basin is the Oum Er Rbia, one of the most important rivers in Morocco. With regard to groundwater, the sub-basin has three phreatic aquifers: Beni Amir, Beni Moussa and Dir, and two deep aquifers: Eocene and Turonian (ORMVAT, 2014). (Figure 1)

The study focused on three agricultural territorial units (ATUs) in the Tadla sub-basin. The ATUs used for this study were: Tadla plain (ATU 1), rainfed agricultural area – private groundwater pumping (ATU 2) and the Dir unit (ATU 3). This choice was based on both strategic and practical considerations. On the one hand, these ATUs are seen by regional decision-makers as homogeneous areas at the regional level with regard to climate, topography and hydro-agricultural planning. On the other, these regions have large-scale irrigation schemes covering 98,300 ha and have benefited from regional agricultural development projects that have addressed production valuation, spatial distribution, water scarcity, land status and the integration of agricultural chains.

Structure of the proposed model

The study sought to develop an agro-economic model of water management at the Tadla sub-basin level based on the simulation of water flows, equilibrium equations of water supply and use, water flows at river nodes and the allocation of water resources. In addition to reflecting the dynamics of interaction between various components (hydrological, agronomic and economic), it aimed at predicting changes in irrigation water shadow price, land use, water consumption and agricultural profit under different scenarios with regard to water availability and water resource allocation policy in the Tadla sub-basin (Figure 2).

TADMOD is a nonlinear economic optimisation model that, given various constraints, can maximize an objective function reflecting a social use that can be value-added at the basin level, or any other function reflecting the preferences and choices of policy-makers. Once the objective function (Eq.1) and constraints functions have been specified, the calibration of the model is obtained using positive mathematical programming (Howitt, 1995).

$$Max\ VA = \sum_{A\_S} \left(\sum_{Ir\_Mo} VA\_PMP_{A\_S,Ir\_Mo} \right) \qquad (1)$$

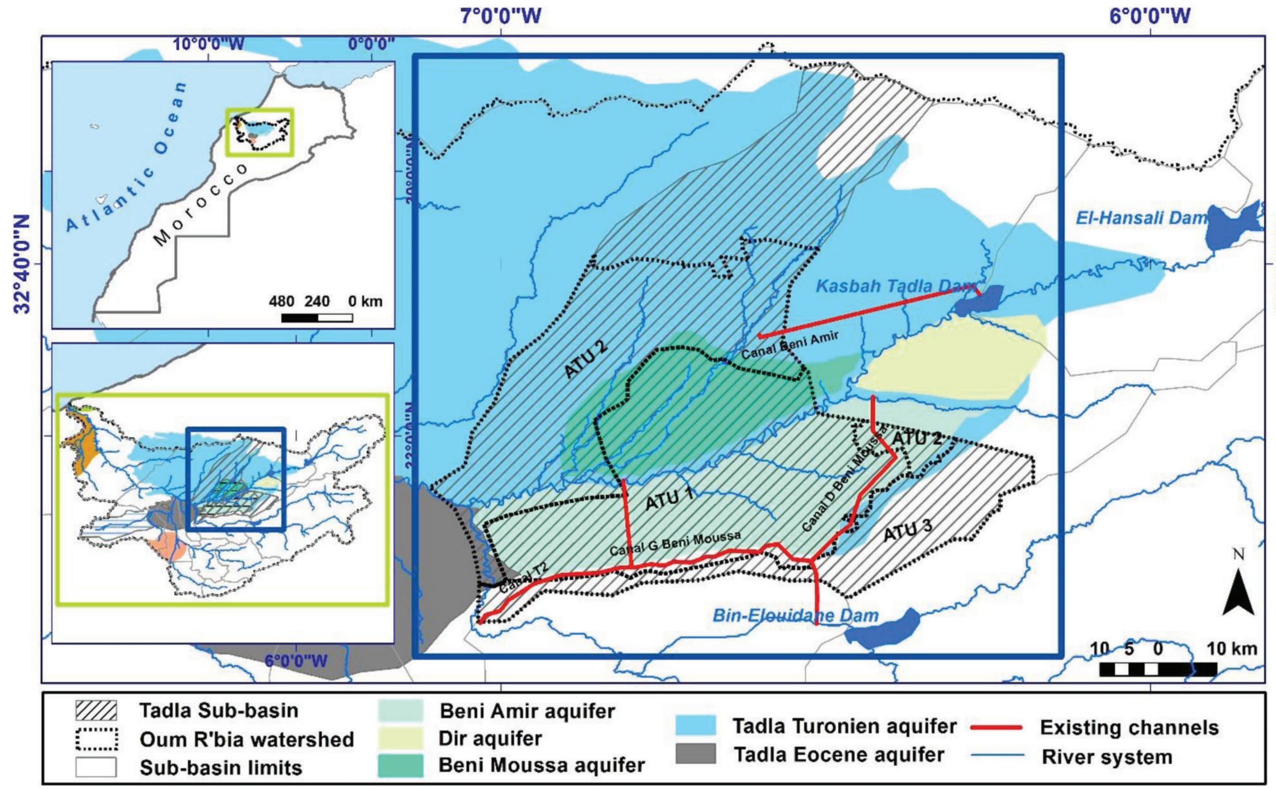

Figure 1: Tadla sub-basin

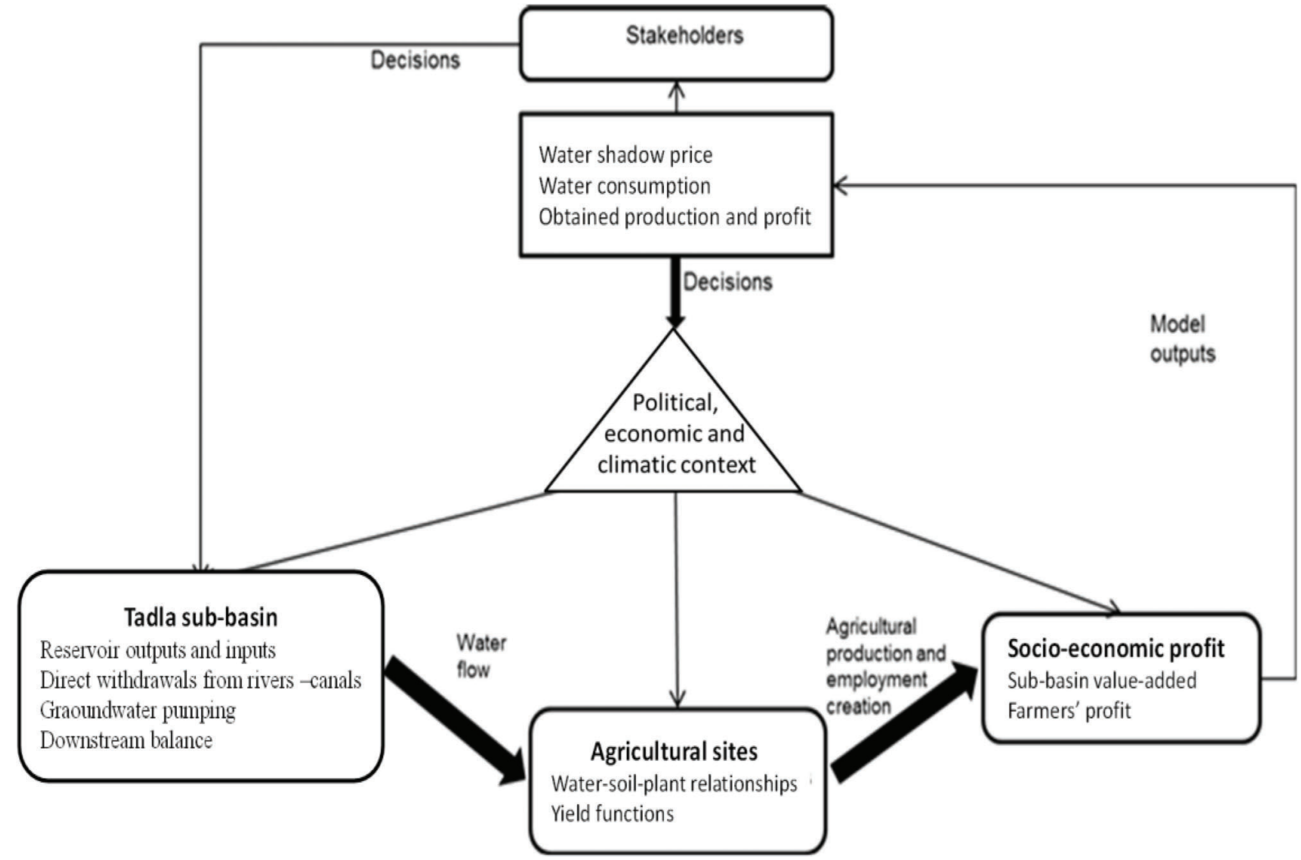

Figure 2: Structure of the TADMOD model for water management in the Tadla sub-basin

'Max VA' is agricultural net value-added at the basin level and 'VA_PMP' is the net value-added per agricultural site (sub-unit of the commune) and per irrigation system after calibration. 'A_S' is the agricultural site, referring to the sub-unit of the commune in order to differentiate modes of access in the same commune to existing irrigation water, 'Ir_Mo'. The net value-added per agricultural site and by mode of access to irrigation water is calculated from the output generated by the agricultural production system and the labour cost, minus costs of production and amortisation.

The Earth availability constraint is also taken into account in the model, so that the sum of cultivated areas by agricultural site 'CULT_AR' does not exceed the available area of arable land 'AR_LAND' in the Tadla sub-basin (Eq.2).

$$AR\_LAND \geq \sum\nolimits_{A\_S,Ir\_Mo,Crop} CULT\_AR_{A\_S,Ir\_Mo,Crop} \quad (2)$$

The initial land-use constraint refers to the part of each crop in the cultivated area by agricultural site and by mode of access to irrigation water. The marginal value of this constraint is used in the model calibration. The model optimizes the objective function on the basis of the observed values (Eq.3 and 4).

$$LAND\_USE_{A\_S,Ir\_Mo,Crop} = LAND\_USE\_Y0_{A\_S,Ir\_Mo,Crop} \quad (3)$$

$$LAND\_USE\_Y0_{A\_S,Ir\_Mo,Crop} = \frac{CULT\_AREA_{A\_S,Ir\_Mo,Crop}}{\sum_{Crop} CULT\_AREA_{A\_S,Ir\_Mo,Crop}} \quad (4)$$

'LAND_USE' defines the variable that determines the part of each crop in the total cultivated area, 'LAND_USE_Y0' refers to the part of each crop in the total arable area and 'CULT_AREA' is the parameter that indicates the area occupied by each crop in the reference year (2009-10).

In the Tadla sub-basin, water quantity used for irrigation ('WAT_USE') refers to water coming from dams and other surface sources ('SURF_WAT') and water pumped from aquifers ('GRD_WAT) (Eq.5).

$$\begin{aligned}\sum_{Crop} WAT\_USE_{A\_S,Ir\_Mo,Crop,PD} \\ = SURF\_WAT_{A\_S,Ir\_Mo,PD} \\ + \sum_{AQ} GRD\_WAT_{A\_S,Ir\_Mo,AQ,PD} \quad (5)\end{aligned}$$

* **'A_S'**: agricultural site; **`Ir_Mo'**: mode of access to irrigation water; **'Crop'**: crop; **'PD'**: period (months); **`AQ'**: aquifer.

The crop yield functions in the model are designed as non-linear approximations of the ratio between the actual and maximum evapotranspiration based on the modified Penman function (FAO, 1998), whereby yield depends on the water demand per hectare.

In order to better reflect the complexity of operating conditions and the valuation of irrigation water in the medium term, TADMOD is being constructed as a 10-year recursive-dynamic model. The introduction of the dynamic element will be done by creating a set of years (10) and a loop. This loop will make iterations taking account of parameters and variables affected by the anticipated changes and introduced over the years. These changes relate to the rate of conversion to water-saving systems, crop extensions, rainfall trends, aquifer recharging and surface water inflows. For dams, the quantity of water remaining at the end of August will be used as the initial quantity for the following year, starting early September.

TADMOD will be sufficiently differentiated in terms of the physical and functional units of the basin (ATUs), commune, land use and mode of access to irrigation water. The model includes type of irrigation by including progressive rates of conversion to water-saving systems over 10 years for each land use. Crop extensions planned for future years under the Regional Agricultural Plan (PAR) were also included.

With regard to changes in water supply, we adopted a linear regression model with a time series of 50 years for the Tadla sub-basin, which shows a declining trend over the years.

The reference year chosen for this research was the 2009-10 crop year, from September to August, when the rainfall was about 475 mm (data obtained from the National Meteorology Direction).

TADMOD is an economic, agricultural and hydrological optimisation model, based on the actual relationship between the different nodes of the hydrological network. These nodes represent physical entities that could be influx, dams, aquifers or demand sites for agricultural water. Water distribution varies among the different agricultural demand sites (Lionboui *et al.*, 2014).

TADMOD is programmed in GAMS (Brooke *et al.*, 1998) and was resolved using the nonlinear solver CONOPT.

Model database

The proposed agro-economic model requires very precise technical data and additional studies in the fields of hydraulics and agriculture. It also requires a detailed knowledge of the agro-hydraulic and economic system of water management in the Tadla sub-basin. These data are collected from regional bodies involved in irrigation water management, including the Office of Agricultural Development, the Provincial Direction of Agriculture, the Regional Direction of Agriculture and the Hydraulic Basin Agency of Oum Er Rbia River.

Working with agricultural development centres, surveys were conducted on crop rotation, standards for use of production factors and yields in relation to commune and to mode of access to irrigation water. In order to validate and complete the database, a survey of "agricultural farms" was conducted with farmers in the study area. The main crops grown in the ATUs studied are given in Figure 3.

The data collected were related to agronomic parameters, such as: yield per crop, production factor requirements, crop areas, effective rainfall, maximum evapotranspiration and the crop yield response coefficient. Data relating to technical and hydrological parameters were also collected, including: loss rate of agricultural water, water demand in relation to agricultural area and farm type, regulated volume and evaporation of reservoirs, and maximum volume, gradient, depth, permeability and storage coefficient of each aquifer. Socio-economic parameters were also considered for each agricultural area, including: agricultural production input prices, selling price of agricultural products, selling price of irrigation water, farm technical-economic efficiency rates and mode of access to irrigation water. In order to simulate interannual variations in economic and water management indicators, we also used data from agricultural development projects, including: rate of conversion to water-saving systems established through National Program of Irrigation Water Economy (NPIWE) projects, and projects focusing on crop expansion.

Understanding the diversity of production potential at the regional level requires designing a typology that enables farm types to be identified and classified. Previous work in the Tadla region on farmer strategies in water management and agricultural production contributed to building the typology for this study. In order to formalize the diversity of behaviour observed at the farm level, especially with regard to water management, we selected the typology described by Bacot (2001), based on access to water resources.

3. Results And Discussion

Water shadow price

The shadow price of water is defined as the marginal increase in the value of the objective function (agricultural profit) if water availability is increased by an additional cubic meter. This shadow price reflects the scarcity of water resources, unlike the financial price. It is therefore among the most important values calculated by TADMOD because it enables the economic value of water in each agricultural site to be assessed (Table 1).

The TADMOD results show heterogeneity in the shadow price values within the same ATU. This illustrates the fact that farmers do not have for the same degree of access to irrigation water. The average shadow price of irrigation water calculated after calibration for the Tadla sub-basin was in the range of 1.33 MAD per cubic meter of water. It varied from an average of 1.19 MAD/m^3 for farms in ATU3 to 1.40 MAD/m^3 for those in ATU1.

In ATU1, the surface water selling price was 0.32 MAD/m^3. The difference between this value and the shadow price (1.40 MAD/m^3) can be explained by the irregularity of surface water supplies through the irrigation system channels coming from the Ahmed El Hansali and Bine Elouidane dams. In addition, some farmers reported that they received irrigation water at inappropriate times, thereby increasing its value.

In ATU2, the average cost of extracting groundwater is estimated to be 0.60 MAD / m^3, according to the Regional Direction of Agriculture. The average shadow price of water calculated for this zone, however, is 1.25 MAD/m^3. In the medium term, farms in this region do not suffer from water availability problems because there is private groundwater pumping. This value, however, is mainly because farmers invest in high-value crops.

For ATU3, irrigation water is private property and those holding the rights to it can sell it. According to the Provincial Direction of Agriculture, the water selling price here is 0.22 MAD/m^3, which is significantly lower

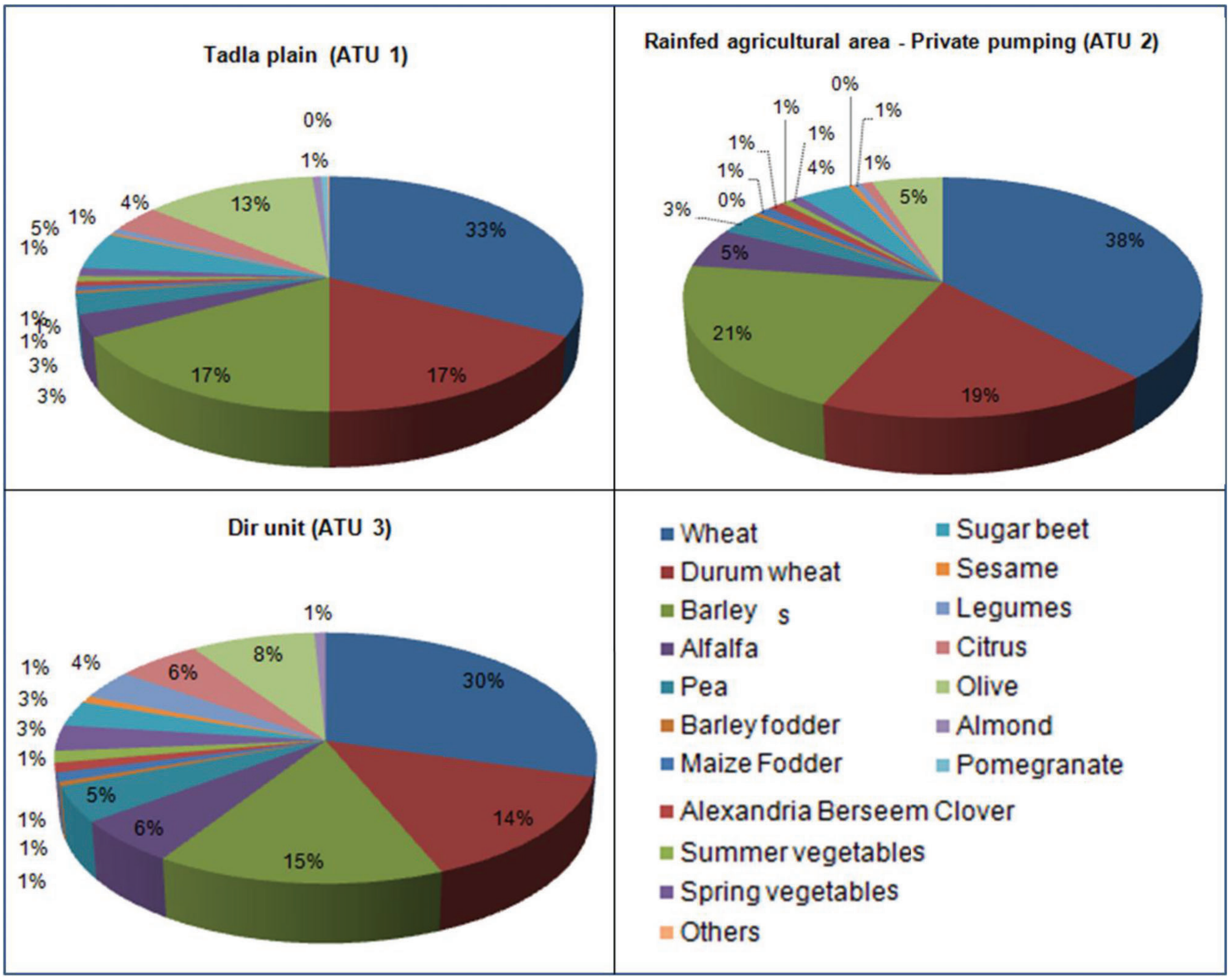

Figure 3: Observed crop share in the different agricultural territorial units (ATUs) of the Tadla Sub-basin in the reference year (2009-10)

Table 1: Frequency distribution of irrigation water shadow price values in the observed agricultural territorial units (ATUs)

Classes (in MAD)	Agricultural territorial units (ATU)					
	ATU 1		ATU 2		ATU 3	
	%	% cumulative	%	% cumulative	%	% cumulative
0.00 – 0.50	3.64	3.64	-	-	-	-
0.51 – 1.00	41.81	45.45	40.00	40.00	31.23	31.23
1.01 – 1.50	20.00	65.45	26.67	66.67	56.27	87.50
1.51 – 2.00	29.10	94.55	33.33	100.00	12.5	100.00
⩾ 2.01	5.45	100.00	-	100.00	-	100.00
Average	1.40		1.25		1.19	
Standard deviation	0.59		0.44		0.36	

than the estimated shadow price (1.25 MAD/m^3 on average) and does not reflect its true value.

In terms of the interannual variation in irrigation water shadow price, Figure 4 shows the trend for this indicator, obtained by simulating the 10 years after the reference year (from 2010-11 to 2019-20). The figure takes into account the conversion and extension projects under PAR and water supply forecasts for the basin based on data from the Hydraulic Basin Agency.

In the years after the reference year, the water shadow price is predicted to increase by 33.2% and might therefore reach 1.70 MAD/m^3 in 2019-20 (Figure 4). This confirms the results obtained by Heidecke *et al.* (2008) in a study conducted in a similar context on decreasing water resources. This is linked to the expected decrease in water resources in the Tadla sub-basin, making irrigation water a production-limiting factor. It is also linked to the programmed intensification projects.

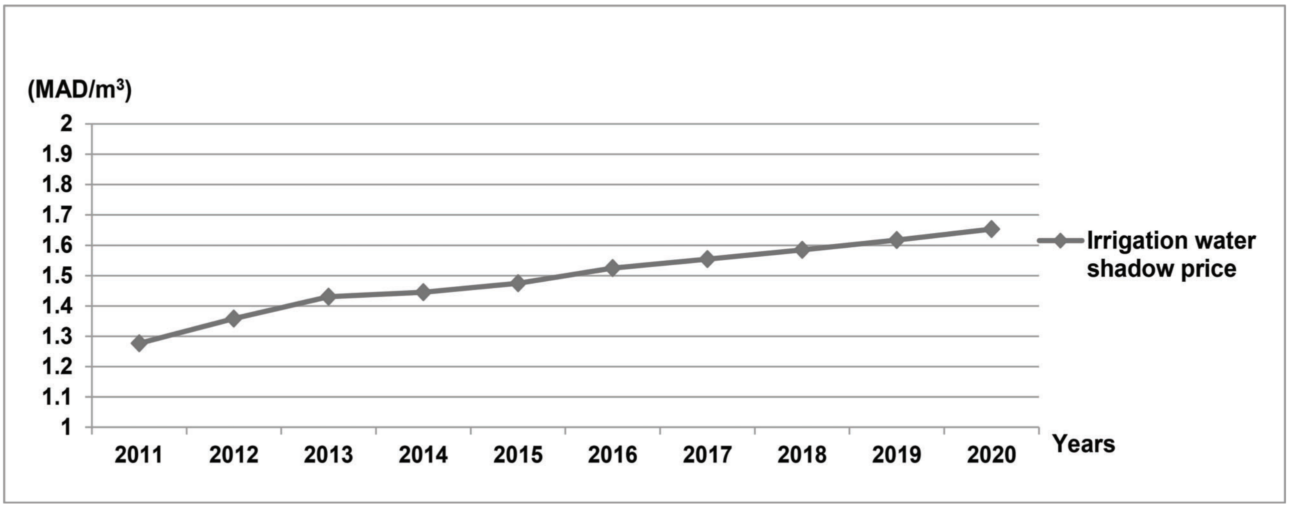

Figure 4: Predicted changes in the irrigation water shadow price in the Tadla sub-basin by TADMOD

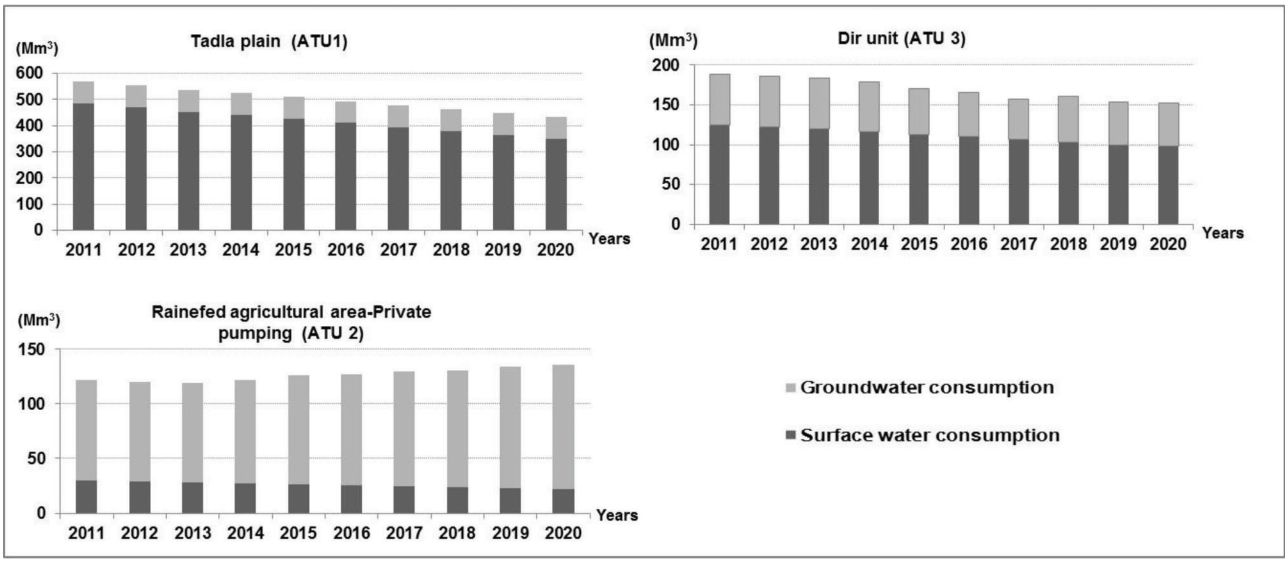

Figure 5: Predicted changes in water consumption in the agricultural territorial units (ATUs) in the Tadla sub-basin

Changes in irrigation water consumption in the Tadla sub-basin

The total surface water consumption across the Tadla sub-basin is about 638.18 million m^3, of which ATU1 consumes 75.45%. Groundwater accounts for the rest of the irrigation water consumption here, with a volume of 265 Mm^3, of which 45.46% is consumed in ATU2.

The change in the irrigation water consumption indicator over the simulated years is shown in Figure 5.

From the 2010-11 crop season through to the 2019-20 season, the total consumption of irrigation water in ATU1 and ATU3 will decrease, particularly in the case of surface water. The volume of water consumed by farms is directly related to the payed fee, which enables them to receive a price signal that encourages them to adopt water conservation practices. Under current agricultural policies, subsidies and outreach programs are being used to encourage the adoption of water-saving systems in order to cope with the expected reduction of surface water inflows in the Tadla sub-basin.

In ATU2, irrigated mainly by groundwater, water consumption will increase slightly. This reflects the increase in the number of wells and boreholes being constructed in this area, as reported by Hamani and Kuper (2007). Encouraged by the availability of groundwater throughout the year, farmers in ATU2 are now diversifying and intensifying their agriculture, thus putting a larger area under crops with high added value, whatever their water consumption.

Cropping system

The reduction in water inflows in the Tadla sub-basin will reduce the cultivated area by 1.90%, from 334,347.58 ha in 2010-11 to 328,177.11 ha in 2019-20. For the three ATUs selected for this study, cropping plans will vary during the simulated years. These changes are shown for each ATU in Table 2.

The declining availability of water in the Tadla sub-basin will lead farmers to opt for crops that require less water, but offer good margins, in order to maximize their profits. There is therefore likely to be an increase in the area allocated to tree crops, sugar beet and vegetables at the expense of cereal and forage crops.

Table 2: Crop share variation in the Tadla sub-basin

	share% Crops	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
ATU1	Cereals	63.90	63.30	62.59	61.96	60.97	60.56	60.16	59.76	59.31	58.92
	Forage	12.09	12.05	11.97	11.77	11.77	11.77	11.78	11.78	11.79	11.81
	Vegetables	2.04	2.11	2.18	2.20	2.27	2.34	2.41	2.47	2.54	2.62
	Sugar beet	4.89	4.89	4.89	6.03	6.04	6.06	6.07	6.08	6.09	6.10
	Citrus	3.45	3.46	3.46	3.44	3.45	3.47	3.48	3.49	3.51	3.53
	Olive	12.10	12.70	13.46	13.59	13.88	14.17	14.46	14.75	15.04	15.34
	Other	1.04	1.05	1.05	1.04	1.05	1.06	1.08	1.09	1.10	1.10
	Legumes	0.35	0.35	0.36	0.33	0.33	0.34	0.35	0.35	0.36	0.36
ATU2	Cereals	83.60	83.17	82.63	82.04	81.85	81.65	81.29	80.80	80.58	80.36
	Forage	1.26	1.25	1.24	1.22	1.22	1.22	1.22	1.22	1.22	1.22
	Vegetables	1.36	1.37	1.39	1.36	1.37	1.39	1.40	1.41	1.43	1.45
	Sugar beet	3.12	3.13	3.14	3.69	3.66	3.65	3.64	3.62	3.62	3.62
	Citrus	1.00	1.00	1.00	0.99	0.99	0.99	1.17	1.47	1.49	1.50
	Olive	7.07	7.47	7.98	8.11	8.29	8.46	8.62	8.79	8.96	9.13
	Other	0.93	0.94	0.96	0.98	1.00	1.01	1.03	1.05	1.05	1.05
	Legumes	1.67	1.68	1.68	1.61	1.62	1.63	1.63	1.63	1.64	1.65
ATU3	Cereals	53.21	51.70	49.88	48.58	47.41	46.26	45.42	44.76	44.18	43.59
	Forage	5.77	5.73	5.70	5.56	5.55	5.55	5.55	5.54	5.55	5.56
	Vegetables	5.75	5.72	5.66	5.44	5.36	5.25	5.17	5.14	5.17	5.20
	Sugar beet	2.60	2.56	2.51	3.07	3.07	3.07	3.07	3.07	3.07	3.07
	Citrus	6.08	6.50	6.91	7.74	8.54	9.35	9.81	9.98	9.95	9.92
	Olive	22.08	23.33	24.98	25.45	25.97	26.49	27.02	27.55	28.08	28.62
	Other	2.22	2.22	2.19	2.11	2.12	2.12	2.12	2.14	2.18	2.21
	Legumes	2.28	2.24	2.18	2.05	1.98	1.91	1.84	1.81	1.82	1.83

Table 3: Value-added in the observed agricultural territorial units (ATUs)

	ATU1	ATU2	ATU3
Value-added /year (millions MAD/year)	1826.54	857.85	496.39
Value-added /ha (MAD/ha)	17231.48	5098.10	7263.69
Cultivated area (ha)	106000	168272	68339
Irrigated area (ha)	98300	42100	24514
Non-irrigated area rainfed agriculture" (ha)	7700	126172	43825

Agricultural value-added

TADMOD maximizes value-added agriculture in the Tadla sub-basin. Unlike the gross margin, which reflects the enrichment of individual producers, value-added measures the wealth creation for the community as a whole (including labour income). It represents the sum of labour remuneration, financial expenses and taxes or subsidies, as well as a producer's gross margin. The average value-added calculated for the Tadla sub-basin is 3,180.78 million MAD/year, with an average per hectare of 9,513.40 MAD. The value-added in terms of each ATU is presented in Table 3.

Table 3 shows the differences between the ATUs in terms of their value-added per hectare. ATU1 has a higher value-added by hectare, on average (17,231.48 MAD/ha). In this unit, 92.74% of the cultivated land has access to irrigation water and farmers obtain high yields. For ATU2 and ATU3, mostly non-irrigated farmland, the value-added is 5,098.10 and 7,263.69 (MAD/ha), respectively. These units are entirely dependent on rainfall, which varies in amount from one year to the next and directly affects crop yields. Farmers here therefore prefer not to invest excessively in these lands, in order to avoid the risks associated with drought.

Based on the TADMOD results, the value-added in the Tadla sub-basin will decrease slightly during the simulated years (Figure 6).

The average value-added calculated for all to the ATUs in the Tadla sub-basin will fall from 3,180.78

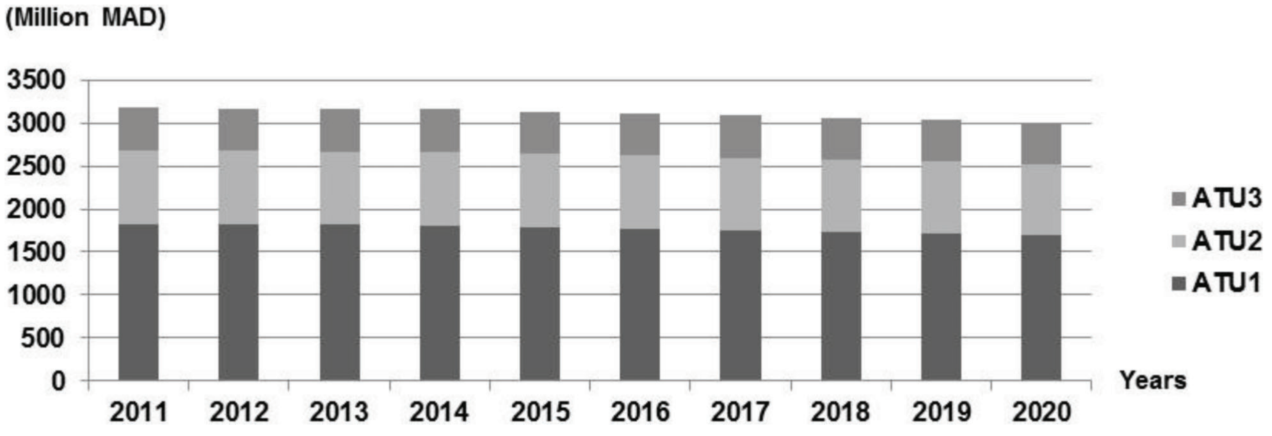

Figure 6: Changes in the total value-added in the Tadla sub-basin over 10 years

million MAD in the first year to 3,009.96 million MAD in 2019-20. This decrease will occur mainly because the cultivated area will decrease as a result of the predicted reduction in irrigation water supplies over this period.

4. Conclusion

Within the context of a predicted downward trend in annual water inflows, this study provided an update on the situation and analysed the interannual variation in the shadow price of water, the use of irrigation water and farmland, and value-added agriculture in the Tadla sub-basin. This was done by using TADMOD, a dynamic agro-economic model that classified ATUs according to their different sources of irrigation. An irrigation typology was included in the model based on rates of conversion over 10 years for each land use. Crop extensions planned for future years as part of PAR were also considered.

Among the most important results of this study were those related to the shadow price of irrigation water, which helped in assessing the economic value of water at each agricultural site in the studied ATUs. An analysis of the reference year (2009-10) showed important differences in water shadow price among agricultural sites. The average value of the shadow price calculated by TADMOD for the Tadla sub-basin was about 1.33 MAD/m^3 of water. This value was much higher than the real selling price of water in the ATUs at the time. The shadow price of irrigation water varied from 1.19 MAD/m^3, on average, for ATU3 sites to 1.40 MAD/m^3 for ATU1 sites. In the 10 years after the reference year, the shadow price of water is going to increase by 33.2%, which may require a revision of irrigation water tariffs in the region. The total consumption in surface water is going to decrease, whereas groundwater consumption will increase slightly to compensate for the scarcity of surface water, as there are no restrictions on groundwater extraction.

The reduction in water inflows in the Tadla sub-basin will also result in a slight decrease (about 1.9%) in the cultivated area, falling from 334,347.58 ha in 2010-11 to 328,177.11 ha in 2019-20. This reduction in cultivated area will encourage farmers to opt for crops that require less water, but offer good margins, in order to maximize their profits. The total value-added of agricultural products generated in the Tadla sub-basin will decrease slightly, mainly because of the reduction in cultivated areas related to the reduced irrigation water supply levels expected during this period.

Finally, this research aimed at providing a scientific approach and an applied tool to control water management and adopt the most appropriate agricultural policies. This operational management tool could lead to help the decision-makers and stakeholders to adopt an efficient irrigation water management at the sub-basin level.

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