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An input–output framework for analysing relationships between economic sectors and water use and intersectoral water relationships in Morocco

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Abstract

Over the last few decades, Morocco has been undergoing a strong and fast water demand increase due to demographic upsurge, irrigated agriculture expansion, flourishing foreign trade and changing standard of living and lifestyles. The continued increase of water demand has imposed a height pressure over national scare water resources. Despite this worrying situation, the imperative of sustainable water use and management has created a need for compulsory information to define and implement economic and water-saving policies in an integrated and informed manner. This paper uses an input–output model of water use to analyse the relationships between economic sectors and water resources use in Morocco (i.e. direct water use) as well as the intersectoral water relationships (i.e. indirect water use). The results show that, on the one hand, Agriculture, hunting and forestry sector exhibits high direct water use. On the other hand, secondary and tertiary sectors display low direct use and high indirect water use. Typical examples of sectors with high indirect water use are manufacture of food and tobacco products and hotels and restaurants sectors. Further by means of the impact analysis, we have demonstrated that the economic sectors whose indirect water use coefficients are high have a significant influence on water resources by means of their "drag effect" on water use of other sectors. The results highlight the added value of conducting an analysis of the intersectoral water relationships and suggest that it is important to take into account in the processes of policy definition not only the direct water use but also the indirect water use, because neglecting them could threaten our water resources.

Keywords: Scare water resources, Input–output model of water use, Economic sectors, Sustainable water use

1 Background

Morocco is among the countries with low per capita water resources endowments. The average annual fresh water resources are estimated at 22 billion cubic metres, which is equivalent to 730 m^3/capita/year. This figure is already lower than the threshold between water-stressed and scarce areas defined internationally to 1000 m^3/capita/year. Groundwater resources account for about 20% (4173 hm^3), of this average while surface water account for 80% (18,248 hm^3) of the total. On the geographical distribution side, the water resources in Morocco are unevenly distributed over space. As shown in Table 1, the northern river basins Sebou and Loukkos contain for about 47% of the total water resources in Morocco, while they are home to only 19% of the total population and cover only 7.43% of the country's area. The structure of water demand in Morocco is dominated by the agricultural sector. In most river basins, the agricultural sector absorbs for about 86% of the total water use, compared to 2% for domestic use and 3% for industrial use.

Over the last few decades, Morocco has been facing a strong and fast water demand increase due to population expansion, irrigated agriculture, flourishing foreign trade and changing standard of living and lifestyles. The continued increase of water demand has imposed a height pressure over national scare water resources. To meet increasing water demand, efforts have been focused on supply side solutions by building hydrological infrastructures for water resources collecting, storage and distribution. The focus only on the supply side has led to neglect the way in which water is used. As a result, the natural quality of surface and groundwater resources has been dramatically deteriorated, groundwater resources have been overexploited in many areas, and the mobilizable conventional water resources have been almost mobilized (Economic, social and Environmental Concil 2014). From Fig. 1, it can be seen that, in 2012, significant parts of surface water resources are in bad to very bad quality in several river basins. This is the case of, for example, Loukkos (1), Sebou (2), Boureg Reg (4) and Tensift (6) river basins whose surface water resources in bad to very bad quality account for about 91, 29, 35 and 34%, respectively, of their total resources. Likewise, Fig. 2 shows that each of the river basins 3, 4, 5, 6, and 9 has up over 50% of their groundwater resources in bad to very bad quality. Moreover, Fig. 3 shows that there has been a severe overexploitation of ground water resources in the river basins 2, 4, 5, 6 and 8.

Therefore, under the current water situation, in order to meet the projected demands in upward trend, Morocco should resort to non-conventional water resources (for

Table 1 Water resources distribution in Morocco. *Source*: created by the authors with data extracted from the National Water Plan (2013) and the Ministry of Energy, Mines, Water and Environment website

River basin	Surface water (10^6 m^3)	Groundwater (10^6 m^3)	Total fresh water (10^6 m^3)	Cumulative proportions	Population (10^4)	Cumulative proportions	Area (10^3 km^2)	Cumulative proportions
Loukkos	3600	146	3746	17	300	10	12.805	1.80
Sebou	5600	1123	6723	47	620	19	40	7.43
Moulouya	1300	610	936	55	250	40	74.145	17.86
Bouregreg	852	84	3880	59	700	63	20.47	20.74
Oum Er Rbia	3300	580	1780	77	500	80	48.07	27.50
Tensift	1140	640	1780	85	272.310	90	24.8	30.99
Ziz Guir Rheris	656	240	896	89	76.250	92	58.841	39.27
Sous Massa	1500	710	2210	98	190	99	126.48	57.06
Sahara	300	40	340	100	41.649	100	305.239	100

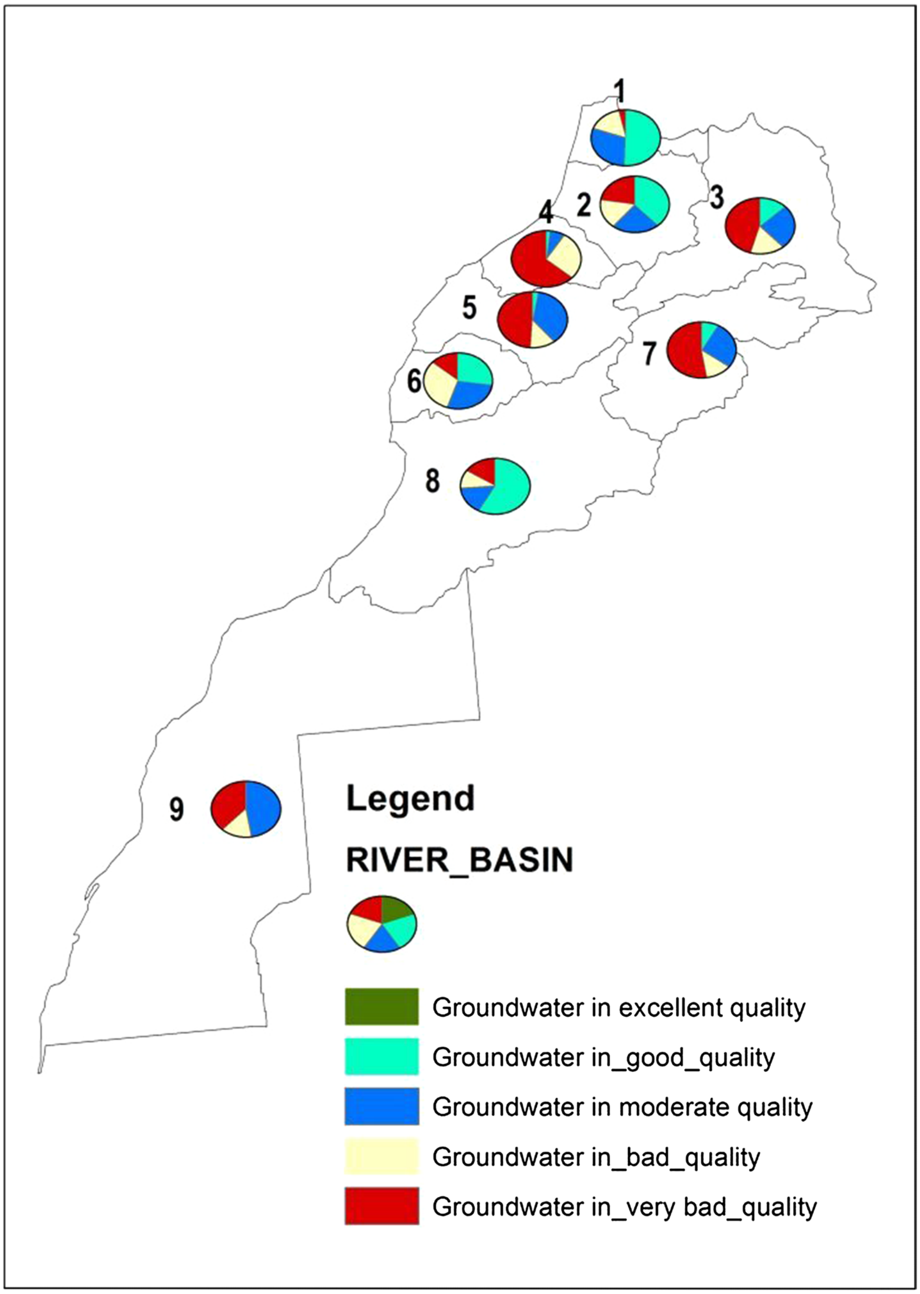

Fig. 1 Groundwater resources quality. *Source*: created by the authors with data extracted from MEMWE report (2014)

examples, by purifying Wastewater, desalinate seawater). This option has already been adopted by Moroccan Water planners, especially to satisfy water demand of irrigated agriculture in low water endowments areas.

Thus, Moroccan water sector is now at a certain step in the expansionary phase with rising financial, social and environmental costs of developing new water supplies, increasing conflicts and competition between water users and appearance of the negative externalities. In other words, we have arrived at the period that Randall (1981) titled

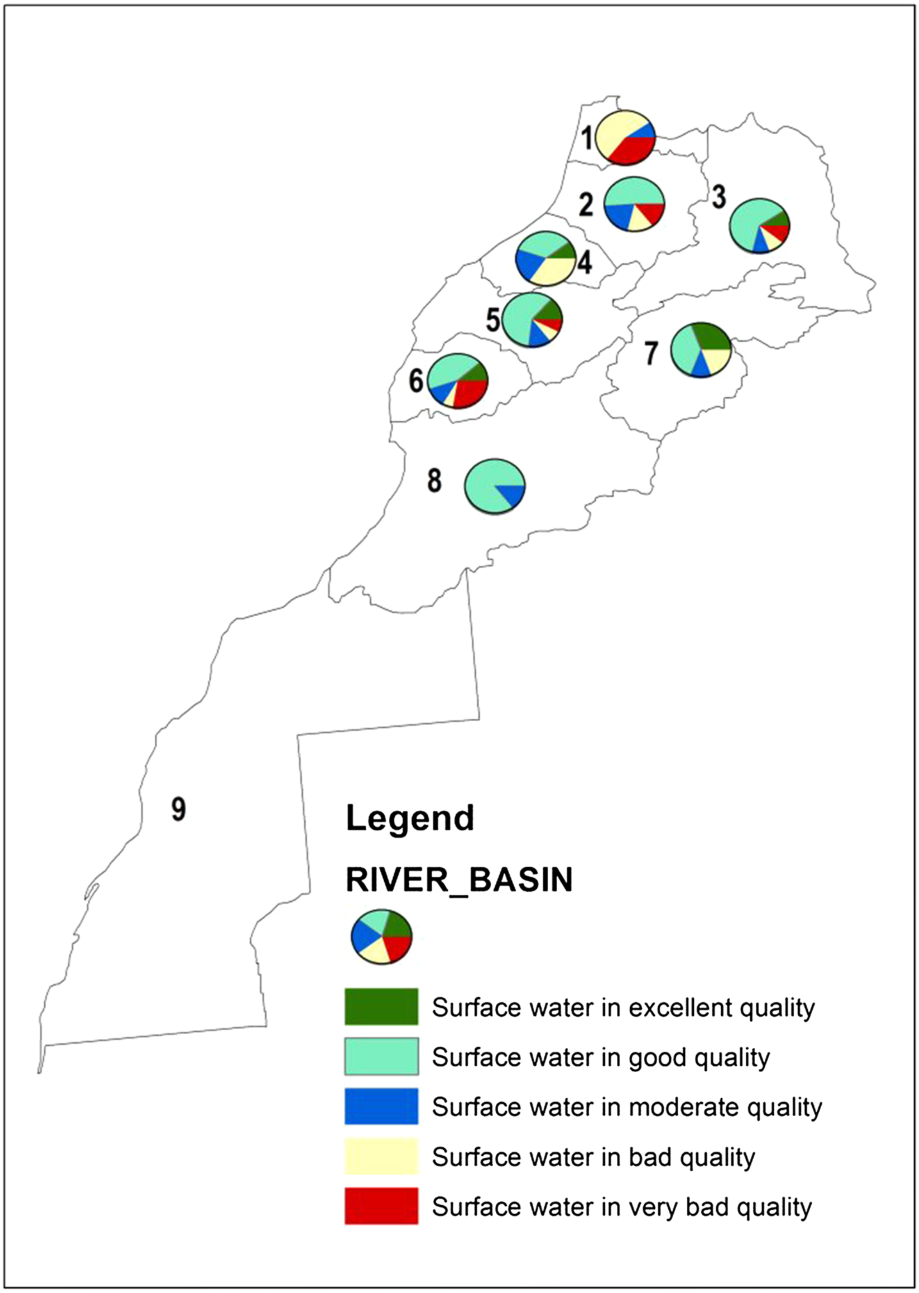

Fig. 2 Surface water resources quality. *Source*: created by the authors with data extracted from MEMWE report (2014)

"maturing water economy". In this context, it is admitted that water supply development paradigm has stalled and become ineffective in Morocco. In fact, any attempt at bridging the gap between water supply and demand must explore solutions in the demand side. The major challenge facing demand-side water management approach today is to conciliate economic growth and rational use of water resources. The ultimate objective of measures aimed at demand management issues should be to use water sustainably. Sustainable water use approach was derived from the notion of sustainable development

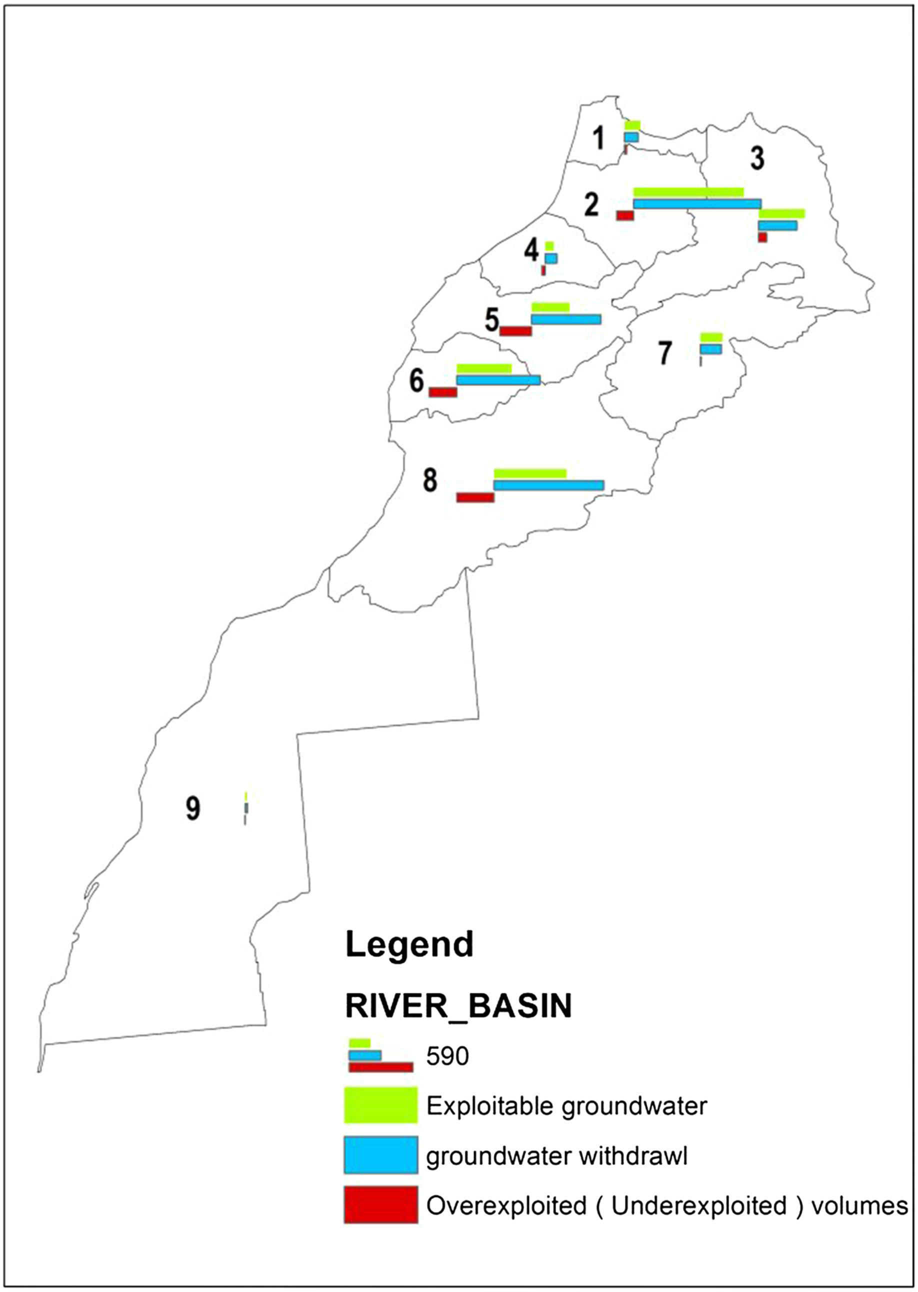

Fig. 3 Distribution of the overexploited groundwater resources volumes. *Source*: created by the authors. Data extracted from MEMWE website

that emerged in the late 1980s as a response to the line of thought that has been highlighting the future effects likely to arise from the conflictive relationship between economic growth and the natural resources uses. This relationship is marked by a problem of exhaustion of non-renewing natural resources, and overexploitation of renewable resources. Sustainable development is defined by Brundtland Commission report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and

Development 1987). This definition point up the current and future generations well-being interdependences, which are closely related to the natural resource endowments. In the same way, sustainable water use can be defined as "that pattern of use which ensures satisfaction of needs for both the present and future generations" (Bithas 2008). In this sense, using water, under the constraint that imposes the concern of maintains them for future generations, constitutes the great challenge that current generations must overcome.

The crucial issue at hand is to figure out ways to put in practice this notion. This issue is still a subject of debate. Nevertheless, in the field of water research, it is largely allowed that any attempt at formulating effective water policy toward sustainable water use requires recognizing the relationships established between the economy and water use (Wang et al. 2009; Manase 2010). However, an integrated water–economic analysis requires an integrated information system bringing together economic and water information. This was the basic idea behind the System of Environmental and Economic Accounting for Water (SEEAW) developed by the United Nations (United Nations Statistics Division 2006) which is a more elaborate version of the framework presented in the Handbook of National Accounting Integrated Environmental and Economic Accounting-2003 (United Nations, et al. 2003). Nevertheless, several countries, including Morocco, have not yet succeeded in carrying out an integrated water information system.

An interesting similar method to analyse the interactions between water and the economy is de input–output (I–O) model of sectoral water use which is a development of the energy use I–O model developed in the early 1970s which is, in turn, an extension of the Loentief I–O model. The basic model developed by Wassily Loentief in the late 1930s is a system of linear equations; each equation describes the distribution of an economic sector's product throughout the economy (Miller and Blair 2009).

With the raising need of a system that provides information on the economy and the environment, Leontief (1970) added to the I–O table a row vector and a column vector to represent, respectably, sectoral emissions of pollutant and the pollution eliminated by the abatement activities. This extended framework has been broadly used (e.g. Leontief and Ford 1972; Stone 1972; Tamura and Ishida 1985; Førsund 1985; Labandeira and Labeaga 1999, 2002; Alcántara and Padilla 2009).

In the wake of the oil crisis of 1973, energy consumption has become the main focus of researchers interesting on natural resources consumption. Thus, an energy I–O model has been developed and extensively used to investigate several kinds of questions relating to energy use and its relationships especially with the economy and the environment. Generally, most of these studies investigate sectoral energy consumption and the energy cost of goods or services (e.g. Clark and Herendeen 1975; Clark et al. 1978; Proops 1977, 1988), the source of changes in energy consumption and emissions by means of the structural decomposition analysis (e.g. Rose and Chen 1991; Lin and Polenske 1995; Chang and Lin 1998; Machado et al. 2001; Ma and Stern 2008; Lim et al. 2009; Weia et al. 2016; Hammond and Norman 2012) as well as the energy–environment relationships and the impact analysis of environmental and economic policy scenario (e.g. Gay and Proops 1993; Casler and Rafiqui 1993; Pearson and Smith 1991); Lenzen 1998; Hawdon and Pearson 1995; Oliveira and Antunes 2004; Llop and Pié 2008; Oliveira et al. 2014).

Whit regard to water issues, studies that analyse the relationships between the economic system and water consumption using the I–O model have generated a substantial literature. According to Velázquez (2006), the first operating water I–O model was constructed by Lofting and Mcgauhe (1968). Since this earliest study, a wide range of water issues have been addressed through the I–O analysis. These comprise water reallocation analysis (e.g. Harris and Rea 1984; Howe et al. 1990; Llop 2013), analysis of the economic impacts of water policy scenarios (e.g. Llop 2008; Dietzenbacher and Velázquez 2007) and a large number of studies that analyse the relationships between the productive structure water use and water pollution, intersectoral water relationships and virtual water trade (e.g. Chen 2000; Lenzena and Foran 2001; Okadera et al. 2006; Velázquez 2006; Dietzenbacher and Velázquez 2007; Guan and Hubacek 2008; Zhao et al. 2009; Wang and Wang 2009; Wang et al. 2009; Zhao et al. 2010; Chapagai and Hoekstra 2011; Zhan-Minga and Chen 2013; Wang et al. 2014).

In Morocco, water has been studied from several perspectives. However, little is known about the way in which the water sector as a whole is linked to the economic structure. Indeed, in order to alleviate water scarcity, Morocco needs to curb water demand. Such a measure requires, in turn, a complete understanding of the water flows, on the one hand, from the environment to the economy and, on the other hand, within the economy.

Water flows from the environment to the economy consist of the withdrawals of water from the environment by the economic units (economic sectors and households). An analysis of those flows provides information on the direct relationships between water resources and the economic units. Moreover, the water flows within the economy consist of water transactions between each national economic sector and the rest of the world and between national economic units. Modelling the water transaction between national economic units allows us to determine the intersectoral water relationships which are, in turn, very useful data for integrated water–economic analysis.

Further, it is also very important to determine the destination of water after it has been used in the production process of goods and services by distinguishing between domestic and foreign destination of water. Such analysis allows us to evaluate, on the one hand, the impact of domestic demand on water resources by quantitatively evaluate the water footprint of Morocco and, on the other hand, the impact of trade with the rest of the world on national water resources by quantifying the virtual water flows.

The term virtual water was introduced by Allan (1993). It is used to refer to the freshwater required in the production process of goods and services. This concept is particularly related to trade. The idea behind it is that water scarce countries could reduce their scarcity by exporting goods and services whose production requires low quantities of water and importing goods and services whose production requires high quantities of water. This trade pattern has emerged as a virtual water strategy to alleviate water scarcity.

The impact of domestic demand on water resources is evaluated by the water footprint of the area concerned. The term water footprint was introduced by Hoekstra and Hung. It was defined as the volume of freshwater needed for the production of the goods and services consumed by the inhabitants of an area (Hoekstra and Chapagain 2007).

In Morocco, there is need to cover all this important water–economy interaction in order to provide the policy makers with relevant information for designing integrated policies. Therefore, the aim of this study is to fill the knowledge gaps by developing and applying an I–O model of water use to Moroccan economy. However, we will limit our analysis to the relationships between the national economic sectors and the national water resources as well as the intersectoral water relationships in order to explore the inter-linkages between water use, and the productive structure, and providing indicators clarifying the economic and environmental decision-making. The method used in this paper is the same as that used, for example, by Zhang et al. (2011), Zhao et al. (2010), Wang et al. (2013) in water footprint analyses. However, we will limit ourselves in this paper to just analyse water use intensity of each economic sector in Morocco. In the framework of virtual water, sectoral water use intensity can be defined as "the virtual water content" of its product (the water used to produce one monetary unity of the product of a given sector). Quantifying the sectoral and the total water footprint of Morocco as well as the virtual water trade analysis will be the subject of a future study.

Thus, the present paper claims to achieve the following objectives: First, adapt the conventional Leontief I–O model to water resources use. Second, investigate the relationships between water use and the economic sectors as well as the intersectoral water relationships, and find out the most direct and indirect water consumers. Third, in order to demonstrate the danger of neglecting indirect water use on water resources, we wonder what would be the amount of change in total sectorial water use and in the total quantity of water consumed by the economy as a whole when there are changes in final demand addressed to the high indirect use water sector compared to the effect of a similar change in the final demand addressed to the large direct water users. We will try to bring reply to this question by means of impact analysis. Finally, our fourth objective consists in leading an analysis aiming at determining the economic benefit of water use.

2 Methods

This paper adopts an I–O model of water use which is a combination of the extended IO model developed by Leontief and the energy use model given in Proops (1977). The model is used to quantitatively assessing the relationships established between economic sectors and water use (i.e. direct use), intersectoral water relationships (i.e. indirect use), and the economic benefits of water use.

2.1 The modified I–O integrating water resources use

2.1.1 Traditional I–O model

First, we begin with the standard I–O identity. Consider a national economy whit n sector. Let x_i denote the total output of sector i and y_i the total final demand for the output of sector i. We can write the basic I–O equation which describes the way in which the sector i's output is distributed to other sectors and to final demand:

$$x_i = \sum_{j=1}^{n} x_{ij} + y_i \tag{1}$$

A fundamental hypothesis in the I–O model is that the purchases of sector j from sector i, x_{ij}—in a given period—depend on the total output of sector j, x_j, in this period. This relationship is represented by the direct input coefficient (a_{ij}), with:

$$a_{ij} = \frac{x_{ij}}{x_j} = ct \tag{2}$$

Once direct input coefficients are taken into account, Eq. (1) can be rewritten as:

$$x_i = \sum_{j=1}^{n} a_{ij}x_j + y_i \tag{3}$$

In matrix term, Eq. (3) is expressed as:

$$x = A \cdot x + y \tag{4}$$

The matrix $A = a_{ij}$ is known as the direct input matrix, $x = x_i$ and $y = y_i$ are, respectively, the column vector of production and the column vector of final demand.

Solving for x gives.

$$x = (I - A)^{-1} y \tag{5}$$

where L is the $n \times n$ identity matrix, $L = l_{ij} = (I - A)^{-1}$ is the Leontief inverse matrix. Each element in L indicates the change in the output of sector i when the demand of sector j varies by one unit ($l_{ij} = \partial x_i / \partial f_j$).

2.1.2 The basic equation of water I–O model

After having presented the basic I–O model, in what follows we develop the I–O model of water use. For that purpose, we are required to begin by distinguishing between two types of water use, namely direct and indirect water uses.

It is important to note that in the I–O model of water use adopted in this paper water is treated as material input into production. So, if we consider for simplicity an economy with two sectors i and j, the production activity of sector i consists in generating output in order to satisfy its own demand by transforming the inputs generated by sector j. In this process, a quantity of water is consumed. This quantity of water is called, in this work, the direct water use of sector i. However, to produce the inputs used by sector i, sector j also uses water. This quantity of water required by sector j to produce the output used by sector i as input is called the indirect water use of sector i. The sum of direct and indirect water uses of sector i is equal to total water use.

Now, we can present the formulation of the water use I–O model by rewriting the basic accounting relationship of the traditional model (Eq. 1) in terms of water use.

Thus, by referring to the above definitions of direct, indirect and total water uses, it will be readily apparent that the output of sector i, x_i, is carried out by using the quantity of water consumed directly by this sector, w_i^d (m^3). In the same way, the production of sector i intended for the intermediate consumption of the sector J, x_{ij}, corresponds to the quantity of water w_{ij} (m^3) consumed by sector i. Finally, the production y_i of sector i for its final demand corresponds to the quantity of water w_{yi}^d (m^3) directly used by sector

i to meet its demand. So, we can write the accounting identity of the I–O of water use model, which is analogous to Eq. (1), as follows:

$$w_i^d = \sum_{j=1}^{n} w_{ij} + w_{yi}^d \tag{6}$$

Moreover, in a way similar to that for the standard I–O model, we can define a technical coefficient of water use matrix $T = [t_{ij}]$, each element of which is a ratio of the indirect quantity of water consumed by sector i, by using the output purchased from sector j, to the quantity of water directly consumed by sector j. So we have:

$$t_{ij} = w_{ij} \Big/ w_j^d \tag{7}$$

Hence,

$$w_{ij} = w_j^d \cdot t_{ij} \tag{8}$$

Replacing w_{ij} with its expression in Eq. (6), we obtain

$$w_i^d = \sum_{j=1}^{n} t_{ij}\, w_j^d + w_{yi}^d \tag{9}$$

Expressed in matrix terms, Eq. (9) becomes

$$w^d = Tw^d + w_y^d \tag{10}$$

And, solving for w^d

$$w^t = (I - T)^{-1}\, w_y^d \tag{11}$$

Notice that the vector of direct water use w^d has been replaced by the vector wt of total water use once the matrix $(I - T)^{-1}$ had been introduced. This is because $(I - T)^{-1} = \rho = [\rho_{ij}]$ is the $n \times n$ total requirements matrix of water use which is analogous with the Leontief inverse matrix in the traditional model. Consequently, p captures the total (direct plus indirect) amount of water required by each sector in order to support a new set of final demands $\left(\partial w_i^t / \partial w_{yi}^d\right)$.

We can see, however, that Eq. (11) doe not allow us to weigh up the repercussions of change in final demand on total water use of each sector because we have not yet introduced the vector of final demand (y). Therefore, in order to introduce it, we have to link the standard I–O with the model of water use. This will become possible by defining indicators corresponding to the notions of direct, indirect and total water uses as defined above.

2.1.3 Indicators of water use

The link between economic accounts and water resources use can be established by the direct water use coefficient (DWUC) defined as follows:

$$\eta_i = w_i^d \Big/ x_i \tag{12}$$

where w_i^d is the amount of water abstracted directly from the water resource system by sector i (m^3); x_i is the total output of sector i (Dirham).

In matrix terms,

$$\eta = w^d \, \hat{x}^{-1} \tag{13}$$

where $\hat{x}^{-1}$ is the diagonal inverse matrix of production,[1] $\eta = [\eta_i]$ is the row vector of direct water use coefficients.

This indicator captures only the direct link between water resources and the economy. However, as noted above, each economic unit abstracts water also indirectly. Therefore, in order to capture the direct and the indirect effects on water resources of changes in the economy, we define a total water use coefficient (TWUC) which is designed to reflect the direct and the indirect impact on the total quantity of water consumed by the economy as a whole of an increase in its demand.

Let us denote the water use of the economy as a whole by "w". We have:

$$w = w^d \cdot \ell \tag{14}$$

where $w^d = [w_i^d]$ is a row vector of direct water use, and ℓ is a unitary column vector.

Equation (14) can be rewritten as:

$$w = w^d \, \hat{x}^{-1} \, x \tag{15}$$

From which

$$w = \eta \cdot x \tag{16}$$

Combining Eqs. (15) and (5), we obtain:

$$w = \eta \cdot (I - A)^{-1} y \tag{17}$$

where $\mu = [\mu_i] = \eta(I - A)^{-1}$ is a row vector of total water use indicator, whose each element μ_i indicates the amount of water abstracted directly and indirectly by the economy when the demand of sector i varies in one monetary unit.

Since we have defined the direct and the total water use coefficient, we can easily find an indirect water use coefficient (IWUC) δi by subtracting the direct water use coefficient η_i from the total water use coefficient μ_i

$$\delta_i = \mu_i - \eta_i \tag{18}$$

Substituting $\eta(I - A)^{-1}$ for μ and in matrix terms, this is given as

$$\delta = \eta \, (I - A)^{-1} - \eta \tag{19}$$

[1] The hat symbol (^) is used throughout this work to denote a diagonal matrix.

Then

$$\delta = \eta\,[(I - A)^{-1} - I] \tag{20}$$

2.1.4 Introducing the final demand vector in the basic equation of the I–O model of water use

Once the direct water use coefficient has been defined, we can now introduce the vector of final demand in Eq. (11). For this purpose, recall the vector $^{d}_{wy}= [w^{d}_{yi}]$ in which each element is defined as the quantity of water directly used by sector i to meet its demand. From this definition, w^d_y can be expressed as:

$$w^d_y = \hat{\eta} \cdot y \tag{21}$$

where $\hat{\eta}$ is the diagonal matrix of direct water use coefficients and y is the column vector of final demand.

Substituting into Eq. (11),

$$w^t = (I - T)^{-1}\,\hat{\eta} \cdot y \tag{22}$$

Hence, Eq. (19) constitutes the basic equation of the model of water use. It allows us to assess the resulting effects of an exogenous shocks in final demand or/and a changes in the direct water requirement per monetary unit on total water use of each sector and on the total water consumed by the economy as a whole.

2.1.5 Water transactions matrix

Once we have developed the model, we can at this point construct a water transactions matrix $w^{*} = w_{ij}$ which captures the intersectoral water relationships ("purchases" and "sales" of water). From this matrix, we can derive the matrix of technical coefficients water use.

In order to do that, we return to the expression of the indirect water use in Eq. (8), namely: $w_{ij} = w^d_j \cdot \mathrm{t}_{ij}$

From the obvious definition of technical coefficients of water use, t_{ij} can be re-expressed in terms of direct and indirect coefficients of water use as follows:

$$t_{ij} = \delta_i / \eta_j \tag{23}$$

Combining Eqs. (8) and (23) gives

$$w_{ij} = w^d_j \cdot \delta_i / \eta_j \tag{24}$$

Replacing δ_i by this term in Eq. (19) and in matrix notation, we obtain

$$\mathrm{W} = \hat{w}^d\,\frac{\hat{\eta}\,(I - A)^{-1} - \hat{\eta}}{\hat{\eta}} \tag{25}$$

Or

$$\mathrm{W} = \hat{w}^d\,\frac{\hat{\eta}\,[(I - A)^{-1} - I\,]}{\hat{\eta}} \tag{26}$$

And therefore

$$W = \hat{w}^d\,[(I - A)^{-1} - I\,] \tag{27}$$

Once we obtain the water transactions matrix, we may derive from it the technical coefficients of water use matrix as follows:

$$T = W \cdot \hat{w}^{d^{-1}} \tag{28}$$

2.2 Impact analysis

Impact analysis in this paper involves defining a change in final demand scenario and analysing its effect on added value and on total water use at sectoral level so as to discover to what extent the model can serve as a useful tool for integrating water–economic analysis in Morocco. Thus, in order to derive the effect on total water use of a change in final demand, we will use the basic equation of the I–O model of water use (Eq. 22). The effect on added value will be obtained by first defining the vector of added value technical coefficients $\theta = [\theta_i]$ whose element θ_i indicates the direct added value created by each sector per unit of its output:

$$\theta_i = v_i^d \Big/ x_i \tag{29}$$

In matrix form, this is:

$$\theta = v^d\,\hat{x}^{-1} \tag{30}$$

The changes in added value (∂v) caused by a change in final demand (∂y) can be obtained as:

$$\partial v = \theta\,(I - A)^{-1}\,\partial\hat{y} \tag{31}$$

2.3 Economic benefits of water use in IO framework

The intent here is to make possible a quantitative assessment of economic return of water use. For this reason, we proceed in much the same way as was done for water use indicators to define two indicators of economic return of water use, namely the direct economic benefits of water use coefficient (DEBC), ϕ_j, and the total economic benefits of water use coefficient (TEBC), β_j.

The direct economic benefits of water use coefficient ϕ_j are defined as the added value of sector j, v_j^d, per its direct water use w_j^d.

$$\phi_j = v_j^d \Big/ w_j^d \tag{32}$$

In matrix term,

$$\phi = v^d (\hat{w}^d)^{-1} \tag{33}$$

where ϕ is the row vector of the direct economic benefits of water use coefficients, $v^d = [v_j^d]$ is the row vector of direct added value, and $(\hat{w}^d)^{-1} = w_j^d$ is the diagonal inverse matrix of direct water use.

The total economic return of water use coefficient is designed to capture the direct and the indirect effects of change in water use of sector j on the total added value created in the economy as a whole.

Let "V" denote the total added value created in the economy as a whole, and "ℓ" be the unitary column vector. So we have

$$\nu = \nu^d \cdot \ell \tag{34}$$

Equation (34) can be rewritten as:

$$V = \nu^d \left(\hat{w}^d\right)^{-1} \left(w^d\right)' \tag{35}$$

where ($'$) indicates transposition of the row vector w^d.

Using Eq. (35), and since $\phi = \nu^d \left(\hat{w}^d\right)^{-1}$

$$V = \phi \cdot \left(w^d\right)' \tag{36}$$

Combining Eqs. (13) and (36), we obtain:

$$V = \phi \cdot \hat{\eta} \cdot x \tag{37}$$

Substituting $(I - A)^{-1}y$ for x yields

$$V = \phi \cdot \hat{\eta} \cdot (I - A)^{-1} y \tag{38}$$

Substituting for y in Eq. (21), from (38), gives

$$V = \phi \cdot \hat{\eta} \cdot (I - A)^{-1} \hat{w}_y^d \cdot \left(\eta^{-1}\right)' \tag{39}$$

Thus

$$V = \phi \cdot (I - A)^{-1} \hat{w}_y^d \tag{40}$$

$\phi \cdot (I - A)^{-1} = [\beta]$ is the matrix of total economic return of water use indicators whose elements β_j indicate the total economic benefits in terms of added value of one unit water used directly by sector j.

3 Data sources

3.1 Economic data

For the empirical implementation of the model, we use the Supply and the Use matrices in monetary units for the Moroccan economy with data for the year 2002, issued by the High Commission for Planning of Morocco (2009). From these matrices, we have derived the matrix of direct technical coefficients. The Supply and the Use matrices aggregate the macroeconomic system in Morocco into 20 activities (two primary sectors, nine secondary sectors and nine tertiary sectors) in this paper, General public administration and Social security sector and Education, health and social action sector have been aggregated to one sector (sector 17) in order to be consistent with the sectoral water use available data.

3.2 Water withdrawal data

The water data adopted in this study are the sectoral water withdrawal (water use)[2] which refer to the volume of freshwater drawn from sources of water by a given sector (Hoekstra 2009). The data on water use are not available in a disaggregated form in Morocco. The gross water used by different sectors, water use of *Agriculture, hunting and forestry* (sector 1), and the water use of industrial sectors in cubic metres for the year 2002 has been obtained from FAO AQUASTAT database. These water data do not take account of green and grey water. It includes only blue water. The industrial water use does not include the recycled water. With regard to the agricultural water data, we point out that it includes water losses in delivery.

In order to obtain the water use of each sector, as a first step, we have subtracted from the gross water use in cubic metres, the amount used by *Agriculture, hunting and forestry* sectors. In a second step, the resulting value has been multiplied by the proportion of each sector's contribution to the total water use of the remaining sectors in monetary units. These proportions are derived from the vector of sectoral water use in monetary units for the year 2002 obtained from the High Commission for Planning of Morocco.

4 Results and discussion

This section presents an analysis of the results derived from the application of the I–O model of water use. For this purpose, we will begin by presenting an analysis of the direct and indirect water uses at sectoral level. Next, by means of the impact analysis we will simulate the impact on water use of changes in the demand in the top direct and indirect water consuming sectors. Finally, we analyse the direct and the indirect benefits of water use at sectoral level.

4.1 Direct and indirect water use analysis

Applying the I–O model of water use, the direct, the total and the indirect water use coefficients were calculated and are expressed in Table 2 and Fig. 4. Before analysing the obtained indicators, let us throw a glance on the vector w^d of direct water use (10^6 m^3) (the first column of Table 2). As we can see, the top three sectors in terms of direct water use in Morocco are: sector 1 (*Agriculture, hunting and forestry*), sector 18 (*General public administration, Social security, Education, health and social work*), and sector 4 (*Manufacture of food and tobacco products*). Their absolute consumptions make up 86.88, 4.3 and 1.2%, respectively.

The highest direct water use occurs in the primary sectors with an amount of 11,053.828 × 10^6 m^3, which makes up 87% of the total. This high water use is mainly the fact of sector 1 (*Agriculture, hunting and forestry*) with a direct water use of 11,050 × 10^6 m^3. The second direct water consumers are the tertiary sectors. Its total direct water use is about 994.242 × 10^6 m^3, accounting for 8% of all water use. The secondary sector is the lowest water consumer sector with an amount of direct water use of 668.932 × 10^6 m^3. Its contribution to the overall water use is about 5% only.

Compared with the primary sectors, the absolute direct water use of the tertiary sectors and the secondary sectors is very low. However, the primary sectors make the lowest

[2] Throughout this paper the term "water use" refers to withdrawals of water.

Table 2 Sectoral direct water use (10^6 m^3) and water use coefficients ($m^3/10^4$ Dirham)

Types of sectors	Sectors	w^d	η	μ	δ
Primary sectors	1. Agriculture, hunting and forestry	11,050	1173.35	1421.18	247.83
	2. Fishing and aquaculture	3.828	4.22	20.90	16.68
	Sub-total	11,053.828	1070.656	–	–
Secondary sectors	3. Mining and quarrying	4.785	1.66	9.20	7.54
	4. Manufacture of food and tobacco products	150.237	15.25	651.79	636.53
	5. Manufacture of textiles, textile products, leather and footwear	96.649	14.06	54.13	40.07
	6. Manufacture of chemicals and chemical products	130.141	35.78	97.77	61.99
	7. Mechanical, metallurgical and electrical industries	54.545	6.05	13.81	7.76
	8. Other manufacturing industries	1.000	0.00	60.88	50.88
	9. Manufacture of coke, refined petroleum products and fuel	37.320	12.83	17.28	4.45
	10. Electricity, gas and water supply	130.141	71.48	82.01	10.53
	11. Construction	64.114	10.65	33.13	22.47
	Sub-total	668.932	14.014	–	–
Tertiary sectors	12. Wholesale and retail trade	133.012	18.89	32.87	13.98
	13. Hotels and restaurants	103.348	52.68	250.95	198.27
	14. Transports	87.080	19.75	27.97	8.22
	15. Post and telecommunication	19.138	9.72	20.03	10.31
	16. Financial intermediation	1.914	0.58	8.42	7.84
	17. Real estate, renting and business activities	51.674	9.71	12.66	2.95
	18. General public administration, Social security, Education, health and social work	546.402	56.61	80.90	24.28
	19. Other community, social and personal service activities	51.674	60.63	79.26	18.63
	Sub-total	994.242	28.809	–	–
Total		12,717.002	137.471	–	–

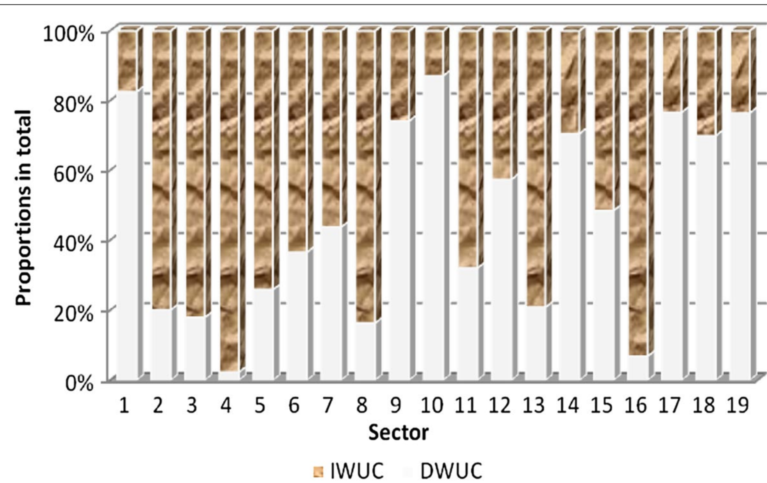

Fig. 4 Proportion of DWUC and IWUC contributions to total water use coefficient of each sector

contribution to the total output and account for only 11.16%, which can be explained by the fact that there is a strong variation of water use efficiency across the three sector types. This statement can be confirmed by analysing the direct water use coefficient (η)

presented in the second column of Table 2. The analysis of these indicators shows three constatations. Firstly, the primary sectors are high direct water-intensive sectors with a DWUC of 1070.65, followed by the tertiary and then the secondary sectors with a low DWUC of 28.809 and 14.014, respectively. Secondly, a comparison of the absolute direct use and the DWUC shows that certain sectors use directly a relatively high quantity of water. However, when we take into account their DWUC, we notice that their consumptions per currency unit produced are relatively low.

This is the case of *Agriculture, hunting and forestry* sector which consumes 150.237 hm^3 of water directly, but its consumption per currency unit produced does not exceed 1% compared to sector 13 (*Hotels and restaurants*) and sector 10 (*Electricity, gas and water supply*) whose absolute direct consumption is lower than that of sector 13 (103.348 hm^3 and 130.141 hm^3, respectively), but whose consumptions per unit produced are about 3 and 4%, respectively. This change in sectors classification once the DWUC is introduced can be explained by the sectoral variation in water use efficiency. Economic sectors with low DWUC are generally a high level of water use efficiency and vice versa. *Agriculture, hunting and forestry* is a typical example of a strategic sector in the Moroccan economy with a high DWUC and therefore with a low water use efficiency. The opposite situation is that of a large set of the secondary and tertiary sectors.

So far the analysis has considered only the direct water use. Now, we will introduce the indirect water use of each sector. This type of water use constitutes the hidden part of the equation that we will try to discover by analysing the total and the indirect water use coefficients. The third and the last columns of Table 2 give the vectors of the total water use coefficients (TWUC) and the indirect water use coefficients (IWUC), respectively.

It shows that the sector 1 (*Agriculture, hunting and forestry*) has high TWUC. Moreover, certain sectors such as sector 3 (Manufacture of chemicals and chemical products), sector 4 (*Manufacture of food and tobacco products*), sector 8 (*Other manufacturing industries*), and sector 13 (*Hotels and restaurants*) show a high TWUC despite its low DWUC.

This situation is explained by the fact that these sectors consume a high amount of water indirectly. The gap between the direct and the total water uses is reflected by the IWUC. It appears from the analysis of this indicator that the indirect water use of the above-mentioned sectors accounts for more than 80% of their corresponding total water use (Fig. 4). The large part of indirect water use of these sectors in their total water use is, generally, due to the fact that this sectors are highly linked to the remaining sectors which are the purchasers of their outputs, and for which they are the providers of the great range of their inputs.

Therefore, if we limit ourselves to analyse only the direct water use of each sector, we will consider the economic sectors with relatively low DWUC—such as *Fishing and aquaculture* (sector 2), *Manufacture of food and tobacco products* (sector 4), *hotels and restaurants* (sector 13), *other manufacturing industries* (8)—as sectors which do not give rise to any risk that can threaten water resources in Morocco, and therefore, do not deserve the attention of a sustainable water resources management policy. We will be led in fact to formulate erroneous conclusions because these sectors consomme indirectly a sufficiently important amount of water to threaten the sustainability of water supply in Morocco.

Table 3 Effects of an increase by 20% of the final demand in manufacture of food and tobacco products

Sectors	Scenario 1		Scenario 2	
	Water use[a]	Added value[b]	Water use[a]	Added value[b]
1. Agriculture, hunting and forestry	9.81	5453.41	8.53	4739.46
2. Fishing and aquaculture	0.11	6.47	6.74	409.1
3. Mining and quarrying	0.47	39.69	1.27	108.46
4. Manufacture of food and tobacco products,	0.29	43.02	18.13	2736.85
5. Manufacture of textiles, textile products, leather and footwear	0.03	5.16	0.08	12.39
6. Manufacture of chemicals and chemical products	1	61.04	1.59	97.2
7. Mechanical, metallurgical and electrical industries	0.09	13.65	0.91	133.01
8. Other manufacturing industries	0	19.66	0	206.28
9. Manufacture of coke, refined petroleum products and fuel	0.59	7.63	1.8	23.28
10. Electricity, gas and water supply	0.62	76.23	1.64	200.45
11. Construction	0	0.38	0.01	1.08
12. Wholesale and retail trade	0.01	5.73	0.01	5.37
13. Hotels and restaurants	0.01	1.23	0.09	8.87
14. Transports	0.11	19.02	0.38	64.87
15. Post and telecommunication	0.02	2.46	0.14	16.72
16. Financial intermediation	0.11	24.92	0.9	200.37
17. Real estate, renting and business activities	0.06	25.04	0.52	235.29
18. General public administration, Social security, Education, health and social work	0.02	24.01	0.01	22.57
19. Other community, social and personal service activities	0.04	2.56	0.5	31.41
Total	9	5831.31	8	9253

[a] Changes in water use are given as a percentage of the actual water use

[b] Increases in added value are given in absolute value (Billion Dirham)

4.2 Impact analysis

In the field of economic planning, the decision makers tend to determine the goals of their socio-economic policies in a one-dimensional manner which generates unexpected consequences on the national water resources. However, in a sustainable development prospective, it is not enough to be based only on the evaluation of the economic repercussions of the economic policies, but it is necessary to balance between the economic results and the environmental consequences of each policy scenario. Thus, for a sustainable use of water resources, it is important to know to what extent the economic guidelines influence water use of the various economic sectors.

The aim of this section is to show to what extent neglecting the intersectoral water relationships could threaten the water resource sustainability in Morocco. For this purpose, we will use the I–O model of water use to analyse the effects of two policy scenarios on total water use and added value at sectoral level. The policy scenarios simulated analyse the impact of an increase of 20% in the final demand of the top water consuming sector in terms of direct water use and the top water consuming sector in terms of indirect water use.

Thus, the first scenario is 20% increase of the final demand in sector 1 (Agriculture, hunting and forestry). The second scenario is 20% increase of the final demand in sector 4 (Manufacture of food and tobacco products). The simulation results are given in Table 3. From the first column showing the effects on added value of the first scenario, we can observe that an increases by 20% of the final demand in Agriculture, hunting and forestry sector generates an additional added value of 5.831 Billion Dirham. It also turns out that this increase in final demand slightly affects the other economic sectors; its effects are mainly direct. In fact, this resulting increase in the total added value is mainly created directly by sector 1 (Agriculture, hunting and forestry), in so far as its additional added value created in response to the shock in final demand is approximately 5453.41 Billion Dirham.

In terms of water use, the simulation results show an increase by 9% of the amount of water consumed by the economy as a whole, which is mainly due to the increase of water use in *Agriculture, hunting and forestry sector* by 9.81%. This means that when a 20% increase of the final demand in sector 1 takes place, Morocco will need an additional water supply of 1094 hm^3 in order to satisfy the water demand of the production structure, including 1090 hm^3 will be absorbed by sector 1.

The economic benefit in terms of added value reported to the environmental cost in terms of water use gives an additional water use of 187563 m^3 for an additional unit of added value following an increase by 20% of the final demand in sector 1.

According to this indicator, it can be concluded that the environmental cost in terms of water use of an increase of the production in sector 1 outweighs the economic benefit in terms of added value.

The simulation results of the second scenario are summarized in the last two columns of Table 3. They show that an increase by 20% of the final demand in sector 2 generates an important additional added value of 9253 Billion Dirham. This increase of the final demand in sector 4 had a significant impact on several other sectors. In fact, the additional added value created in the sector under study accounts for only 29.5% of the total generated added value. The remaining 70.5% is generated by the other economic sectors. This wide range of sectorial variations reveal a high integration of *Manufacture of food and tobacco products* sector in the national economy; in other words, this sector has a high "drag effect" on the total economic production.

With regard to water use, the second scenario leads to an increase of the total water use by 8%. An interesting result that we should point out is that in the same way that added value, the sector 4 had a high "drag effect" on the water use of several other sectors. The total water use of sector 4 has risen by 18.13%, which accounts for only 3% of the cumulative effect on water use caused by the final demand scenario. The remaining 97% is due to the increase of water demand in other sectors. The most sensitive sectors to this final demand scenario are: sector 1 (*Agriculture, hunting and forestry*), sector 2 (*Fishing and aquaculture*), sector 9 (*Manufacture of coke, refined petroleum products and nuclear fuel*), sector 10 (*Electricity, gas and water supply*), and sector 6 (*Manufacture of chemicals and chemical products*) (in this other), with an increase in their corresponding water use of 8.53, 6.74, 1.8, 1.64 and 1.59%, respectively. Furthermore, a comparison of the results provided by the two final demand scenarios reveals a relevant fact. Although the water use of sector 4 (*Manufacture of food and tobacco products*) accounts for only 1.2% of the total water use, compared with 87% in sector 1 (*Agriculture, hunting and forestry*), an increase of 20% in sector 1 final demand generates an increase in the total water use which is very close to the increase generated by a 20% rise of the final demand in sector 4. This is due to the fact that sector 2 consumes a large amount of water indirectly. Indeed, its demand exerts a high influence on the production of the rest of economic sectors. This in turn leads to an increase in their water use. The meaning of these results is as follows. If we take into account only the direct water use of *Manufacture of food and tobacco products* sector in the processes of defining a policy aiming at improving its production by 20%, we will believe only in an increase of 27.5 hm^3 in the total amount of water consumed by the economy as a whole. In reality, however, this production increase requires an additional amount of water for about 982.40 hm^3.

Given these results, it is possible to confirm that the biggest indirect water consumers sectors, detected by means of the previous analysis, exert a great effect on the national water resources through the intersectoral water relationships despite their low direct water uses. Moroccan policy makers should be aware of these intersectoral water relationships and paying a particular attention to the greatest indirect water consumer sectors.

4.3 Sectoral economic benefits of water use

The fourth principle of Dublin statement states that "Water has an economic value in all its competing uses and should be recognized as an economic good." (The International Conference on Water and the Environment 1992).

The main motif behind this recognition consists of the willingness to implement politically the economic principle of efficiency of water use and allocation. However, following this objective highlights the need to assess the sectoral economic returns of water use as an indicator for policies of water allocation among different sectors because efficient use

Table 4 Indicator of direct economic benefits of water use (φ_j), indicator of total economic benefits of water use (β_j) and economic benefits of water use multiplier (m)

Sectors	φ_j	β_j	m
1. Agriculture, hunting and forestry	5	231.05	46.21
2. Fishing and aquaculture	1576.91	3678.29	2.33
3. Mining and quarrying	1694.97	2092.32	1.23
4. Manufacture of food and tobacco products	99.75	1135.90	11.39
5. Manufacture of textiles, textile products, leather and footwear	157.63	947.99	6.01
6. Manufacture of chemicals and chemical products	44.95	1153.70	25.67
7. Mechanical, metallurgical and electrical industries	257.57	964.16	3.74
8. Other manufacturing industries	12,202.8	15,498.50	1.27
9. Manufacture of coke, refined and petroleum products	32.35	1027.23	31.75
10. Electricity, gas and water supply	85.69	808.03	9.43
11. Construction	321.20	4790.41	14.91
12. Wholesale and retail trade	378.65	1973.82	5.21
13. Hotels and restaurants	86.57	795.99	9.19
14. Transports	192.11	2389.01	12.44
15. Post and telecommunication	610.60	1469.16	2.41
16. Financial intermediation	10,782.6	14,194.70	1.32
17. Real estate, renting and business activities	804.70	1392.38	1.73
18. Public admin, Education, health and social work	137.36	1417.54	10.32
19. Other community, social and personal service activities	118.65	499.40	4.21

and allocation of water require consideration of the value economic value of water used by competing economic sectors.

In this section, we have used the added value per unit of water used as an indicator of the direct economic benefits of water used by each economic sector, from which an indicator of total economic benefits of water use has been derived (Table 4).

The DEBCs listed in the first column of Table 4, showed that besides the fact that *Agriculture, hunting and forestry* (sector 1) is the greatest water consumer sector, its economic benefits of water use are lowest. The DEBC of sector 1 is only of 5 Dirham/m^3. With the exception of the *Manufacture of chemicals and chemical products* (with a DEBC of 44.95 Dirham/m^3), *Manufacture of coke, refined and petroleum products* (with a DEBC of 32.35 Dirham/m^3), *hotels and restaurants* (with a DEBC of 86.57 Dirham/m^3) *and Electricity, gas and water supply* sectors (with a DEBC of 85.69 Dirham/m^3), all the remaining sectors had relatively high economic benefits of water use coefficients.

Furthermore, from the second and the third columns of Table 4, which list the total economic benefits of water use coefficient and the economic benefits of water use multiplier (EBWMs), respectively, we can made two interesting observations. On the one hand, we can observe that the *Agriculture, hunting and forestry* sector had the highest EBWC despite having the lowest DEBC. Its EBWM is of 46.2, which means that for each 1 m^3 of water consumed directly, it generates indirectly 46.21 Dirham of added value. On the other hand and in an inverse way, the economic sectors that have the largest DEBCs show low EBWMs. This situation can be explained as follows: First*, the Agriculture, hunting and forestry sector* is weakly integrated in the economy, and therefore, it generates a high added value indirectly. As shown by means of the impact analysis conducted in the previous section, the Agriculture, hunting and forestry sector has an important indirect impact on the added value generated by *Manufacture of chemicals and chemical products (sector 6), Mining and quarrying (sector 3), Manufacture of food and tobacco products (sector 4),* and *Electricity, gas and water supply (sector 10).* It must also be pointed out that the common feature of these sectors is that they have low DEBCs. Therefore, the high EBWM observed in sector 1 can be attributed to its high added value generated indirectly and to the high economic benefits of water used in those sectors on which it has a greater drag effect.

The same happens with those sectors whose EBWMs are very low, but in an inverse way. In fact, these sectors are less integrated in the economy or/and linked to other sector with low DEBCs.[3] An exceptional case, however, is the *Manufacture of food and tobacco products* sector whose EBWM is more than four times less than that in *Agriculture, hunting and forestry* sector although the first is more integrated in the economy then the later.[4] Two arguments can be advanced in order to explain this situation. First, the DEBC of sector 4 is far higher than that of sector 1. Second, if we take a closer look at sector 4 and at its intersectoral relationships, we will find that this sector is highly linked to sector 1 as purchaser of water from it. Through these results, two important

[3] For a classification of productive sectors of the Moroccan economy performed by using the unweighted Rassmussen approach, see, for instance, Tounsi, et al. (2012).

[4] Tounsi et al. (2012), found that the manufacture of food products, beverages and tobacco products sector (with a backward and forward linkage indices of 1.389 and 1.091, respectively) is more integrated than the agriculture, hunting and forestry sector (with a backward and forward linkage indices of 0.996 and 1.449, respectively).

facts arise that we should point out. Firstly, most primary sectors and section that the large share of the added value created indirectly by sector 4 is owned to sector 1. Since sector 1 consumes considerable water resource and its DEBC is tertiary sectors display high economic benefits of water use, except the sectors with relatively low DEBC above mentioned, and the fishery and aquaculture sector. Therefore, they are the sectors that should be encouraged while taking account, however, of their indirect water use. Secondly, *Agriculture, hunting and forestry* sector exhibits a low added value per unit of water used. Thus, the greater water saving could be made in this sector.

5 Conclusions

In this paper, we have presented a methodology which allows us to conduct integrating water–economic analysis. The methodology has consisted of redefining the classical I–O model in order to integrate the economic information provided by the I–O table with hydrological information on direct sectoral water use. The model has been applied to Moroccan economy in order to analyse the relationships established between the economic structure and water resource and the intersectoral water relationships.

One of the first conclusions that we can formulate from the analysis carried out in this paper is that the model permits a consistent analysis of the relationships between the production potential of each sector and water use and, therefore, it constitutes a useful tool for integrating water–economic analysis and policy scenario modelling.

Further, from the quantitative results derived from the application of the model to Moroccan economy, we have been able to draw two relevant conclusions that we will briefly restate. First, the analysis of direct and indirect water uses at sectoral level reveals that, on the one hand, A*griculture, hunting and forestry* sector exhibits high direct water use. On the other hand, secondary and tertiary sectors display low direct use and high indirect water use. Typical examples of sectors with high indirect water use are sector 4 (*Manufacture of food and tobacco products*) and sector 13 (*Hotels and restaurants*). In addition, we have demonstrated by means of the impact analysis that the economic sectors whose indirect water use coefficients is high have a significant influence on water resources by means of their "drag effect" on the water use of other sectors. So, we have concluded that it is very important to take into account in the processes of policy definition not only the direct water use but also the indirect water use because each change introduced into the production of a sector with high indirect water use will be inevitably reflected on water use of the other sectors and will have, undoubtedly, harmful consequence on the water resources in Morocco.

Second, by means of the economic benefits of water use analysis at sectoral level, we have found that the industrial and service sectors display relatively large economic benefits of water use than the agriculture. This leads us to conclude, on the one hand, that Morocco has an economic structure based on sectors that consume a large amount of water, both directly and indirectly. This structure is based mainly on A*griculture, hunting and forestry* (sector 1), *Manufacture of food and tobacco products* (sector 4) and h*otels and restaurants* (sector 8). On the other hand, the greater water saving in Morocco could be made in the A*griculture, hunting and forestry* sector. Given Morocco's limited water resources, if we want to face a sustainable economic development, the agricultural sector should modify the use of water to a great extent by adopting alternative water-saving technology. However, we cannot claim that agricultural water use should give way to other uses relying solely on the added value per unit of water used because. In fact, considered in isolation, this indicator highly inflates the estimated benefit of transferring water from agricultural sectors (with low added value per unit of water used) to industrial sectors (displaying a high added value per unit of water used) (Young 2005). For this reason, affirming such conclusion requires a detailed and comprehensive study that encompasses economic, social and environmental aspects.

Abbreviation
MEMWE: the Ministry of Energy, Mines, Water and Environment.

Authors' contributions
The authors wish to declare that the article was written in collaboration and each author contributed to 33.33% of the article. All authors read and approved the final manuscript.

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