Water saving potential in the RBD of Thessaly

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Abstract: The prolonged issues regarding the quantitative and qualitative characteristics of the water resources in the River Basin District of Thessaly (TRBD) have resulted in the environmental degradation and the reduction of the availability of water. Agriculture is the major water user, constituting up to 95% of total water demand. The pressures anticipated from the ongoing climate change are expected to cause further degradation, given the present status of the water resources. This research attempts to examine and quantify the water saving potential of TRBD, mainly for the agriculture sector, following the recommendations of the European legislation, the principles of sustainable development and environmental protection. Water saving tools are documented in several countries, including technical measures, such as drip irrigation systems and the modernization of the transfer networks, as well as deficit and scheduled irrigation practices and water reuse. These measures and practices are tested for their potential effect on water demand in TRBD, in addition to changing a portion of cotton cultivation areas to olive groves. To this end, the volume of irrigation demand is estimated at $2088\times10^6\ m^3$, while total water demand stands for $2204\times10^6\ m^3$. Afterwards the study proceeds to the evaluation of the water saving potential both independently and combined. The potential of water savings in TRBD is proven high, 14.3% of total water demand for technical measures, 10.7% if deficit irrigation is applied to specific crops, while it may reach 28.8% in case the measures are combined.

Keywords: WFD, RBD of Thessaly, Water saving, Irrigation, Water resources management.

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1 Introduction

TRBD is in Central Greece and is considered the major agricultural region of Greece. Numerous water bodies, both surface and underground, have been recorded by the RBDMPs facing quantitative and quality degradation [1]. The above are thought to be caused due to poor management and overexploitation of water resources [2]. Moreover, the droughts of previous decades have revealed the significant water scarcity TRBD is facing [3]. TRBD is water stressed, with an annual average of Water Exploitation Index plus estimated about 30.8% [4].

Considering the expected implications of climate change in southern Europe, water scarcity as well as the occurrence and intensity of droughts, is expected to be intensified, resulting in more pressures to the water resources. As far as the agricultural sector, it is expected that climate change will cause an increase to crops' irrigation water requirements. This is attributed to shortage of rainfall as also to increase of temperature, resulting in the increase of evapotranspiration Water efficient technologies are considered a significant tool towards the adaptation to climate change [5].

Following the notion of both the Water Framework Directive 2000/60/EC (WFD) and of the Brundtland report, the River Basin District (RBD) is considered the most suiting unit towards achieving sustainable development and water resources management [6]. The identification of , both point and diffused pressures is followed by the evaluation of their impacts on water resources of the RBD. The impact evaluation is followed by the formation a River Basin District Management Plan (RBDMP), which includes a specific Programme of Measures (PoMs), towards achieving high quality (chemical/ecological) and quantitative status for the water bodies. Sustainability is therefore a term , as also a target for water resources management.

Achieving high levels of water use efficiency is considered essential [7]. Besides reducing pressures to water resources, high efficiencies have beneficial effects for the adopting users. This can be achieved through water saving measures and practices, reducing water demand and proper cost recovery strategies. Since, the agricultural sector is the major water user in TRBD, [2], emphasis is given at this study to water savings in irrigation. A change of water transferring and application technologies, as well as the adoption of water saving practices, has displayed in many cases significant beneficial effects on agricultural water consumption.

The modernization of water networks, primarily with the lining and automatization of open channels rationalizes water transfers [8]. The construction of pressurised pipes provides the most efficient way of transferring water [9]. In the RBD of Ebro, Spain, two national modernization projects, including the shift to pressurised pipes as well as the adoption of drip irrigation, aim at reducing irrigation water demand about 15%, while increasing the productivity of both water and land [10]. In TRBD, even urban pressurized networks display high losses, at 29.9% [11]. This implies the necessity of proper maintenance of existing piped networks [12].

The application of the irrigation water is generally done by three methods: (a) surface/gravity, (b) sprinkler and (c) drip with efficiencies of 60%, 75% and 90% respectively [13]. The modernization of the application methods, in combination with pressurised pipes, can reduce irrigation demand up to 50% [9].

The use of drip irrigation systems has been documented to result in water savings up to 60%, reduction of fertilizers usage, and so of quantitative and quality pressures to water bodies [14]. Additionally, increase of water productivity is documented, along with raise of the value of produced crops with reduced water consumption [15]. Moreover, the reduction of crops infections is attributed to the usage of drip irrigation systems [16].

Site specific case study has reported that drip irrigation of sugar beets in South Italy gives higher production compared to sprinkler irrigation. Specifically, for drip irrigation at 50% of the crops irrigation needs, sucrose production is 10.6 t/ha, while sprinkler irrigation at 100% of the crops irrigation needs results in 9.3 t/ha of sucrose production [17]. In Anatolia, Turkey, irrigation of cotton with drip systems gives the highest production and water productivity, regarding the three methods of irrigation [18]. In Brazil, tomato cultivation using drip irrigation systems gave also higher water productivity compared to sprinkler, while reducing water demand by 31% [19].

Setbacks of adopting drip irrigation are also examined. In areas of low precipitation, about 200 mm/ year, there has been observed increase of soil salinity [16]. In Spain, an increase of energy consumption, irrigated areas and crops have also been recorded [20]. The above are not considered significant enough regarding TRBD to outweigh the water saving potential of shifting to drip irrigation. Two more aspects of the adoption of the aforementioned new technologies are clarified by Berbel et al. [14]. These are the legal framework regarding water usage, which should include an upper limit to water abstractions and the need of an intensive attempt to provide farmers the proper advice.

Scheduled irrigation is considered the calculation of the optimum water quantity, duration and time of irrigating a crop [13]. In Zaragoza, Spain, proper irrigation scheduling has increased water use efficiency by 16%, saving 17 $m^3/10^3\ m^2$ without altering crop yields [21]. Additionally, developments of software and low-cost moisture sensors are considered an extra tool for proper irrigation scheduling. In California, it is estimated that water demand can be reduced by 10% only via irrigation scheduling [15]. Many crops, even with high sensitivity to water shortage, can withstand deficit irrigation, if the latter is done properly, employing irrigation scheduling [22].

Deficit irrigation is considered as the exposure of crops to specific levels of water stress for their growth season, or a specific growing period, without causing a significant reduction of their yields [23]. In California, it is estimated that deficit irrigation under proper scheduling, may reduce water demand by 3.14%, while increasing the quality of the products [15]. Also, considering the competitive uses of freshwater, an increase of a farmer's income may be attributed to deficit irrigation [24]. It should be noted that major crops in TRBD, such as cotton and olive trees are considered resistant to water stress [13].

Water reuse is considered to reduce outflows to possibly sensitive receiving water bodies [25]. It is also accredited of saving freshwater usage and fertilizers, as far as agriculture is concerned [25, 26]. Water reuse may also be applied in recharging aquifers with quantitative or salt-water intrusion problems [27]. Numerous potential uses are referenced, such as urban, industrial, recreational etc. Regarding agricultural water reuse for irrigation purposes, many countries are reusing treated wastewater. Spain, Italy, Cyprus and Israel are some examples where treated wastewater is used for irrigation purposes under financial sustainability while saving abstractions of freshwater.

Water reuse in agriculture may increase the quantity and/or the quality of products [28] along with reducing the use of fertilizers [29]. Furthermore, it raises the fertility of poor-quality soils [30]. A concern regarding water reuse may be considered the increase of soil salinity in many cases. Recent studies have also focused on the presence and potential danger to human health of Emerging Organic Contaminants (EOCs) and Antibiotic Resistant Genes (ARGs) [31, 32]. Drip irrigation and irrigating non eaten raw crops are some of the key solutions of the above research.

2 Study area – Data used

2.1 Study area

TRBD, shown in Fig. 1 (Appendix), is almost identical to the prefecture of Thessaly, covering an area of about 13000 km^2. It is comprised of two sub-basins, the Pinios river basin (11000 km^2) and the river basin of Almiros–Pilion (2000 km^2) [1].

The climate conditions are mainly grouped in three categories; the eastern part has a Mediterranean climate, the central plain a continental and the western a mountainous with high rain and snow accumulations. The average annual rainfall and temperature of TRBD are estimated at 678 mm and 16-17 °C, respectively [1].

The central plain, the largest plain of Greece, is crossed by the Pinios river, which flows from west to east. Other major tributaries, such as Enipeas, Sofaditis and Titarisios contribute to Pinios, whose total length counts 213 km while its annual runoff is estimated about 3165×10^6 m^3. The central plain also hosts aquifers of significant capacity, created from Quaternary deposits and Neogene sediments [1].

Human activity is concentrated around five major cities, Larisa, Volos, Karditsa, Trikala and Tirnavos. Agricultural land use accounts for 45% of total land in the sub-basin of Pinios and 34% in the Almiros - Pilion sub-basin [1].

The implementation of the WFD resulted in the recording of 82 surface water bodies, of which 72 are river, 3 heavily modified (2 lakes and 1 river-lake) and 7 coastal water bodies [1]. 47/72 (65%) of the river water bodies are subjected to high seasonal (summer) quantitative pressure, having abstractions over the 50% of the average summer runoff. Annual quantitative pressure is found high in 8/72 (11%), while another 8 river water bodies face moderate pressures. Out of the 72 river water bodies, none has high and only 30/72 (42%) have good ecological status. Chemical status is found good in 56/72 (78%) river water bodies. Abstractions from surface water bodies are mentioned in the RBDMP as 300×10^6 m^3.

TRBD hosts water storage infrastructure of about 320×10^6 m^3 [33]. Additionally, the recreation of Lake Karla is expected to store 60×10^6 m^3 of water to be abstracted.

Groundwater is considered the main source of freshwater in TRBD. Abstractions are estimated about 923×10^6 m^3, where renewable resources are 1891×10^6 m^3 for the groundwater bodies. Out of the 33 recorded bodies of groundwater, 10 (30%) are reported as in poor quantitative status. Moreover, due to long-term overexploitation, a reduction of non-renewable water quantities is observed around 3000×10^6 m^3 [1]. Water level is recorded is some cases to have fallen from 15 up to 100m below the levels of past decades [34]. Furthermore, many incidents of subsidence are attributed to over-abstractions of aquifers [35]. Regarding their chemical status, 4 (12%) groundwater bodies are reported as in poor state.

The main driver of quantitative and quality pressures is the agricultural sector [1]. Numerous unregistered private wells contribute to the degradation of water resources, while local authorities do not promote the efficient use of water resources [36].

TRBD hosts 15 Wastewater Treatment Plants (WWTPs). Among them, Larisa, Volos, Trikala and Karditsa have an annual average inflow of 35.35×10^6 m^3, the biggest share of the total 40.38×10^6 m^3. All of them have secondary treatment, while the vast majority does also tertiary treatment [37]. In TRBD, a survey has given positive feedback regarding farmers' willingness to pay for treated wastewater [38], while in the nearby basin of Nestos, 64.2% of farmers were found willing to pay for treated wastewater at a price lower than freshwater [39].

2.2 Data used

The available data about crop cultivation areas and production have been obtained from the production records in the prefecture of Thessaly [40]. Taking under consideration the insignificant spatial difference between the prefecture and TRBD, as also the fact that the main agriculture activity occurs in the central plain, part of both, using this data will cause no significant variations over the calculation of irrigation demand.

Wheat and other cereals (except maize) are found to be the most widely cultivated crops in an area of 1525 km^2. Cotton follows with a cultivated area of 842 km^2, while olive groves cover an area of 286 km^2. Trees, other than olive groves are also cultivated in an area of 233 km^2. Significant cultivation of clovers (298 km^2) and maize (261 km^2) is also observed. The sum of cultivated areas equals 3906 km^2 [40]. The distribution of the above crops' cultivation areas is displayed in Figure 2.

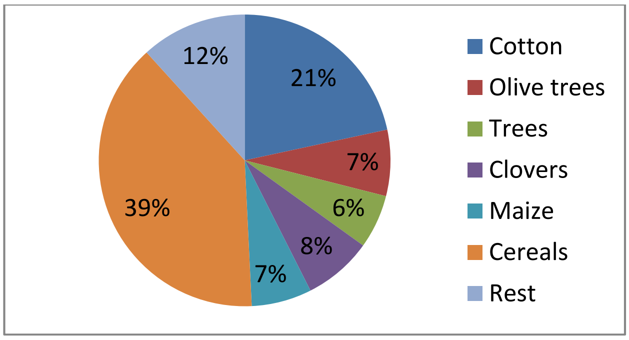

Figure 2, Major crops cultivation areas in TRBD

Irrigation water requirements data have been calculated by Vagenas [41] for the regions of Magnesia and Larisa, parts of TRBD. For some widely cultivated crops like cotton, sugar beets, wheat and maize, irrigation needs are calculated specifically, while for others, the irrigation needs are calculated by category of crops (ex. Trees, horticulture, etc.). In Table 1 examples of the above data are displayed. Olive trees in Greece are suggested to be irrigated with 290 mm [42], instead of 496 mm mentioned by Vagenas [41] for trees.

Table 1, Indicative crops cultivated area and irrigation needs

Crop	Cultivated area (km^2)	Irrigation needs (mm)
Cotton	841.73	499.1
Sugar beets	10.86	636.7
Maize	260.87	529.9
Clover	298.01	612.9
Vines	51.61	301.4
Horticulture	78.51	457.2

The only data source regarding the freshwater abstractions was the 1st Revision RBDMP of Thessaly [1]. Concerning the surface water bodies, information was available for their annual runoff, abstracted water volume and the intensity of abstraction. In Table 2, examples of surface water bodies consisting river sections, along with their annual abstractions of water, are displayed. For the groundwater bodies the volumes of naturally fed and abstracted water were documented.

Table 2, Examples of surface water bodies and their annual freshwater abstractions, [1]

Surface water body	Annual water abstractions ($\times 10^6\ m^3$)
Pinios R.1	687.73
Pinios R.8	468.18
Enipeas R.1	421.98
Enipeas R.2	55.59
Sofaditis R.1	201.06
Sofaditis R.2	93.46

In TRBD about 78.3% of cultivation areas have their irrigation water obtained by private wells, while the rest are supplied via public networks [43]. Michas and Gkiokas [43] have documented current distribution of water transferring methods for public irrigation schemes in three out of four prefectures of TRBD, as shown in Table 3. It is notable that only in prefecture of Trikala irrigation water transferring is performed mainly with pressurised networks. Nevertheless, efficiency of pressurised networks is found about 75-80%, lower than the optimal operative value of 90% [9]. Moreover, efficiency of open channels is ranging from 52 to 60%.

Table 3, Public networks water transferring technologies [43]

Prefecture / Type	Larisa	Trikala	Karditsa
Pressurised, underground pipes	11%	15%	5%
Pressurised, surface pipes	30%	82%	31%
Open channels, lined	5%	-	35%
Open channels, not lined	54%	3%	32%

For the field application technologies regarding the public networks, there is data for the 53 irrigation management authorities of TRBD [44]. The volumes of irrigation requirements and on-field irrigation demand, which includes the application losses, are available. Application losses are considered in the Supporting document #8 [44], as 80.75% for sprinkler irrigation systems and as 85% for drip irrigation systems. Application losses for the areas irrigated from the authorities range from 16.63% to 21.39%, averaging 19.09% of irrigation needs. No data is available as far as private irrigation is concerned.

Regarding water uses except agricultural, water demand data is obtained from the 1st Revision of the RBDMP of Thessaly [1]. Urban water demand stands for $94\times 10^6\ m^3$, industrial water demand for $9\times 10^6\ m^3$ and water demand for live stock for $13\times 10^6\ m^3$.

3 Methodology

3.1 Water demand

The current status of water demand is mapped, especially for the agriculture sector. Data about crop cultivation areas and irrigation needs are combined with the documented technologies that are used to transfer and apply the irrigation water, in order to estimate the current irrigation demand for TRBD. Irrigation demand is calculated when water transfer and application losses are included in irrigation needs. This is done separately for irrigated land by public networks (publicly irrigated) and private wells (privately irrigated), as described in equations (1), (2).

$$ID = ID_{Pr} + ID_{PN} \quad (1)$$

$$ID_i = \frac{IN_i}{(AE_i \times TE_i)} \quad (2)$$

Where:
ID: Total irrigation water demand of TRBD
ID_i: Irrigation demand
$IN_i := \alpha_i \times IN$, Irrigation needs,
α: the percentage of area
AE_i: Application efficiency
TE_i: Transfer efficiency
Where Pr stands for privately irrigated areas and PN stands for publicly irrigated areas

For the calculation of total irrigation needs, IN, the sum of each crop's water requirements is calculated. Due to the gaps of knowledge for some crops' irrigation needs and the expected implications of climate change, the calculated value is amplified by 10%. The amplified value stands for TRBD's total irrigation needs. This is displayed in equation (3).

$$IN = 1.1 \times \sum_{j=1}^{n} \left(CA_j \times In_j\right) \quad (3)$$

Where:
IN: Total irrigation needs of TRBD
CA_j: Cultivated areas
In_i: Irrigation needs

For the publicly irrigated areas, transfer and application efficiencies are calculated. Taking under account: (a) open, not lined channels have an efficiency of 60%, open, lined channels 70% and pressurised pipes 90%, when properly operated [9] and (b) the size of each prefecture, an averaged TE_{PN} is calculated. This averaged efficiency is considered mutual also for the prefecture of Magnesia. Application efficiency derives from the average ratio of application losses documented from the irrigation management authorities and the considered efficiencies. Calculating the present distribution of application technologies and applying their efficiencies, as mentioned by Dworak [9]; for drip and sprinkler irrigation systems, 90% and 75% respectively, results in the value of AE_{PN}.

As far as privately irrigated areas are concerned, it is assumed: (a) there are no transfer losses ($TE_{Pr} = 1$) and (b) there is a slight more efficient usage of application methods than public networks.

Total water demand is the sum of total irrigation water demand, urban water demand, industrial water demand and livestock water demand.

3.2 Freshwater abstractions

The lack of recording gross water abstractions from surface water bodies drives the research to an estimation of the afore mentioned quantity. This is done taking into account: (a) the recorded abstractions from each water body, (b) that abstractions are calculated as "Gross abstractions – Returns" for each water body, (c) the majority of rivers are divided in sections, each section constituting a river water body and (d) that abstractions from upstream water bodies are included in every downstream water body [44].

3.3 Water saving potential

Since the beneficial effect of the discussed technologies and practices towards water saving is recognized, the methods are applied to TRBD. Their effect in reducing water demand is calculated for various scenarios and their combination. Lastly, as a measure with both financial sustainability and water saving potential, changing the mixture of two widely cultivated crops (cotton and olive trees) is also tested for its water saving capacity.

Technical measures include the modernization of public irrigation water networks (M), offering 90% efficiency [12], along with the adoption of drip irrigation methods instead of sprinkler, at X% of cultivated areas (D at X%). Drip irrigation systems when properly operated are thought to apply the irrigation water with 90% efficiency. Their effect on total water demand is calculated by altering TE_i and AE_i for the modernization of networks and the adoption of drip irrigation systems respectively.

The examination of scheduled irrigation is done in combination with deficit irrigation (SDI). Crops examined are cotton (C), olive trees (O) and the rest of the trees (T) cultivated in TRBD. SDI at X% stands for scheduled deficit irrigation at X% of crop irrigation needs. Olive trees, since their significant ability to withstand water stress, are examined in some cases separate from the rest of the trees, for irrigation needs at 290 mm. For the cases examined, the calculation of water savings is done by changing the In_j, for the crops examined.

Hence, achieving sustainable freshwater abstractions is the long-term target, further water saving measures may be required. Water reuse provides an alternative, easily accessible water source, at least from the four major WWTPs. The quantity of water reuse reduces total demand for freshwater abstractions. Additionally, regarding that ginned cotton productivity is low, about 0.50 €/m^2 [40, 45] and its irrigation needs are high, this research engages the water saving potential of changing cotton cultivation areas with olive groves. Olive trees, producing olive oil, in Greece present average productivity of 0.37 €/m^2, while requiring less cultivation cost [40,46]. The change is examined for different spatial extents, under SDI of olive trees at 290 mm. The calculation of water savings of the above measure is performed by altering CA_j for cotton and olive groves, while $In_{olives} = 290\ mm$.

4 Results - Discussion

4.1 Water demand

Following the methodology towards the calculation of total water demand, TE_{PN} is calculated at 75.99%. Regarding application efficiency, drip irrigation systems are found to be used in the 9% of publicly irrigated areas, while the rest 91% is irrigated with sprinkler systems, resulting in be AE_{PN} of 76.14%. Therefore, for the privately irrigated areas, it is assumed that 30% of irrigation is performed by drip irrigation systems and the rest 70% by sprinkler systems. The above assumption, results in the estimation of AE_{Pr} at 78.95%. These results, displayed in Table 4, demonstrate the significant impacts of transferring irrigation water with a non-efficient network to overall efficiency. While AE is similar for both irrigation regimes, overall efficiency for public networks is lower by more than 20%.

Table 4, Efficiency parameters

	Public networks	Privately irrigated
AE_i	76.14%	78.95%
TE_i	75.99%	100%
$AE_i \times TE_i$	57.86%	78.95%

As mentioned, 78.3% of cultivation areas are privately irrigated and the rest 21.7%, publicly irrigated. Therefore, α_{PN} equals to 0.783 and α_{Pr} to 0.217. The results regarding key volumes towards the calculation of present total irrigation water demand are displayed in Table 5.

Table 5, Key volumes of present status

Present volumes	$10^6\ m^3$
IN	1527.28
IN_{PN}	332.03
IN_{Pr}	1195.25
ID_{PN}	573.86
ID_{Pr}	1513.98
ID	2087.84

The concluded value of total irrigation needs (IN) for TRBD is 1527×10^6 m^3. Total irrigation water losses are calculated, as the difference between demand and needs, at 561×10^6 m^3. Privately irrigated areas present 319×10^6 m^3 losses, the 26.7% of their irrigation needs (1195×10^6 m^3). On the other hand, losses are found to be 242×10^6 m^3 for the areas irrigated with public networks, the 72.9% of their irrigation needs (332×10^6 m^3). Total present irrigation demand (ID) is calculated at 2088×10^6 m^3.

Total water demand accounts for 2204×10^6 m^3. Irrigation water losses, 25.44% of total water demand, constitute a large share in the formation of irrigation demand, especially for areas irrigated from public networks. Additionally, it is observed that irrigation demand stands for 94.74% of total water demand, confirming that emphasis should be given in water saving in the agriculture sector.

4.2 Freshwater abstractions

Freshwater abstracted from groundwater bodies is estimated by the 1st Revision of the RBDMP of Thessaly at 923×10^6 m^3.

For the surface freshwater abstractions, the following can be extracted from the 1st Revision of the RBDMP of Thessaly [1]. Firstly, the most downstream sections of tributaries of Pinios have water abstractions calculated at 754×10^6 m^3. Pinios river sections 8 to 5 have abstractions of 117×10^6 m^3. River water bodies, discrete from Pinios, have abstractions of 9.0×10^6 m^3. The abstractions of Pinios sections 12 to 9 and 4 to 1 are not calculated, as well as of the upstream sections of its tributaries. All the above quantities are not referring to gross abstractions, but "Abstractions – Returns". "Abstractions – Returns" are calculated by the present research to be at least 880×10^6 m^3, based on the RBDMP data.

Considering the above, it is assumed, that gross water abstractions from surface water bodies are 1000×10^6 m^3. Then total water abstractions can be considered about 1923×10^6 m^3.

Difference from total water demand then is about 15%, a reasonable percentage due to the unknown exact quantity of abstracted surface freshwater and the numerous unregistered private wells. It is evident that gross abstractions from surface water bodies vary from the abstractions mentioned in the 1st Revision of the RBDMP of Thessaly [1]. This can be attributed to the method of presenting the abstracted volumes in the RBDMPs, concealing the exact volumes of gross abstractions and water returns and as an effect, lacking the necessary clarity.

4.3 Water saving potential

The highest volume of saved water occurring for the adoption of the technical measures mentioned is $315\times10^6\ m^3$, 14.3% of total water demand, as shown in Fig. 3. This amount of saved water occurs with the widespread adoption in 90% of cultivation area (3515 km^2) of drip / micro-sprinkler irrigation systems combined with the full modernization of public irrigation water networks.

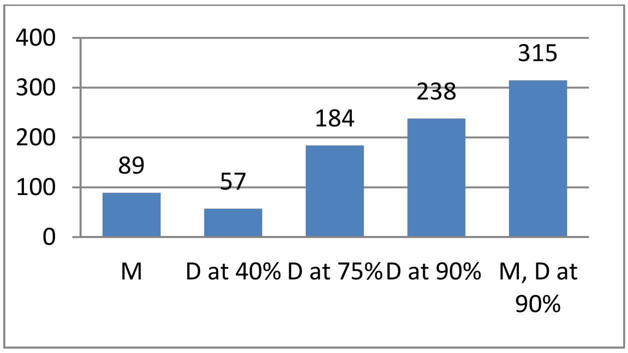

Figure 3, Technical measures water savings, ($\times10^6\ m^3$)

The above combination compared to the present status, alters AE_{PN} from 76.14% to 88.24%, AE_{Pr} from 78.95% to 88.24% and TE_{PN} from 75.99% to 90.00%. As a result, irrigation water demand (ID) is reduced by the aforementioned quantity.

The most effective application of scheduled deficit irrigation, as displayed in Table 6, is that of SDI at 80% for cotton and trees, while olive trees are irrigated with 290 mm, saving $235\times10^6\ m^3$, 10.67% of total water demand. These savings are achieved by reducing the irrigation needs (In) of cotton, trees and olive trees, resulting in a decrease of IN, and therefore of ID.

Table 6, Scheduled deficit irrigation water saving

Measure	Water savings ($\times10^6\ m^3$)
C SDI at 90%	58
O SDI at 90%	20
C, O SDI at 90%	77
C, O SDI at 80%	154
C, O & T SDI at 80%	193
C & T SDI at 80%, O SDI at 290 mm	235

Combination of technical measures and scheduled deficit irrigation may result in significant volumes of saved water, while having a minimum negative impact in crop production. Even moderately effective measures, in case of combining, may save larger volumes of water. This is attributed to the reduction of In of the selected crops, simultaneously to the improvement of the efficiency factors.

As shown in Table 7, the modernization of networks when combined with the widespread use of drip systems and scheduled deficit irrigation of cotton, olive groves and trees in TRBD is capable of water savings about $479\times10^6\ m^3$, 21.74% of total water demand.

Table 7, Combinations of technical measures and scheduled deficit irrigation

Measure	Water savings ($\times10^6\ m^3$)
D at 40%, C, O, SDI at 90%	132
D at 75%, C, O, SDI at 90%	254
M, D at 90%, C, O, T SDI at 80%	479

Water reusing from the four major WWTPs may save $35\times10^6\ m^3$ in total. Scenarios are examined for different extents of change from cotton cultivation to olive groves. A change of 15% of cotton cultivated areas (127 km^2) to olive groves, may reduce water demand by $117\times10^6\ m^3$. A wider swift from cotton plants to olive trees in the 60% of the cotton cultivated area (507 km^2) can decrease water demand by $225\times10^6\ m^3$, 10.21% of total water demand, as IN is reduced by $165\times10^6\ m^3$.

Finally, the combination of all mentioned measures results in water savings of $634\times10^6\ m^3$, 28.75% of total water demand. This potential may be achieved after networks are modernized and properly operated, drip irrigation is used widely, at 90% of cultivated areas, cotton cultivated areas become olive groves at 60%, olive trees are irrigated with 290 mm, while the rest of the trees and the remaining cotton receive scheduled deficit irrigation at 80% of their needs and wastewater is reused from the four major cities. Figure 4 breakdowns current and the discussed highest water saving scenario's water demand. It should be noted that for the water saving scenario abstracted water is lower than total water demand by the volume of reused water, $35{\times}10^6\ m^3$.

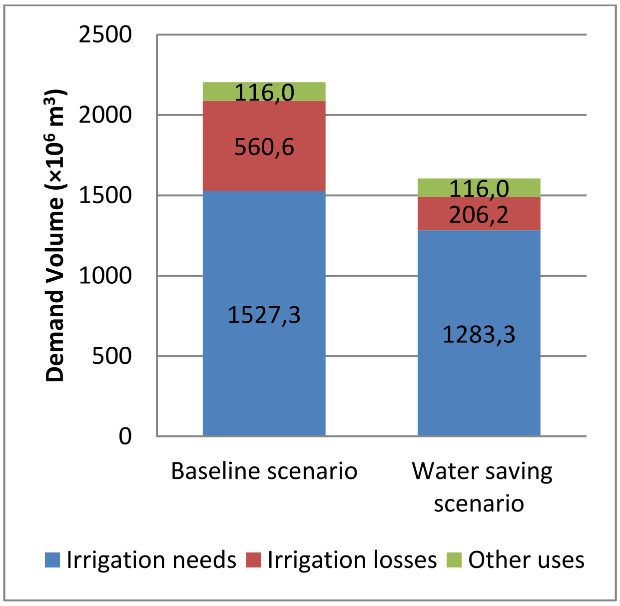

Figure 4, Total water demand breakdown for baseline and highest water saving scenarios

Table 8 presents the differences regarding key parameters for the present and the most water saving scenario. Transfer and application efficiencies are highly increased. Irrigation demand still constitutes 92.77% of total water demand. Nevertheless, IN and irrigation water losses are reduced by $244{\times}10^6\ m^3$ and $355{\times}10^6\ m^3$ respectively. ID_{Pr} is reduced by $376{\times}10^6\ m^3$, 25% of its present value. On the other hand, ID_{PN} is reduced by $223{\times}10^6\ m^3$, 39% of its present value. Reused water can be applied either in aquifer recharging or for urban green spaces uses. The amount of potentially saved water equals about 42% of present IN.

Table 8, Impact of combined measures on key parameters

Parameter	Difference
AE_{PN} (%)	+ 12.10
AE_{Pr} (%)	+ 9.29
TE_{PN} (%)	+ 14.01
IN ($\times 10^6\ m^3$)	- 243.98

5 Conclusions – Future research

The aim of the present research work is the calculation of the water saving potential of TRBD. In order to achieve it, the irrigation water demand is calculated to be $2088{\times}10^6\ m^3$, constituted of irrigation needs, up to $1527{\times}10^6\ m^3$, in addition to transfer and application losses, up to $561{\times}10^6\ m^3$. The total water demand, including the domestic, industrial and livestock sectors, is $2204{\times}10^6\ m^3$.

Moreover, the present research concludes that gross abstractions from surface water bodies are at least $880{\times}10^6\ m^3$. Irrigation water distribution networks present low efficiency, less than 58%. Irrigation via private wells consist a major driver of quantitative pressures for the groundwater bodies, as its demand stands for the 80% of their annual renewable resources. Additionally, the fact that 65% of river water bodies are subjected to high quantitative pressures, implores the need of a sustainable solution. Under this context, water saving measures have been examined, as a solution, less disturbing to the environment, compared to the construction of new storage infrastructure.

Water savings potential is calculated up to $315{\times}10^6\ m^3$, or 14.3% of total water demand for technical measures, comprised of swift to drip irrigation systems and the modernization of water distribution networks. Deficit irrigation under proper scheduling for cotton, olive groves and trees cultivation may also save $235{\times}10^6\ m^3$, 10.7% of total water demand. Changing 507 km^2 (60% based on current crop area) of cotton cultivation areas to olive groves, results in savings of $225{\times}10^6\ m^3$, 10.2% of total water demand, if olive trees are irrigated with 290 mm. Combining the aforementioned measures in TRBD, along with water reuse, water savings may reach a volume of $634{\times}10^6\ m^3$, 28.8% of the total water demand.

These results demonstrate the large water saving potential of TRBD, which is judged capable of providing a significant relief to the water resources of TRBD. Pressures from private wells of irrigation will drop from 80% to 60% of groundwater bodies' renewable resources. Moreover, it is notable that total water savings equal about 20% of Pinios' average annual runoff. Technical measures as well as irrigation scheduling and deficit irrigation are to be adopted in the short term. Changing the yearly cotton crop to olives trees will require further assessment for its implementation if necessary.

Future research might focus on the application of models towards improved identification of the hydrological cycle components in the region alongside with seasonal variation of water demand as well as the development of proper legal framework, providing incentives to farmers.

Appendix

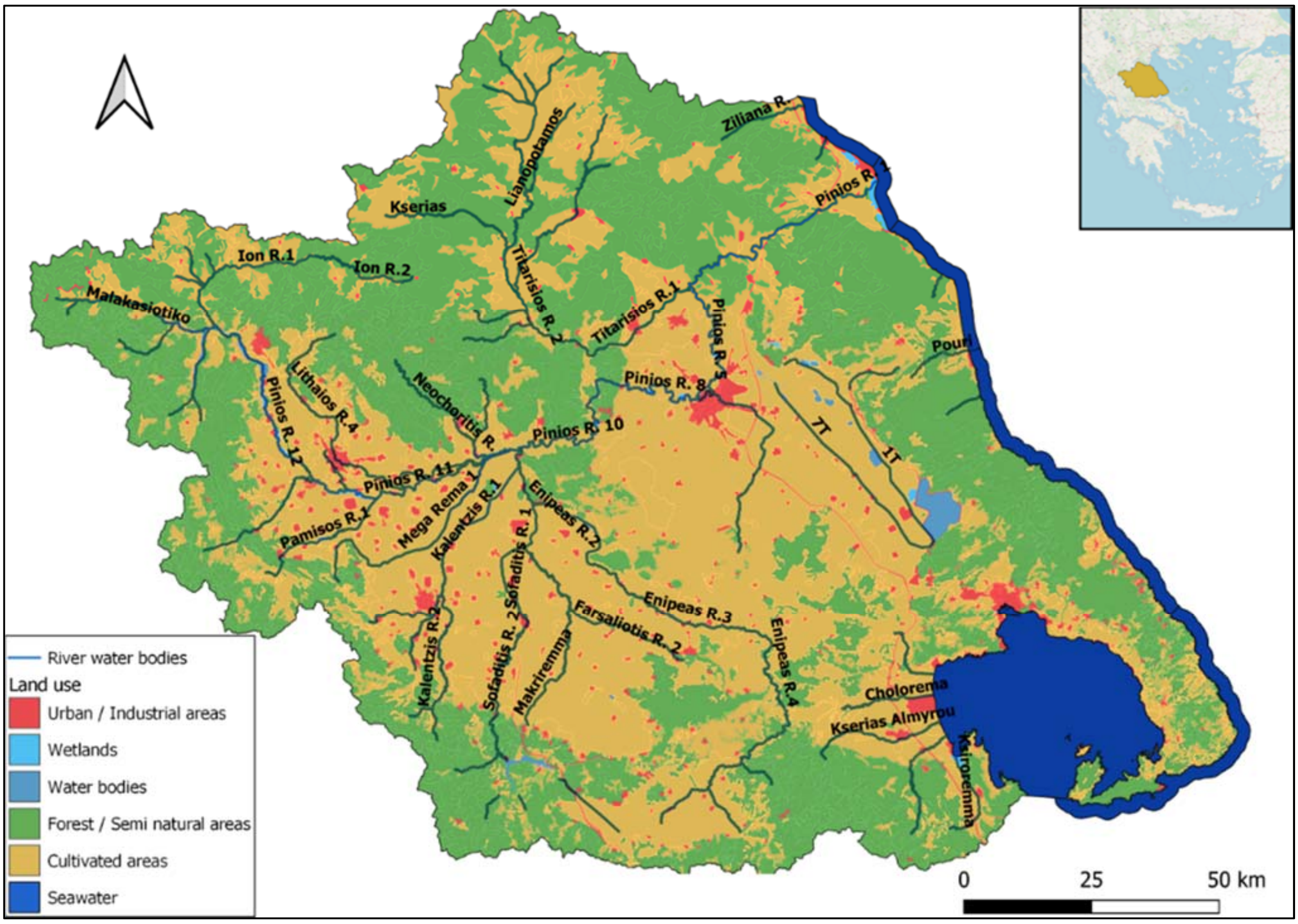

Figure 1, Land cover and river water bodies map of TRBD

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