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An economic optimization modeling for sustainable water resources in agriculture: case of Tadla and Souss-Massa

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Abstract

As for many other countries of the world, climate change is impacting drastically the water resources in Morocco and the consequences will be severe in our country for years to come. This situation generally results in a significant reduction in agricultural production, particularly in non-irrigated areas. It also has impacts on the availability of surface and underground water. Indeed, surface water supply experience a very important variation depending on the rainfall conditions and the favorable regions of Morocco generally located in the North present a less pronounced variation than those located in semi-arid and arid areas. This work was carried out in two regions of Morocco namely, Souss-Massa and Tadla. A dynamic optimization model was developed based on mathematical programming. The advantage of this type of model is its ability to reflect the relationship and links between various components (hydrologic, economic and agronomic) and to simulate the impact of any variable related to climate change or economic consequences due to policy choices. The main results of this work show that: (i) Surface and groundwater availability is decreasing in the two basins; (ii)The water resource shadow price increased in the two sites over time by changing from normal climatic conditions to drought conditions; and (iii) the reduction of some irrigated lands in favor of others more efficient and more profitable crops. Accordingly, the management of water resources should be based on integrated approaches in order to take into account the entire water cycle as well as the different actors involved in the use of this resource. The use of integrated water management policies is more efficient and will ensure the sustainability of water resource use activities, in particular the agricultural sector.

Keywords: climate change, water resources, agriculture, dynamic optimization, economic price

Une modélisation économique pour une utilisation durable des ressources en eau en agriculture : cas du Tadla et du Souss-Massa

Résumé

Comme pour de nombreux autres pays du monde, le changement climatique a un impact drastique sur les ressources en eau du Maroc et les problèmes qui y sont associés seront plus graves dans les prochaines années. Cette situation se traduit généralement par une réduction significative de la production agricole, en particulier dans les zones non irriguées. Elle a également des impacts sur la disponibilité des eaux de surface et souterraines. En effet, l'approvisionnement en eau de surface connaît une variabilité très importante selon les conditions pluviométriques de l'année, les régions favorables du Maroc généralement situées au Nord présentent une variation moins prononcée que celles situées dans les zones semi-arides et arides. Par conséquent, les impacts du changement climatique que le Maroc a perçus ces dernières années, en particulier l'irrégularité des débits des eaux de surface et la baisse des niveaux des eaux souterraines affectent gravement les dotations en eau des zones irriguées. Ce travail a été réalisé dans deux régions du Maroc à savoir, Souss-Massa et Tadla. Un modèle d'optimisation dynamique a été développé sur la base de la programmation mathématique. L'avantage de ce type de modèle est sa capacité à refléter la relation et les liens entre les différentes composantes (hydrologique, économique et agronomique) et à simuler l'impact de toute variable liée au changement climatique ou aux conséquences économiques dues aux choix politiques. Parmi les principaux résultats de ce travail, nous constatons que : la disponibilité des eaux de surface et souterraines diminue dans les deux bassins ; Les prix économiques de la ressource en eau ont augmenté dans les deux sites au fil du temps en passant de conditions climatiques normales à des conditions de sécheresse; La réduction de certaines terres irriguées au profit d'autres cultures plus efficaces et plus rentables. Par conséquent, la gestion des ressources en eau doit être basée sur des approches intégrées afin de prendre en compte l'ensemble du cycle de l'eau ainsi que les différents acteurs impliqués dans l'utilisation de cette ressource. L'utilisation de politiques de gestion intégrée de l'eau est plus efficace et garantira la durabilité des activités d'utilisation des ressources en eau, en particulier le secteur agricole.

Mots clés : changement climatique, ressources en eau, agriculture, optimisation dynamique, prix économique

النمذجة الاقتصادية للاستخدام المستدام للموارد المائية في الزراعة: حالة تادلة وسوس ماسة

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ملخص

كما هو الحال في العديد من البلدان الأخرى في أنحاء العالم، يعتبر تغير المناخ ذو تأثير كبير على موارد المياه في المغرب، الشيء الذي يمكن أن يصبح أكثر خطورة في السنوات القادمة. ينتج عن هذا عادة انخفاض كبير في الإنتاج الزراعي، كما أن له تأثيرات على توافر المياه السطحية والجوفية خاصة في المناطق غير المسقية .تشهد إمدادات المياه السطحية تقلبًا كبيرًا للغاية بحسب ظروف هطول الأمطار في السنة، فالمناطق الواقعة شمال المغرب تعرف تساقطات أكثر انتظاما من تلك الموجودة في المناطق الوسطى والجنوبية. ولذلك، فإن تغيرات المناخ التي شهدها المغرب في السنوات الأخيرة، ولا سيما عدم انتظام تدفقات المياه السطحية وانخفاض مستويات المياه الجوفية، اثرت بشكل خطير على الموارد المائية للمناطق المسقية .هذا العمل تم تنفيذه في منطقتين بالمغرب هما سوس ماسة وتادلة. من خلاله، تم تطوير نموذج ادارة مياه السقي بناءً على البرمجة الرياضية. النموذج الذي تم تطويره ينتمي إلى فئة نماذج ادارة المياه المتكاملة. تتمثل ميزة هذا النوع من النماذج في قدرته على عكس العلاقة والروابط بين هذه المكونات المختلفة ومحاكاة تأثير أي تغيير متعلق بالمناخ أو العواقب الاقتصادية بسبب الخيارات في السياسات الفلاحية. من بين النتائج الرئيسية لهذا العمل إذا اعتمدنا على السيناريوهات المختلفة المرتبطة بتغير المناخ، نلاحظ أن: توفر المياه السطحية والجوفية آخذ في التناقص في المنطقتين؛ ارتفاع الأسعار الاقتصادية لموارد المياه في كلا الموقعين بمرور الوقت بسبب تغير الظروف المناخية العادية إلى ظروف الجفاف؛ تقليص مساحات بعض الزراعات المسقية بسبب تراجع ربحيتها لصالح محاصيل أخرى أكثر كفاءة وربحية. في الاخير، يجب أن تستند إدارة الموارد المائية إلى نهج متكامل من أجل مراعاة جميع الظروف السوسيواقتصادية وكذلك الجهات الفاعلة المختلفة المشاركة في استخدام هذه الموارد. يعتبر استخدام سياسات الإدارة المتكاملة للمياه أكثر كفاءة وسيضمن استدامة القطاعات المستعملة للمياه، وخاصة القطاع الزراعي.

الكلمات المفتاحية : تغير المناخ، موارد المياه، الزراعة، التحسين الديناميكي، السعر الاقتصادي.

Introduction

Sustainable management of water resources has become a central element for the implementation of sectoral water resources policies and one of the most studied issues in research institutions working on natural resource management (Qian, 2016; Fu *et al.*, 2017). Given this importance, water management around the world was one of the urgent issues to be addressed at the United Nation Climate Change Conference (COP 25) held in Madrid in December 2019. Especially since half of the world's food comes from irrigated areas and drained land (Lobell *et al.*, 2003; Bastiaanssen *et al.*, 2007).

In Morocco, the effects of climate change can be dramatic on agriculture knowing that production is closely linked to the quantity and distribution of annual rainfall in rainfed areas, on the one hand, and to the amount of water stored in reservoirs and aquifers for irrigated perimeters on the other hand (Benabdelouahab *et al.*, 2016). In addition, the competition for access to water resources increases between sectors. In this context, agriculture that is considered as the most water-consuming sector, with more than 78% of mobilized water, risks to make facing many problems related to water management. Therefore, this sector is required to increase its productivity by growing crops that optimizes water use. However, since water is available to users at a subsidized price, users have no incentive to conserve this resource which are sometimes overexploited or wasted instead of considering it as a scarce resource(Lionboui *et al.*, 2016a). In addition, the increasing cost of water mobilization observed in recent years, reflects a growing imbalance between water supply and demand in most of the country's watersheds. The alarming depletion of groundwater, the drying up of springs, the deterioration of the quality of water, as well as the risk of dwindling water resources as a result of climate change are all signs of the worsening of the situation (MDCE, 2015). This has led to a strong mobilization to establish institutional reforms and agricultural policies for a more efficient allocation of water resources between different users. With the coming into force of the water laws, first the law 10-95 and later the law 36-15, state policies have been redirected towards a decentralized management of water resources according to good governance rules.

The management of water resources is an interdisciplinary issue. Therefore, integrated approaches, obtained using hydro-economic models, which represent the hydrological, environmental and economic aspects of water resources systems in a coherent framework, becomes currently important (Brouwer and Hofkes, 2008; Blanco-Gutiérrez *et al.*, 2013; Kahil *et al.*, 2016; Momblanch *et al.*, 2016). These models have allowed water managers to move from a static vision of a simple water supply management problem with a single goal, to a vision on demand management with respect to the socio-economic aspect in the long term (Harou *et al.*, 2009). In this context, different types of interdisciplinary modeling frameworks have been developed to respond to different scales, particularly in the agro-economic field (Peña-Haro *et al.*, 2009; Esteve *et al.*, 2015).

Thanks to advances in computer techniques which allow developing models of large-scale systems, the two bioeconomic models developed within the framework of INRA research projects used digital technologies to model such a complex system which is the watershed (Elame *et al.*, 2016; Lionboui *et al.*, 2016a; Lionboui *et al.*, 2018b; Elame *et al.*, 2020).

In order to analyse water resources sustainability, this research develops a general methodology for water management modeling in watersheds dominated by irrigated agriculture. The adopted methodology is applied to Tadla and Souss Massa regions. The research was based on field data collecting and surveys conducted in the two areas. The socio-economic conditions of the study area are specifically analysed, and suggestions are presented based on the economic optimization modeling results.

Methodology

Choice of appropriate scale for water management

The various regional and local stakeholders involved in water policy and their often divergent interests generate conflicts of water use and excessive demand that can only be managed through an integrated, decentralized and concerted water resource. Such management could only be conceived within the framework of a homogeneous unit that brings together the maximum number of stakeholders "the river basin" (or watershed in some literature) (Barbosa *et al.*, 2017). Indeed, the river basin constitutes the indicated entity for a global and integrated management of water, because it is within the hydrological network of the basin that human activities (urbanization, agriculture, tourism, industry, etc.) and hydro-agricultural developments (dams) influence the quality of the resources and the environment, from upstream to downstream. This entity with its social, economic and environmental dimensions stands out as the most appropriate water management area. Thus, this work was carried out at the level of two basins in Morocco; Souss Massa and Tadla (figure 1). The issue of sustainability of water resources is acute in these two basins which are characterized by irrigated agriculture and a semi-arid climate.

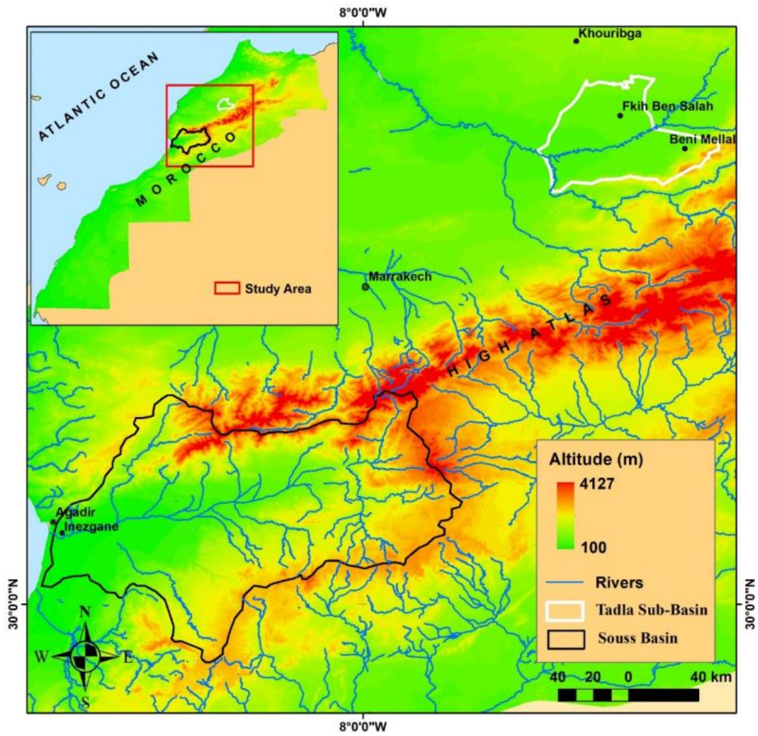

Figure 1: Location of the Souss Massa and Tadla basins

Watershed is a very complex system due to these hydrological, geological and climatological characteristics where activities and water use conflicts are concentrated between the different agents having a direct or indirect action on the system. In this context, an integrated management of water resources at the basin level is crucial and will allow the development of an appropriate analysis tool to manage the allocation of these resources.

The basin systems were represented by dynamic and logical relationships in time and space chosen according to several parameters specific to each study area such as climate, crops, nature and input costs agriculture, the efficiency of irrigation networks and systems, etc.

Models Structure

Complexities of water allocation and water use at the basin scale require a holistic approach for water resources management and planning in order to get optimal and sustainable water allocation and at the same time, an efficient and an equitable water use (McKinney *et al.*, 1999).

In this paper, we summarize the main aspects taken into consideration during the development of two agro-economic models of water management (MIBAS: "*modèle integeré du basin*"), within the Medium-Term Research Projects program (PRMT) of the National Institute of Agronomic Research (INRA Morocco). The developed models belong to the integrated river basin models category. They were developed at the basin level, based on the simulation of water flows, water resources-uses equilibrium equations of reservoirs and aquifers, water flows at the different nodes of rivers and the allocation of water resources. In addition to reflecting the dynamics of interactions between hydrological, agronomic and economic components, these models allow simulating the change of the water shadow price, land use, water consumption and agricultural profit under different scenarios (figure 2).

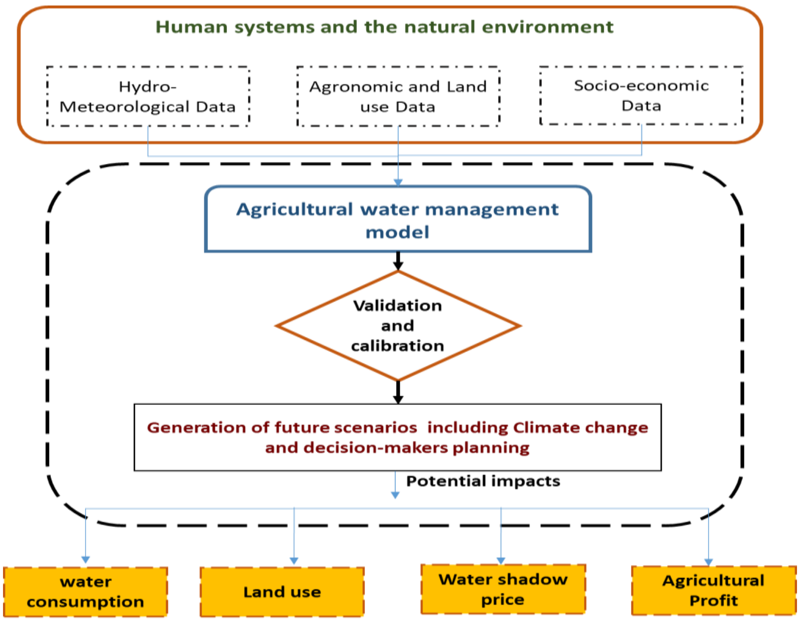

Figure 2: Structure of the agricultural water management model (MIBAS)

The advantage of this type of model is its ability to reflect the relationship and links between these various components listed above and to simulate the economic consequences due to policy choices (Rosegrant *et al.*, 2000; Cai *et al.*, 2003; Cai *et al.*, 2008). The model represents an efficient and useful tool for decision support on policy choices on water allocation and setting priorities for institutional and incentive reforms that guide water resources allocation. The proposed models are based on real links between different spatial units of the hydrological network and connected by interconnections or nodes. Spatial units represent river flows, reservoirs, aquifers, or water demand sites (agricultural demand area, drinking water, industrial water, etc.) (Heinz *et al.*, 2007; Heidecke and Heckelei, 2010; Elame *et al.*, 2016; Lionboui *et al.*, 2016a; Lionboui *et al.*, 2018b; Elame *et al.*, 2020). The water distribution includes the agricultural, industrial and municipal water use. Irrigation water is allocated according to water use efficiency, water requirements and crops productivity, while for the other sectors, such allocation is determined exogenously in the model. In the case of surface water, basic units are nodes distributed across the basin and represent water supplies, storage entities, and water demand of different sectors, while for groundwater nodes represent different aquifers used for agricultural, municipal, and industrial purposes.

In addition, the proposed modeling framework is based on a nonlinear optimization where, given a number of constraints, we seek to maximize an objective function reflecting a social utility that could be the overall profit generated at the watershed level, or any other function reflecting the preferences and choices of decision-makers. Once the objective function (Eq.1) and the constraints functions specified, the calibration of the model is obtained using a technical programing method called positive mathematical programming (PMP) (Howitt *et al.*, 2012).

$$Max\ Pt = \sum_{Ag\_A}\left(\sum_{Irri\_S} Pt\_PMP_{Ag\_A,Irri\_S}\right) \quad (1)$$

Where, "Max Pt" represents the agricultural profit at the basin level and "Pt_PMP" is the agricultural profit per agricultural zone and by irrigation system after calibration. "Ag_A" indicates the agricultural zone according to different irrigation water access modes "Irri_S". The profit per agricultural area and irrigation access modes is calculated from the production generated by the totality of production system minus the costs of agricultural inputs and depreciation.

The model developed is sufficiently disaggregated by physical and functional sub-units of the watershed, by agricultural areas, by agricultural speculation and by irrigation sources.

In order to best reflect the complexity of the conditions for exploiting irrigation water in the long term, the proposed model is dynamic recursive. The introduction of the dynamic aspect in the model was achieved through the creation of a set of years and a loop. This loop will make iterations taking into account parameters and variables that will be influenced by the expected variations and that will be introduced during the set representing the years. These variations concern conversion rates in water saving

systems, crop extension, precipitation, groundwater recharge and surface water supplies. For reservoirs, the quantity of water remaining from year 1 (end of August) will be used as the initial quantity of year 2 (beginning of September).

The model is programmed in General Algebraic Modeling System GAMS, and solved using the nonlinear solver "CONOPT" (Brooke *et al.*, 1998).

Models data

The developed models require very precise technical data and additional studies in the hydraulic and agronomic fields. It also requires a thorough knowledge of the agro-hydraulic and economic system, the functioning of water management in the Souss Massa and Tadla basins as well as their potential of water resources. These data are collected from regional actors in irrigation water management, namely the Agricultural Development Offices, the Provincial Agricultural Directorates, the Regional Directorate of Agriculture and the Souss Massa and Oum Er Rbia Hydraulic Basin Agencies.

Surveys were also carried out at the work centers of the two studied regions on land use, standards for the use of agricultural inputs, as well as yields levels by crops, by agricultural areas and by mode of access to irrigation water. Finally, in order to validate and complete the database, a farm survey was carried out among farmers in the study areas. The main crops observed at the level of the agricultural areas studied are taken into consideration in the developed models (figure 3).

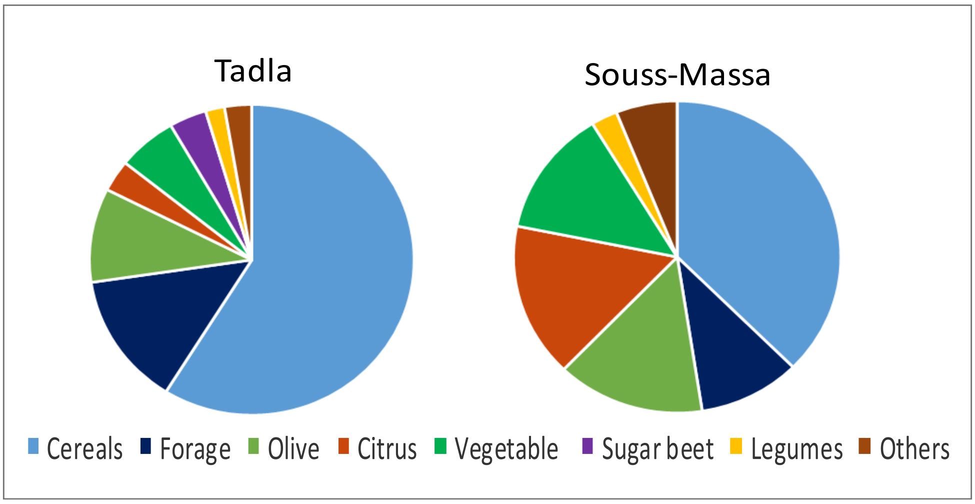

Figure 3: Different crops existing in agricultural areas

The collected data concern, firstly, agronomic parameters such as: crop yields, input use, crop area, effective rainfall, maximum crop evapotranspiration and yield response coefficient per crop. Also, they include technical and hydrological parameters such as: the loss rate of irrigation water, water demand by agricultural zone and by farm, the evaporation in reservoirs, the maximum volume of aquifers, their coefficient of storage, their gradient, the depth of each groundwater, its permeability and the regularized volume of reservoirs. Socio-economic parameters were also taken into account by agricultural area such as the selling price of agricultural products, inputs price, selling price of irrigation water by agricultural area, the technico-economic efficiency rates of farms and the mode of access to irrigation water.

Dynamic testing of basin models

In many semi-arid regions of the world, climate change issues, such as water resources scarcity, are of paramount importance in overcoming obstacles to development. The water value increases and presents itself as a quantitative and qualitative constraint to its domestic, industrial and particularly agricultural use. Given the multidimensional and multi-scalar nature of climate change, this research assesses the potential effects of climate change on agriculture in the study area. This climate impact scenario is based on the results of the MAGICC / Schengen model for North Africa itself based on the on the average scenarios SRES A2 developed in conjunction with the fourth assessment of the Intergovernmental panel on climate change (IPCC). This IPCC scenario describes a very heterogeneous world characterized by high population growth, low economic development and slow technological progress (Wigley, 2008; Ngoy and Shebitz, 2020). For our case study, the same assumptions will be adopted. In this context, it is also assumed that technological progress remains constant and that there will be no significant impact on yields variation by 2030.

The proposed modelling framework will simulate the impact of climate change and political choices on water resources and agricultural lands. Furthermore, it captures the behaviour of various water users while analysing conjunctive water resources (surface and groundwater) changes and suggest a better allocation of water resources. The agricultural sector is the central point of this work whereas the other sectors have been introduced as exogenous parameters. As a result, the agriculture sector will undergo the consequences of any climate or economic change affecting the availability or water supply. Following are the results of the climate change scenario for the two basins.

Results and discussion

Water availability: an increasing scarcity

Given that climate change scenarios predict a decline in precipitation and water inflow, the agricultural water use in Tadla and Sous-Massa basins tends to decrease (Figure 4). Indeed, the total amount of water used for irrigation purposes in Souss Massa basin is around 710 million cubic meters (m^3) the first year (2015) and 630 million m^3 the last year of the scenario (2030) which means a decrease of 11% of water resources use.

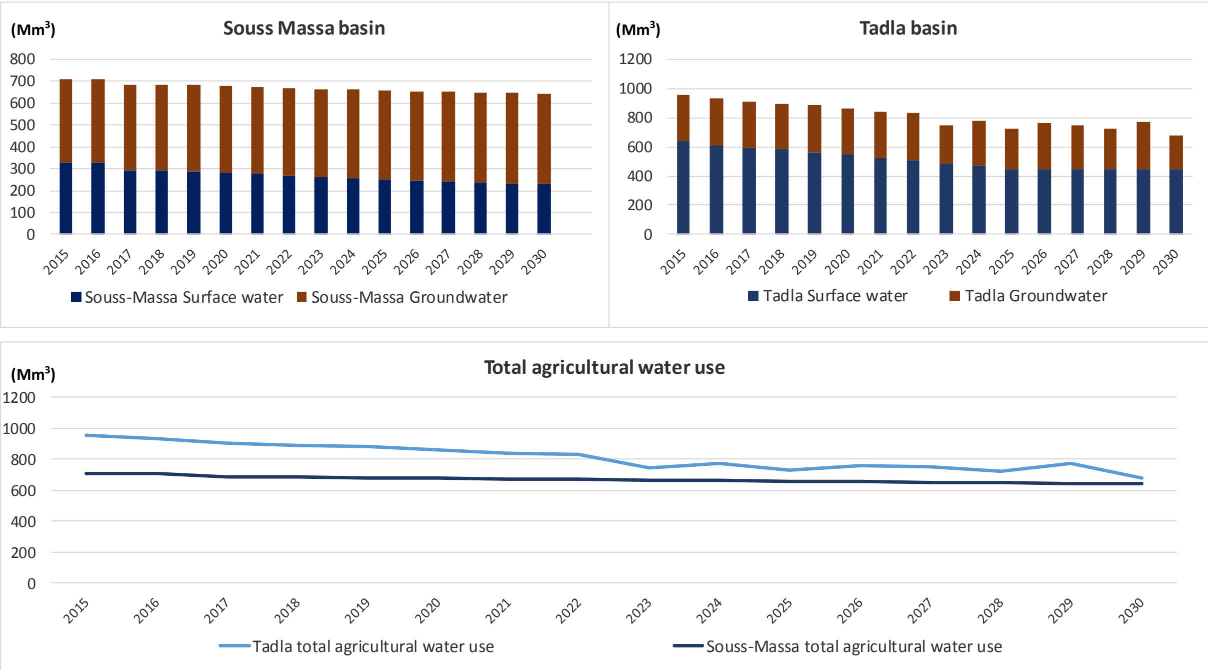

Figure 4: Agricultural water use scenario in the study area

The use of surface water starts to decrease from the year when water inflows and precipitation decline becomes important. The use of surface water dropped by more than 100 million m^3, representing more than 37% decrease the next 15 years. However, the groundwater resources use has risen by more than 40 million m^3, equivalent to 10% of the total amount of groundwater for irrigation (Elame *et al.*, 2020).

The results of the climate change scenario for the Tadla basin follow the same shape of the Souss-Massa basin registering a decline in water resources use over the 15 years of the scenario. This decrease is mainly due to the reduction in cultivated areas caused by the expected decrease in surface water resources during the simulated period. While groundwater consumption will tend to stabilize over the years since farmers tend to compensate for the decrease in surface water supplies (Lionboui *et al.*, 2018a). Given the awareness of decision-makers of the importance of sustainable water resources management, agricultural policies in Morocco have proposed a set of measures, such as the granting of subsidies and launch outreach programs, to encourage the adoption of water saving systems in order to cope with the expected reduction in surface water inputs and the drop in groundwater levels, particularly in the studied basins.

The water shadow price

Knowing that the shadow price is an important indicator that reflects water scarcity at the basin scale (Bierkens *et al.*, 2019), this work has computed the water shadow price variation through years for the two basins. The analysis of the results reveals important differences in the water shadow price according to the agricultural zones.

Under the effects of climate change, the value of water becomes more and more important (figure 5).

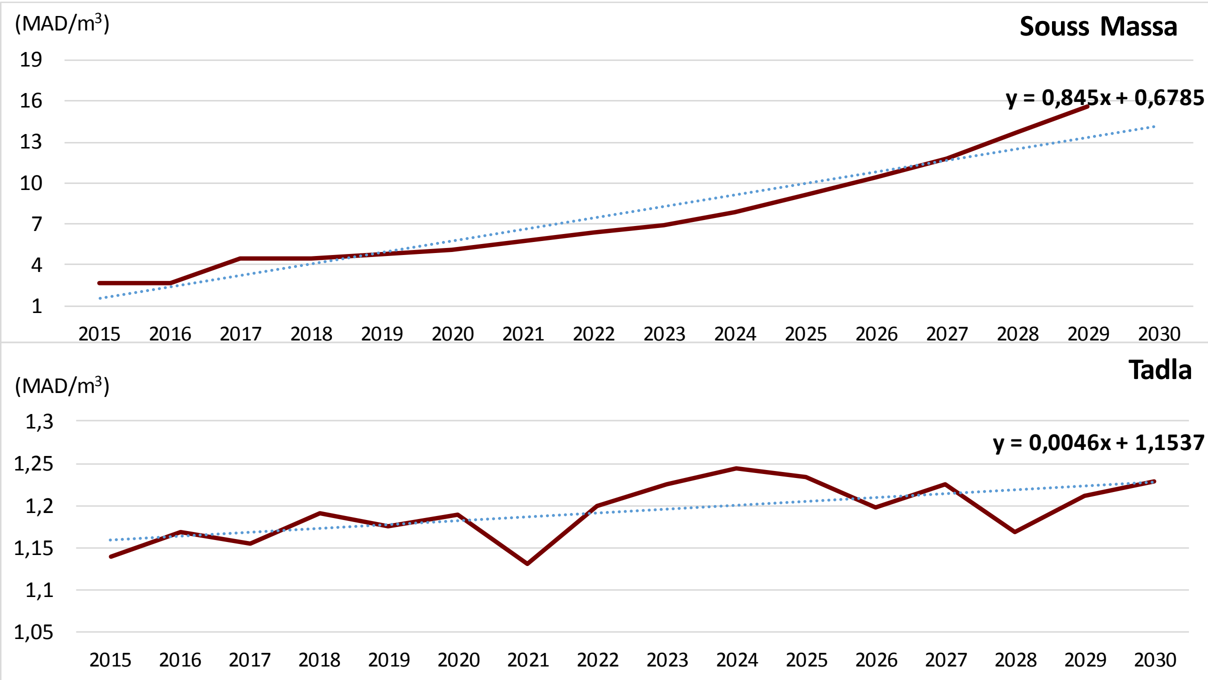

Figure 5: Change in agricultural water shadow price

The results show that climate change can have an impact on increasing irrigation water shadow price through the simulated years in the two studied basins. The average economic price of water in the Tadla basin rises up from 1.13 MAD/m^3 to 1.25 MAD/m^3 and from 2.6 MAD/m^3 to 15 MAD/m^3 for the Souss-Massa basin.

The high value of the water shadow price in the Souss-Massa could be explained by the current state of water scarcity at the basin scale knowing that there is a high variability in surface water flows and a deficit beyond 300 Mm^3 of groundwater. In addition, the climate change scenario predicts a decrease in precipitation and water flows which affect drastically the economic value of water resources.

The agricultural profit

In many semi-arid regions of the world, climate change issues, such as water resources scarcity, are of paramount importance in overcoming obstacles to development (Mueller and Tickamyer, 2020). Thus, the net agricultural profit at the level of the two studied basins Tadla and Souss-Massa, would experience a downward

trend under climate change where the value of water increases and appears as a quantitative and qualitative constraint to its use, especially in agriculture (figure 6).

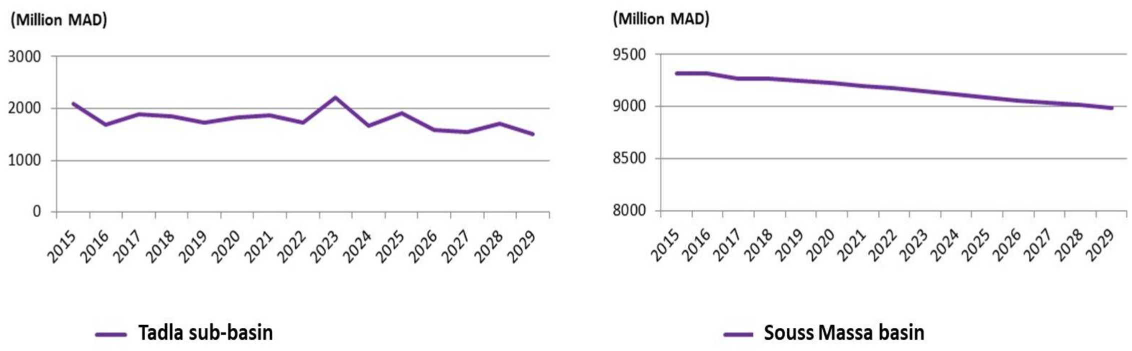

Figure 6: Agricultural net profit trend under climate change

The total net profit created in the Tadla and Souss-Massa basins is to significantly decrease from the first to the last year taken into consideration by the model. This decrease is explained by a decrease in irrigated areas at the profit of rainfed areas. We have to mention that the agricultural profit in the Souss-Massa includes animal production profit in comparison with the Tadla basin that only comprises crop production.

We can also notice that agricultural water is better valued in the Souss Massa Basin, which is due mainly to the existence of high value-added agriculture at the level of this basin compared to Tadla sub-basin. In fact, using drip irrigation and intensive cropping under greenhouse (tomatoes and other vegetables) makes the Souss-Massa region one of the most competitive agricultural regions in North Africa.

In order to adapt to the declining trend of water resources, farmers are being led to adapt with the new situation. They are called upon to optimize their choice by opting for crops that require less water and realize significant profit margins to maximize their revenue, especially in Tadla (Lionboui *et al.*, 2016b).

Conclusion

For a sustainable development of water resources, several orientations and objectives have been defined around the world, in particular in the arid and semi-arid areas. In order to apply these guidelines to the sustainable management of water resources systems, it is important to transform them into operational concepts specific to each region. Accordingly, this research develops a modeling framework that focuses on a quantitative analysis of irrigation water resources for a sustainable management goal. To address the issue of water resources management, an integrated agronomic, economic and hydrological model (MIBAS) was developed to analyze climate change impacts and sustainability issues related to water resources management in two basins; Tadla and Souss-Massa. Indeed, we developed a decision support approach for long-term sustainable water resource management adapted to semi-arid watersheds, where irrigation is the main water user. The main results show that climate change scenario predicts a significant water resources decrease for the two basins in the next fifteen coming years. The water shadow price will increase reflecting water scarcity trend in the two basins with a high scarcity level for the Souss-Massa basin. The agricultural profit in the two basins will also decrease due to a decrease of irrigated areas and yields. Consequently, this modeling tool has led to simulate the climate change impact and to manage water in a sustainable way through a reallocation of water resources at the basin scale. This is the originality of this research, which shows the feasibility and effectiveness of advanced modeling in the sustainability analysis, a concept of the utmost importance, which will strongly influence water resources management in the future.

References

Barbosa MC., Mushtaq S. and Alam K. (2017). Integrated water resources management: Are river basin committees in Brazil enabling effective stakeholder interaction? Environmental Science & Policy, 76.p. 1-11.

Bastiaanssen WGM., Allen RG., Droogers P., D'Urso G. and Steduto P. (2007). Twenty-five years modeling irrigated and drained soils: State of the art. Agricultural Water Management, 92.p. 111-125.

Benabdelouahab T., Balaghi R., Hadria R., Lionboui H., Djaby B. and Tychon B. (2016). Testing Aquacrop to simulate durum wheat yield and schedule irrigation in a semi-arid irrigated perimeter in Morocco. Irrigation and Drainage, 65.p. 631-641.

Bierkens MFP., Reinhard S., de Bruijn JA., Veninga W. and Wada Y. (2019). The Shadow Price of Irrigation Water in Major Groundwater-Depleting Countries. Water Resources Research, 55.p. 4266-4287.

Blanco-Gutiérrez I., Varela-Ortega C. and Purkey D. (2013). Integrated assessment of policy interventions for promoting sustainable irrigation in semi-arid environments: A hydro-economic modeling approach article. Journal of Environmental Management, 128.p. 144-160.

Brooke A., Kendrik D. and Wilson A. (1998). GAMS: A User's Guide. Scientific Press. Redwood City, Calif., USA.

Brouwer R. and Hofkes M. (2008). Integrated hydro-economic modelling: approaches, key issues And future research directions. Ecological Economics, 66.p. 16-22.

Cai X., McKinney D. and Lasdon L. (2003). Integrated Hydrologic-Agronomic-Economic Model for River Basin Management. Journal of Water Resources Planning and Management, 129.p. 4-17.

Cai X., Ringler C. and You JY. (2008). Substitution between water and other agricultural inputs: Implications for water conservation in a River Basin context. Ecological Economics, 66.p. 38-50.

Elame F., Doukkali R. and Fadlaoui A. (2016). Modélisation économique de l'impact des changements climatiques sur les ressources en eau : cas du bassin de Souss-Massa (Maroc). New-médi, 15.p. 10-18.

Elame F., Doukkali R. and Lionboui H. (2020). Dynamic Modeling of Climate Change Impact on Agricultural Lands and Water Resources. In: Leal Filho, W., Luetz, J., Ayal, D. (Eds.), Handbook of Climate Change Management: Research, Leadership, Transformation. Springer International Publishing, Cham, pp. 1-21.

Esteve P., Varela-Ortega C., Blanco-Gutiérrez I. and Downing TE. (2015). A hydro-economic model for the assessment of climate change impacts and adaptation in irrigated agriculture. Ecological Economics, 120.p. 49-58.

Fu ZH., Zhao HJ., Wang H., Lu WT., Wang J. and Guo HC. (2017). Integrated planning for regional development planning and water resources management under uncertainty: A case study of Xining, China. Journal of Hydrology 554, 623-634.

Harou J., Pulido-Velazquez M., Rosenberg DE., Medellvn-Azuara J., Lund JR. and Howitt RE. (2009). Hydro-Economic Models: Concepts, Design, Applications and Future Prospects. Journal of Hydrology, 375.p. 627-643.

Heidecke C. and Heckelei T. (2010). Impacts of changing water inflow distributions on irrigation and farm income along the Drâa River in Morocco. Agricultural Economics, 41.p. 135-149.

Heinz I., Pulido-Velazquez M., Lund JR. and Andreu J. (2007). Hydro-economic modeling in river basin management: Implications and Applications for the European Water Framework Directive. Water Resour Manage, 21.p. 1103-1125.

Howitt RE., Medellín-Azuara J., MacEwan D. and Lund JR. (2012). Calibrating disaggregate economic models of agricultural production and water management. Environmental Modelling & Software, 38.p. 244-258.

Kahil MT., Ward FA., Albiac J., Eggleston J. and Sanz D. (2016). Hydro-economic modeling with aquifer–river interactions to guide sustainable basin management. Journal of Hydrology, 539.p. 510-524.

Lionboui H., Benabdelouahab T., Elame F., Hasib A. and Boulli A. (2016a). Multi-year agro-economic modelling for predicting changes in irrigation water management indicators in the Tadla sub-basin. International Journal of Agricultural Management and Development, 5.p. 96-105.

Lionboui H., Benabdelouahab T., Elame F., Hasib A. and Boulli A. (2018a). Estimating the Economic Impact of Climate Change on Agricultural Water Management Indicators. Pertanika Journal of Science and Technology, 26.p. 749-762.

Lionboui H., Benabdelouahab T., Hasib A. and Boulli A. (2016b). Analysis of farms performance using different sources of irrigation water: a case study in a semi-arid area. International Journal of Agricultural Management and Development, 6.p. 145-154.

Lionboui H., Benabdelouahab T., Hasib A., Elame F. and Boulli A. (2018). Dynamic Agro-Economic Modeling for Sustainable Water Resources Management in Arid and Semi-arid Areas. In: Hussain, C.M. (Ed.), Handbook of Environmental Materials Management. Springer International Publishing, Cham, pp. 1-26.

Lobell DB., Asner GP., Ortiz-Monasterio JI. and Benning TL. (2003). Remote sensing of regional crop production in the Yaqui Valley, Mexico: estimates and uncertainties. Agriculture, Ecosystems and Environment, 94.p. 205–220.

McKinney DC., Cai X., Rosegrant MW., Ringler C. and Scott CA. (1999). Integrated Basin-Scale Water Resources Management Modeling: Review and Future Directions. Sri Lanka: International Water Management Institute 6.

MDCE (2015). Projet de performance. Ministère Délégué aurès du Ministre de l'Energie, des Mines, de l'Eau et de l'Environnement, Chargé de l'Eau, Rabat, Maroc.

Momblanch A., Connor JD., Crossman ND., Paredes-Arquiola J. and Andreu J. (2016). Using ecosystem services to represent the environment in hydro-economic models. Journal of Hydrology, 538.p. 293-303.

Mueller JT. and Tickamyer AR. (2020). Climate change beliefs and support for development: Testing a cognitive hierarchy of support for natural resource-related economic development in rural Pennsylvania. Journal of Rural Studies, 80.p. 553-566.

Ngoy KI., and Shebitz D. (2020). Potential Impacts of Climate Change on Areas Suitable to Grow Some Key Crops in New Jersey, USA. Environments 7, no. 10: 76.

Peña-Haro S., Pulido-Velazquez M. and Sahuquillo A. (2009). A Hydro-Economic Modeling Framework for Optimal Management of Groundwater Nitrate Pollution from Agriculture. Journal of Hydrology 24.

Qian Y. (2016). Sustainable Management of Water Resources. Engineering, 2.p. 23-25.

Rosegrant M.W., Ringler C., McKinney D.C., Cai X., Keller A. and Donoso G. (2000). Integrated economic–hydrologic water modeling at the basin scale: the Maipo river basin. Agricultural Economics, 24.p. 33-46.

Wigley TML. (2008). MAGICC/SCENGEN NCAR, Boulder, CO, USA.