Wiem Daoud Ben Amor*
Hela Moalla Frikha**

HIERARCHICAL STRUCTURING FOR THE OLIVE TREES IRRIGATION PROBLEM IN TUNISIA

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Abstract

The problem of choosing the best type of water for the irrigation of olive trees is one of the decisions that have a crucial impact on the water resource management. To solve this problem, we propose a multi-expert approach, implying several quantitative and qualitative criteria and combining the AHP method and Shannon's entropy probability method. First, we use the AHP method to calculate all criteria weights for the various hierarchical levels as well as weights of the alternatives. Using the results obtained, we rank the types of water according to four experts. However, the data supplied by the experts are contradictory. We therefore combine these results according to the experts' importance. We used Shannon's entropy to determine the importance degree of each expert, to aggregate the results. The proposed approach showed that using well water was selected as the best for irrigation. Reuse of treated wastewater was classified as second, followed by desalinated brackish water and, next, by desalinated seawater.

Keywords: olive trees irrigation, multicriteria decision aid, multi-expert, AHP, incertitude, Shannon's Entropy.

1 Introduction

Water is a primary need for all living beings. It is essential for any socio-economic development. It is an important factor for the development of the agricultural, industrial, touristic and vital sectors. However, irrigation is the main water consumer in the agricultural sector. The main objective is to promote

* University of Sfax, Higher Institute of Industrial Management of Sfax Road of Tunis km 10.5, 3021, Sfax, Tunisia, e-mail: waymadaoud@gmail.com.
** University of Sfax, Higher Institute of Industrial Management of Sfax Road of Tunis km 10.5, 3021, Sfax, Tunisia, e-mail: hela_frikha_moalla@yahoo.fr.

a stable agricultural activity when rainfall does not cover the needs of cultivated plants. Currently, the olive sector is a strategic sector in Tunisia at the economic, social, cultural and environmental levels, and the region of Sfax is one of the main olive growing regions in Tunisia. The area of olive cultivation in this region is estimated at about 340 700 ha currently representing about 19.5% of the national olive areas which cover 1.74 million ha. The olive population is about 7 million trees, representing 8.5% of the national olive population of 78 million trees. According to the Regional Commissions for Agricultural Development of Tunisia (2015)[1], Sfax is also the leading region in olive oil production, since it has contributed about 23.19% of the national production over the last decade (2006-2015) with an average production estimated at 22 674 tons. Accordingly, the olive sector is a major agricultural activity in our country. Good quality water resources in agriculture contribute to the agricultural development. In this context, the central objective is to find the best water type for the irrigation of olive trees on the basis of a study of the vegetative, productive, technological, financial, environmental and sanitary criteria related to the fruits. To achieve this goal, we propose an approach based on a multicriteria decision aid model which implies several quantitative and qualitative criteria. First, we implemented the AHP method to determine the priorities of each water type according to each expert. However, the results obtained from the AHP method appear contradictory. In order to aggregate them, Shannon's entropy is used to calculate each expert's weight. These two methods use the opinion of several experts about the choice of the best type of water for the irrigation of olive trees in the Sfax region.

AHP is a technique that facilitates complex multi-criteria decision-making, using a systematic, rational and transparent process. In addition, the AHP method helps to capture subjective and objective evaluation measures while providing a useful mechanism for verifying the consistency of the assessment measures and alternatives (Saaty, 1990; Frikha et al., 2015). In our study, we chose to work with the AHP method because our problem is hierarchically structured; it includes fifty five criteria, subcriteria and four alternatives. In addition, several experts have been contacted, which means the existence of several decision matrices. AHP, which incorporates several criteria, is proposed to determine the weights of a dataset provided by different experts. Finally, it must be verified that the information provided by the decision-makers is consistent and does not contain uncertainty.

According to our study, since the data provided are uncertain, imprecise, imperfect and conflicting, the weights of criteria and alternatives deduced from AHP are also uncertain. Consequently, we obtain judgments in the form of subjective probability distributions, which raises the question of how to combine

[1] http://www.semide.tn/CRDA.htm

the information of several experts to obtain a better specific result. Sandri et al. (1995) have argued that uncertainty models play a crucial role in the assessment of expertise since no one can state his judgment or advice with absolute certainty. In addition, we cannot claim that the information provided has the same importance: it depends on the reliability of the expert. Hence the aggregation of information is based on the experts' weights. In conclusion, to reduce conflict, manage imperfection and calculate the experts' weights, Shannon's entropy method is used (Shannon, 1948).

2 A literature review

Several papers have dealt with the issue of water management. For instance, Domènecha et al. (2013) proposed two economic models based on growth and decay, such as (NAIADE) and (C-K-Y-L). A social multicriteria evaluation was carried out to explore the feasibility of both models. NAIADE is a new approach to improve evaluation and decision making. This method aims at evaluating each alternative with respect to each criterion and allows a ranking of the alternatives, while the C-K-Y-L approach is based on a pairwise comparison between the alternatives according to the criteria. The main objectives of these multicriteria assessments are: to compare four unconventional water sources (desalinated seawater, regenerated water, rainwater and greywater) in order to gain knowledge of their actual and perceived social-environmental performance, to find solutions to reduce water consumption, to test the feasibility and the desirability of the water supply for different alternatives and to highlight the opportunities and barriers to social and voluntary action for decay. In this paper, there are no qualitative data. Moreover, in a context of a decreasing use of water, there is a lack of reliability of a water supply system.

The multicriteria method used (NAIADE) does not supply criteria weights. Haring et al. (2016) used the AHP multicriteria decision-making method for better water management in agriculture in the Huang-Huai-hay river basin. The assessment system of irrigation water management is based on five indices or criteria, such as the technology index, the engineering index, the management index, the environmental index and the economic index.

The AHP method has been improved to calculate the weight of each index in the water management assessment indexing system for irrigation. Irrigation water management levels were obtained using the Gray correlation method and the overall fuzzy assessment method to improve the level of water management in agriculture. In this paper, the method used can give contradictory, uncertain and conflicting results. Similarly, Ben Brahim et al. (2014) used a compromise program to improve irrigation practices based on the use of recycled water and to determine if farmers would be willing to pay more for water if irrigation programs were improved and the factors influencing their decision analyzed. Their study examines a binary logistic regression analysis to meet these objectives and develops a compromise programming model based on a multi-objective technique. Compromise programming belongs to a group of multicultural analysis methods called distance methods. This technique identifies the closest solutions to the ideal through distance measurement. In this paper, farmers and policy makers used only recycled water for irrigation regardless of other types of water. Slobodan et al. (2008) proposed the Pareto optimum for the decision concerning water resources. This approach captures the uncertainty associated with weight assignment, provides decisions with a wide range of solutions to select the best one and to demonstrate the utility of the method used. A situation is said to be a Pareto optimum if it is impossible to improve the result for one actor without risk of damage to another one. The authors used ideal positive and negative solutions (TOPSIS) and a set of weights attributed to the objective functions in the form of triangular fuzzy numbers. The solution to this problem is obtained by transforming each objective function into a set of three objective functions to demonstrate the utility of the used method. Nunes et al. (2017) proposed a SWAT model to study the impact of climate and socioeconomic changes on the availability of water. This model is a tool for soil and water assessment. It is used to quantify and predict the impact of land management practices on water, sediments, and yields of agricultural chemicals.

The results obtained by the authors imply that the availability of water is resistant to climate change and that the issue of a future decrease in water availability could be solved by a supply and demand strategy. PROMETHEE is a multi-criteria overseeing method that has been applied by Abu Taleb et al. (1995).

The purpose of using this method is to minimize the extraction of groundwater that ensures quality and quantity, to obtain a high probability of cost recovery, to maximize water supply (new development projects, reuse of wastewater and others) and to promote water conservation and efficiency. A scientific analysis was developed by Lu et al. (2016), who showed the influence of the dynamic change of the ground for every period of growth of the cultures and the irrigation of the water regenerated on the yield and the quality of fruits and vegetables with regard to the irrigation drip by the subterranean waters on a ground tests of soil. They also showed that the irrigation by drip favors an increase of the yield of the tomato and allows to obtain a higher rate of water preservation. The papers listed (Domènecha and al., 2013; Sun et al., 2017; Ben Brahim et al., 2014; Slobodan et al., 2008; Nunes et al., 2017; Lu et al., 2016) focused on the reuse of treated wastewater. No paper, however, combines the four water alternatives to solve the irrigation problem, namely: the reuse of treated wastewater, the desalination of brackish water, the desalination of marine waters and the use of well water. Finally, optimization methods and multicriteria methods have not been used, so far, in the literature to solve our problem. Instead, most researchers have used qualitative scientific analysis.

3 The hierarchical structure of the problem

The choice of the best water type for olive irrigation in the region of Sfax based on the collected information from experts and researchers in the field of olive growing becomes a major challenge for the management of water resources. The determination of the best water alternative is based on several criteria: environmental (C1), production (C2), pomological (C3), physico-chemical (C4), social (C5), technological (C6) and financial (C7). Each of these criteria is divided into subcriteria of several levels. In addition, the different types of water for the irrigation of olive trees – the alternatives of our problem – are: reused treated wastewater (AL1), desalinated marine water (AL2), desalinated brackish water (AL3), and well water (AL4) (Figure 1).

Our approach is divided into two parts. The first one deals with multicriteria analysis. It will consist in an overview of the evaluation criteria and subcriteria as well as the alternatives to solve our problem. The second part handles the probabilistic analysis with multiple criteria used in the cultuvation of olive trees. These two parts deal with the opinion of several experts cultivation about the choice of the best water type for olive tree irrigation in the Sfax region.

3.1 Criteria

The choice of the best water is based on several criteria, namely: environmental (C1), production (C2), pomological (C3), physico-chemical (C4), social (C5), technological (C6) and financial (C7); each of them will be divided into more specific subcriteria (there are fifty-five criteria and subcriteria and four alternatives). These criteria generate subcriteria which are divided into subsubcriteria. Accordingly, these different levels of criteria will be represented in the form of a hierarchical structure. They were chosen after an exhaustive review of the literature on sustainable development specific to the olive sector in Tunisia. We also used discussions with researchers from an olive tree institute and with multidisciplinary researchers.

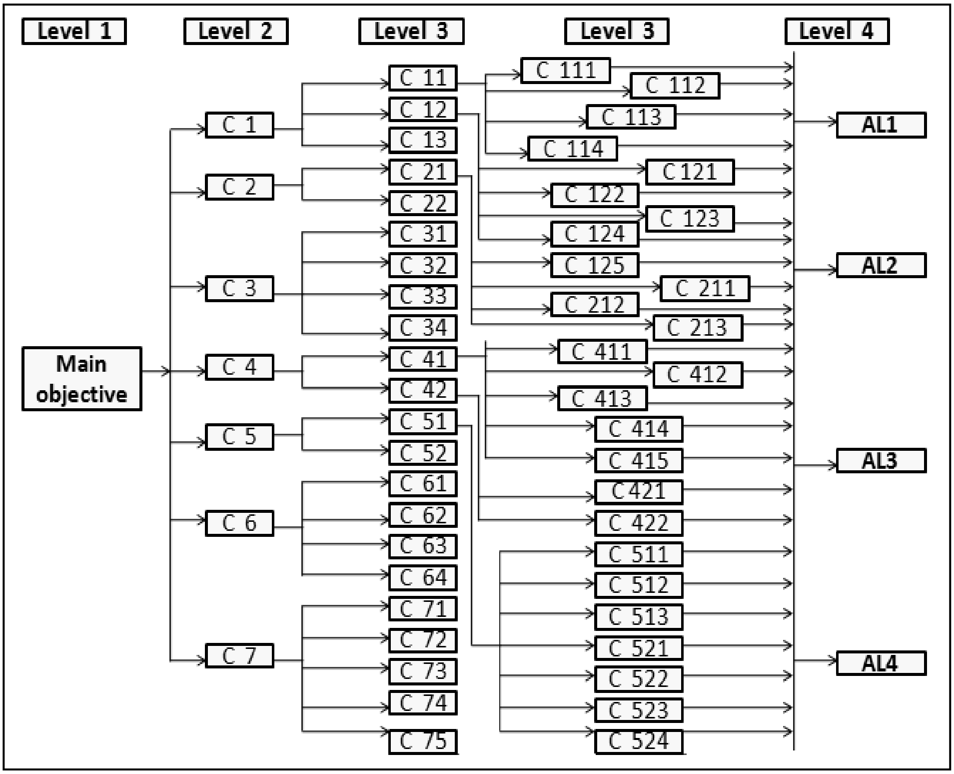

Figure 1: Hierarchical structure for choosing the best water type for olive tree irrigation

The environmental criterion **(C1)** breaks down into three subcriteria at level 3 (soil fertility (C11), salinization of irrigated soil (C12), effect on groundwater (C13)) (Figure 2). Specifically, (C11) is the ability of the land to ensure, on a regular and repeated basis, the growth of crops (Bedbabis et al., 2015) which depends on various soil components involved in the supply of plants in water and nutrients. In addition, the soil is a living vegetative cover, which facilitates the water cycle. This criterion is taken into consideration to improve the quality of the soil, its fertility and health status for the protection of the environment in the case of irrigation by different types of water. The subcriterion "soil fertility" is composed of several subsubcriteria at level 4 (preservation of the physical properties of the soil (C111) (Bedbabis et al., 2014; Ben Rouina, 2011), texture (C112), depth (C113), salinity (C114) (Bedbabis et al., 2010; Ben Ahmed et al., 2009).

The quality of water used in irrigation is a first-order factor in soil salinization. Therefore, the salinization of the irrigated soil (C12) must be minimized as long as salt has a negative effect on the physical and chemical properties of soil and water table. The effects of irrigation water on the ground are judged through the total concentration of this water in soluble salts and by the water content of absorbable sodium (Leone et al., 2007). This subcriterion includes several subcriteria at the fourth level (availability of water sources (C121), mode of irrigation (C122) (Bedbabis et al., 2015), socioeconomic factors (C123), effect of the irrigation of plants (C124), effect of the irrigation on the physico-chemical properties (C125)).

Finally, the effect on groundwater (C13) is the third subcriterion. The irrigation mode has a direct influence on the risk of contamination. Underground or gravity irrigation can affect the quality of groundwater and surface water. Direct contamination may occur during the maintenance of the irrigation system. Sprinkler irrigation creates contaminating aerosols that can be transported over long distances, while gravity-fed and flood irrigation exposes workers to high health risks, especially when land use is unprotected against soil salinization (Peasey et al., 2000).

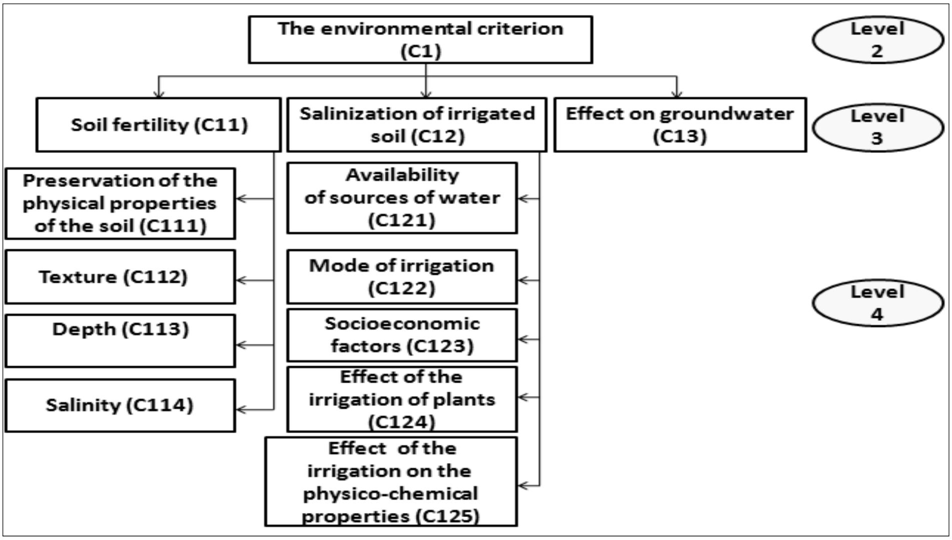

Figure 2: Decomposition of the environmental criterion into subcriteria

The production criterion (Wiesman et al., 2004) (C2) (Figure 3) splits into vegetative growth (C21) and oil quality (C22). The first subcriterion (C21) depends on several factors, such as light, water supply, mineral elements and the load of olives. In our problem and for this type of criteria, we aim at finding the best water alternative to improve production. The improvement in production is mainly due to good vegetative growth. Criterion (C21) splits into three subcriteria (number of flower clusters / linear meter per shoot (C211), number of flower buds / linear meter (C212), number of fruit tied / linear meter of the shoot

(C213)). The goal of (C22) (oil quality) is to find the impact of irrigation through this type of water on yield (Clodoveo, 2012). The higher the production of olives, the larger the increase of the amount of olive oil.

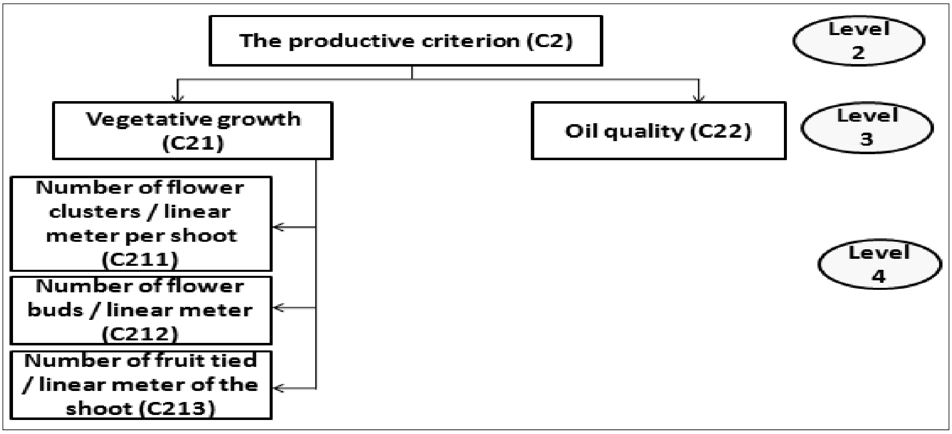

Figure 3: Decomposition of the production criterion into subcriteria

As for Criterion (**C3**) (Figure 4), there are four subcriteria at the third level (production (C31), average fruit weight (C32), pulp / core ratio (C33), fat content (C34)). Pomological criterion is used for the characterization of olive varieties. It allows to classify the varieties according to their yield in olive oil. The objective of (C31) is to obtain higher and more consistent levels of olive production while minimizing the cost of exploiting water resources (Gucci et al., 2007). In addition, (C32) is a pomological criterion for olives that must be calculated because this indicator is very important for the characterization of oil varieties olives, given its impact on the fat content and, consequently, on the oil yield (Fourati et al., 2003). In general, the average value of (C33) depends on the variety and type of water used in irrigation. Irrigation of olive trees with water of good quality leads to an improvement in the consistency of the fruit pulp, which has a direct impact on their commercial value because this consistency is an important quality criterion for olives. High water availability in the soil during the growing season increases the production, the fruit size, the pulp-core ratio and the oil content of the olives expressed as a percentage of dry weight. The fat content (C34) is a criterion of great economic importance, as the ultimate goal of olive cultivation is the production of oil. This criterion can be determined by various methods such as nuclear magnetic resonance.

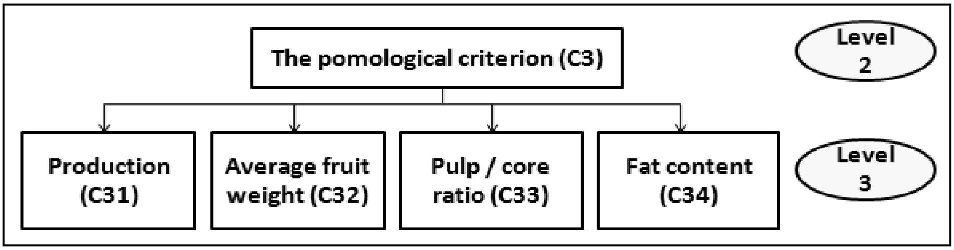

Figure 4: Decomposition of the pomological criterion into subcriteria

The physicochemical criterion (**C4**) is the fourth one considered in our problem (Figure 5). It is divided into two subcriteria, namely quality (C41) and purity (C42). These are also subdivided into subcriteria. The concept of 'quality', especially for virgin olive oil, must be defined and a judicial control of the respect of commercial indices and authenticity must be established (Gharsallaoui et al., 2011; Bedbabis et al., 2016). The criteria of olive oil quality are: acidity (C411), peroxide value (C412), ultraviolet absorbance (C413), chlorophyll quantity (C414) and polyphenol content (C415). The purity criterion is also divided into two subcriteria at the fourth level (oil quality (C421), acidic component (C422)). The objective of the purity criterion (C42) is to find the impact of irrigation by this type of water on olive oil. Commercially speaking, the taste has a very important effect on the quality, which is measured by organoleptic evaluation (C421) (Bedbabis et al., 2015; Bourazanis, 2016). Thus, certain characteristic defects are prohibitive for the marketing of olive oil. The most important are the olive oils obtained from olives stored in bad conditions, the olive oils appear mold if the olives are long stored even under the right conditions (mold) and the olive oils poorly preserved (rancidity). The quality of irrigation water has a direct influence on the acidic component of olive oil (C422). Indeed, olive oil consists of several types of acidic components, the most important of which is oleic acid. (It is an excellent energy food, a basic ingredient of the Mediterranean cuisine.)

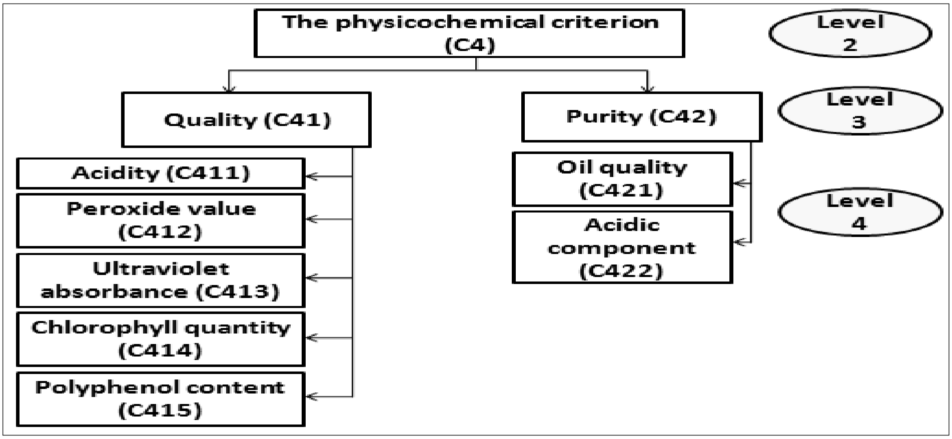

Figure 5: Decomposition of the physicochemical criterion into subcriteria

The choice of the best water is also based on a social criterion **(C5)** which is divided into two subcriteria (Figure 6) (Health Risk (C51) and Water Quality (C52)). The choice of water and irrigation method of olive trees is very important for good quality of oil. In particular, we are here concerned with the sanitary quality of the olive tree and the soil in terms of bacteria. This criterion (C51) also splits into three subcriteria at level four (tree (C511), soil (C512) and irrigation mode (C513)). Irrigation water has an influence on the sanitary quality of the olive tree (C511) (Bedbabis et al., 2015). In addition, an increase in salinity causes toxic effects which appear much more easily when the salts are brought directly into the leaves during irrigation. In addition, the irrigation mode influences soil contamination and clogging (C512) (Bedbabis et al., 2015; Petousi et al., 2015). Indeed, Azzouzi et al., (2015), found that the use of treated wastewater for 20 years is not recommended because it generates a high level of organic contaminants in the soil. (C513) has a direct influence on the risk of contamination. In 2006, the World Health Organization (WHO) recommendations have predicted risk levels, depending on the irrigation technique and crop types (WHO, 2016). As for water quality (C52), it is divided into four subcriteria at the fourth level (guarantee of the safety of the farmers (C521), no deterioration of the soil quality (C522), physicochemical characteristics of the soil (C523) and bacteriological aspects (C524) (Khabou et al., 2009). The quality of water used for irrigation is an essential parameter for crop yield, maintaining soil productivity and protecting the environment. Thus, the physical and chemical properties of the soil, such as its structure (aggregate stability) and permeability are very sensitive to the type of potentially exchangeable ions present in irrigation water (C523) (Ayoub-Tebini H., 1981). Water chosen for the irrigation of olive trees must be of good quality so as not to cause the deterioration of soil quality

(C522). Indeed, the degradation of cultivated soils depends very much on the type of water. In addition, poor water quality is a serious threat to the viability and safety of agricultural products from intensive farming systems (C524) (Asano, 1998; Materon, 2003).The safety of the operators must also be guaranteed (C521). The choice of the best category of water for the irrigation of olive trees stimulates the production and the quality of the oil which guarantees the safety of the farmers.

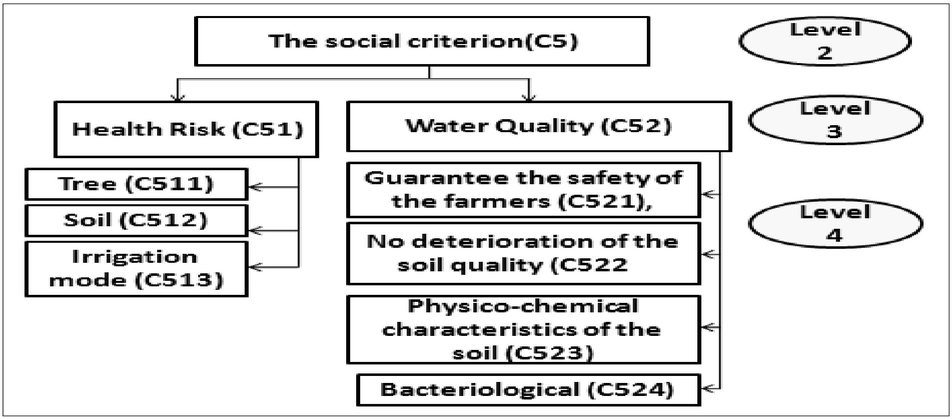

Figure 6: Decomposition of the social criterion into subcriteria

Next, we take also into account the technological criterion (**C6**) (Figure 7) which is divided into several subcriteria (irrigation technique (C61), the time required for irrigation (C62), simplicity (C63) and processing reliability (C64)). Most farmers use traditional water-intensive techniques, such as gravity irrigation, which generate significant losses through soil evaporation and deep percolation (Zin El-Abedin et al., 2018). Today, irrigation systems are diversified. Among the most effective are full coverage, drip and sprinkling. (C62) is the amount of time needed to complete the installation of an unconventional water supply system. Inadequate or poorly designed irrigation systems can spread pathogens and pollutants in crops. The objective of (C63) is to apply the most reliable irrigation technique and especially the simplest and least time-consuming. Drip irrigation is considered to be the simplest such technique in agriculture. Finally, reliability (C64) includes skills and knowledge required from farmers and workers, land ownership, and land and water rights.

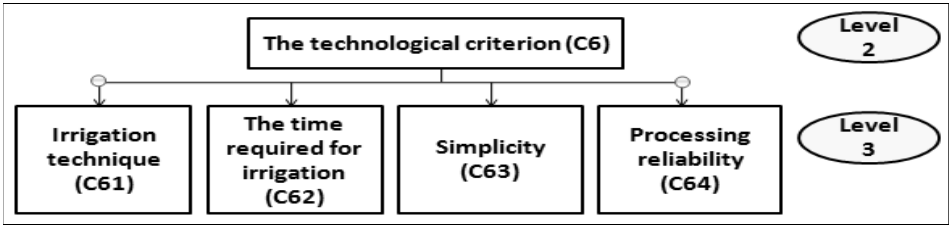

Figure 7: Decomposition of the technological criterion into subcriteria

We consider also the financial criterion (**C7**) (Figure 8). It is divided into five subcriteria (cost of irrigation (C71), water intake (C72), electrical input (C73), cost of water transfer for irrigation (C74) and amount of used water (C75)). The objective of (C71) consists in evaluating the economic efficiency of irrigation, whether it is cost-effective. This cost assessment will determine whether the selected water is the least expensive or not and will lead to significant economic gains. For (C72), access to a reliable supply of water is often the main constraint of irrigation. Furthermore, water has a fundamental role in the life of olive trees. In addition, drought directly influences plant growth and yield in arid and semi-arid regions. The use of unconventional water is the major solution for irrigation. But the farmers refuse to use it because they believe that this water is worthless. In economics, energy efficiency (C73) consists in reducing energy consumption, with an equal service level. This is the case of agriculture, installation of equipment or materials for irrigation, which facilitates the distribution of water for the farmer. The objective of (C74) is to choose the most efficient type of water with the minimum cost of transfer (Berbel**,** 2018). Irrigation water requirements depend on water requirements of the crops and the water they naturally have. In fact, the objective of (C75) is to choose the most efficient water alternative while minimizing the amount used for irrigation of olive trees. Excessive irrigation leads to costly waste, which can lead to a deterioration of the quality of the olives and results in fertilizers placed deep in soil (Nielsen**,** 2018).

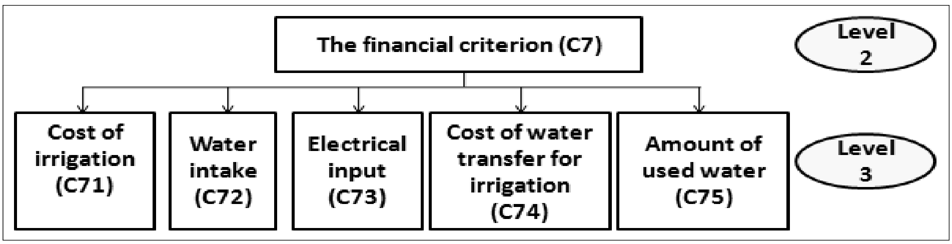

Figure 8: Decomposition of the financial criterion into subcriteria

3.2 Alternatives

The alternatives, which are the different types of water possible to use to irrigate the olive cultivation in Sfax were fixed after meetings with scientists of an institute of the olive tree. The different types of water for olive irrigation available in the Sfax region of Sfax are:

– **Reused treated wastewater (AL1)** (Bedbabis et al., 2015; Brahim-Neji et al., 2014; Bourazanis et al., 2016; Valdes-Abellan et al., 2017; Makram et al., 2012) Wastewater is a very important alternative in the context of the overall management of water resources in agriculture. Reuse of wastewater in agriculture contributes to the conservation of freshwater and energy, which improves the quality of life. Finally, reuse of wastewater in agriculture can be a way of protecting the environment and especially a mean of recycling the nutrients contained in the soil;
– **Desalinated seawater (AL2)** (Ghassemi et al., 2013; B. Rjula et al., 2010) results from a process that produces fresh water from brackish or salty water. Desalinated seawater is a resource rarely used for irrigation because of its cost. Desalination of seawater is a reliable technique which is also less expensive than the recycling waste water;
– **Desalinated brackish water (AL3)** (Valdes-Abellan et al., 2017; Wiesman et al., 2004) refers to all saline waters with less salinity than seawater. Desalination of brackish water is a solution to avoid the risk of salinity. This use will normally be for human consumption or for industrial, agricultural, activities, and so on;
– **Well waters (AL4)** (Singh, 2018; 2016; 2014; Hamamouch et al., 2017; Chen, 2018; Autovino et al., 2018). Wells are soil-based structures that extract, economically and efficiently, groundwater from an aquifer. There are three main types of wells: dug wells, dark wells and drilled wells.

4 The proposed model for choosing the best water alternative for olive trees irrigation

4.1 AHP method for ranking water alternatives

Multicriteria decision aid methods are methods for aggregating multiple criteria to choose one or more actions or solutions. In this methodological framework, we use the AHP method (Sun et al., 2016; Frikha et al., 2015) which is a powerful and flexible tool in decision-making. It is a multicriteria aggregation process developed by Saaty (1990), which makes it possible to break down a complex problem into a hierarchical system, in which binary combinations are established at each level of the hierarchy. The method begins with the definition of the main objective to be achieved or the decision to be made about determining the best type of water for irrigation of olive trees. This main goal breaks down into a hierarchical structure of evaluation criteria and subcriteria. In the last hierarchical level, we find the types of water to be evaluated (the alternatives). The AHP method consists of the following steps:

- Break the problem into a hierarchical structure (Figure 1).
- Perform binary combinations level by level: This involves pairwise comparison of the relative importance of all the elements from the same level of the hierarchy with the element from the higher level. Each expert is asked to provide matrices of pairwise comparisons of all the criteria, and of all the subcriteria corresponding to the criterion of the higher level, and so on, until reaching the matrices of comparisons of the types of water corresponding to each sub criterion.
- Determine the priorities: Three operations are necessary to calculate the priorities: add the columns of the matrix, normalize the matrix and calculate the average of the rows. We determine the weights of all criteria and subcriteria as well as the weights of water types for the irrigation of olive trees, according to each subcriterion, and that according to each of the contacted experts.
- Synthesis of the priorities: Once the priorities for all the criteria in the hierarchy have been determined, the weight of each alternative with respect to all the criteria and subcriteria are calculated and a ranking of all types of water is obtained. We thus obtain the main eigenvector of the $n \times m$ reciprocal matrix.
- Check the consistency of judgments: The AHP method validates the reliability of the results by calculating a consistency index. This index will allow us to detect significant inconsistencies in the data provided.

  The Coherence Index is calculated as follows:

$$\text{IC} = \frac{(\lambda max - n)}{(n - 1)} \tag{1}$$

where $\boldsymbol{\lambda_{max}}$ is the maximum eigenvalue, n is the size of the matrix, IC is the Coherence Index which represents the level of reliability of the judgments provided.

The Coherence Ratio (CR) is calculated as:

$$\text{RC} = \frac{\boldsymbol{IC}}{\boldsymbol{CIA}} \tag{2}$$

where CIA is a random index developed by Saaty.

Using the consistency ratio, we compare the actual reliability with theoretical reliability. If RC $\leq$ 0.1 (10%), the matrix is regarded as sufficiently coherent. When this value exceeds 10%, the assessments may require revisions.

To obtain a reliable result, several experts are contacted (Table 1). Reliance on a single expert can lead to unreliable and uncertain solutions, as expert knowledge of a single expert is often regarded as the best or the only source of information. In addition, the experts often share the same education and the same literature and visit the same conferences which will have a similar influence on their quantification of uncertain knowledge (Hofer, 1986). Therefore, it is mandatory to conduct an expert opinion poll when expert judgment is an important basis for quantification.

Table 1: Distribution of the sample of experts

Expertise field	**Expert**	**Farmer**	**Responsible of Regional Commissariat for Agricultural Development**	**Researcher**	**Responsible of the Olive Tree Institute of Sfax**	**Responsible of the Agricultural Development Delegation of Sfax**
Expert 1	*	*			*	
Expert 2			*			
Expert 3				*	*	
Expert 4		*				*

A questionnaire has been proposed to determine the experts' opinion. It must be carried out on an individual basis. It consists of two main parts:

- ✓ The first part is simple and consists in identifying and characterizing the respondent's situation, including his area of expertise.
- ✓ The second part deals with the objectives to be evaluated and the alternatives of the study. According to the opinion and the experience of the respondent, the comparative evaluation consists in pairwise comparisons of the importance of one criterion at each level of the hierarchy. The comparative evaluation is performed using Saaty's fundamental scale (Saaty, 1990).

We will present an explanatory example of the calculations for a single expert (Expert 3) and a single level given the large number of calculations (Tables 2-6, Figure 9).

Table 2: Pairwise Comparison Matrix of Criterion C1 for Expert 3

	C11	**C12**	**C13**
C11	1	1	0,5
C12	1	1	1
C13	2	1	1
Sum	4	3	2,5

Table 3: Determination of subcriteria weights

	C11	C12	C13	Sum	Weights
C11	0,25	0,333333333	0,2	0,783333333	0,261111111
C12	0,25	0,333333333	0,4	0,983333333	0,327777778
C13	0,5	0,333333333	0,4	1,233333333	0,411111111
Sum	1	1	1		1

Table 4: Verification of subcriteria judgment consistency

	C11	C12	C13
priority	0,261111111	0,327777778	0,411111111
C11	1	1	0,5
C12	1	1	1
C13	2	1	1

	C11	C12	C13	Sum	Sum/weight
C11	0,261111111	0,327777778	0,205555556	0,794444444	3,042553191
C12	0,261111111	0,327777778	0,411111111	1	3,050847458
C13	0,522222222	0,327777778	0,411111111	1,261111111	3,067567568
Sum	1,044444444	0,983333333	1,027777778		9,160968217
λmax					3,053656072
IC					0.026828036
RC					4.625523468

RC < 10%. Hence the judgments are consistent.

Each expert is asked to compare, pairwise, the types of water used for irrigation, denoted ALT_i i = 1,…, 4 from the fifth level of the hierarchy with respect to the criteria and subcriteria of the fourth level. (The results of weight calculations according to Expert 3 are shown in Tables 5 and 6 and Figure 9).

Table 5: The alternative weights for Expert 3

	Weights	AL1	AL2	AL3	AL4
C111	0,450043706	0,294157925	0,074249709	0,436873543	0,436873543
C112	0,117438811	0,223513911	0,076711811	0,123120592	0,576653685
C113	0,190646853	0,105916593	0,16154583	0,253647215	0,478890363
C114	0,241870629	0,29805452	0,048147717	0,377574557	0,276223206
C121	0,043882347	0,29805452	0,048147717	0,377574557	0,276223206
C122	0,554795892	0,29805452	0,048147717	0,276223206	0,276223206
C123	0,174955527	0,29805452	0,048147717	0,377574557	0,276223206
C124	0,128520914	0,633333333	0,066666667	0,066666667	0,233333333
C125	0,09784532	0,625	0,125	0,125	0,125
C13	0,411111111	0,051699819	0,185999095	0,087599731	0,674701355
C211	0,128501401	0,585714286	0,053968254	0,053968254	0,306349206

Table 5 cont.

C212	0,276610644	0,585714286	0,053968254	0,053968254	0,306349206
C213	0,594887955	0,412443439	0,053968254	0,053968254	0,306349206
C22	0,875	0,669026807	0,105099068	0,088432401	0,137441725
C31	0,272457651	0,669380843	0,142322272	0,071466171	0,116830714
C32	0,497278107	0,634259259	0,141137566	0,10542328	0,119179894
C33	0,168712378	0,616946559	0,159250009	0,098316218	0,125487214
C34	0,061551864	0,616946559	0,159250009	0,098316218	0,125487214
C411	0,205401715	0,57486631	0,069136746	0,069136746	0,286860199
C412	0,10978003	0,57486631	0,069136746	0,069136746	0,286860199
C413	0,17584118	0,57486631	0,069136746	0,069136746	0,286860199
C414	0,281755373	0,57486631	0,069136746	0,069136746	0,286860199
C415	0,227221702	0,57486631	0,069136746	0,069136746	0,286860199
C421	0,25	0,375	0,125	0,125	0,375
C422	0,75	0,375	0,125	0,125	0,375
C511	0,128501401	0,051784822	0,175668821	0,15589816	0,616648197
C512	0,276610644	0,038919414	0,117673993	0,421703297	0,421703297
C513	0,594887955	0,06223344	0,109931996	0,104118043	0,723716521
C521	0,354249354	0,042261905	0,12797619	0,12797619	0,506448413
C522	0,245306495	0,048065489	0,204895922	0,084664244	0,662374346
C523	0,068292068	0,039479576	0,310106113	0,263319901	0,38709441
C524	0,10992986	0,043030039	0,104486861	0,852483101	0,342445491
C61	0,178075397	0,667468046	0,155260412	0,11691592	0,060355621
C62	0,104662698	0,208474419	0,058027252	0,071468112	0,662030216
C63	0,104662698	0,667468046	0,155260412	0,11691592	0,060355621
C64	0,612599206	0,667468046	0,155260412	0,11691592	0,060355621
C71	0,089357579	0,187156094	0,059690355	0,063596605	0,689556946
C72	0,164650529	0,29805452	0,048147717	0,377574557	0,276223206
C73	0,219951875	0,29805452	0,048147717	0,377574557	0,276223206
C74	0,120851922	0,193877278	0,144732757	0,0444426	0,616947365
C75	0,405188095	0,411342593	0,162268519	0,190046296	0,236342593

Table 6: Alternative weights for Expert 3

Expert 3	w_{AL1}	w_{AL2}	w_{AL3}	w_{AL4}	Sum
w_j	4.33256669	1.206038011	1.785311004	3.658094211	10.98200992
$w_{j\ normalized}$	0.394514913	0.19819425	0.162566872	0.3309879	1

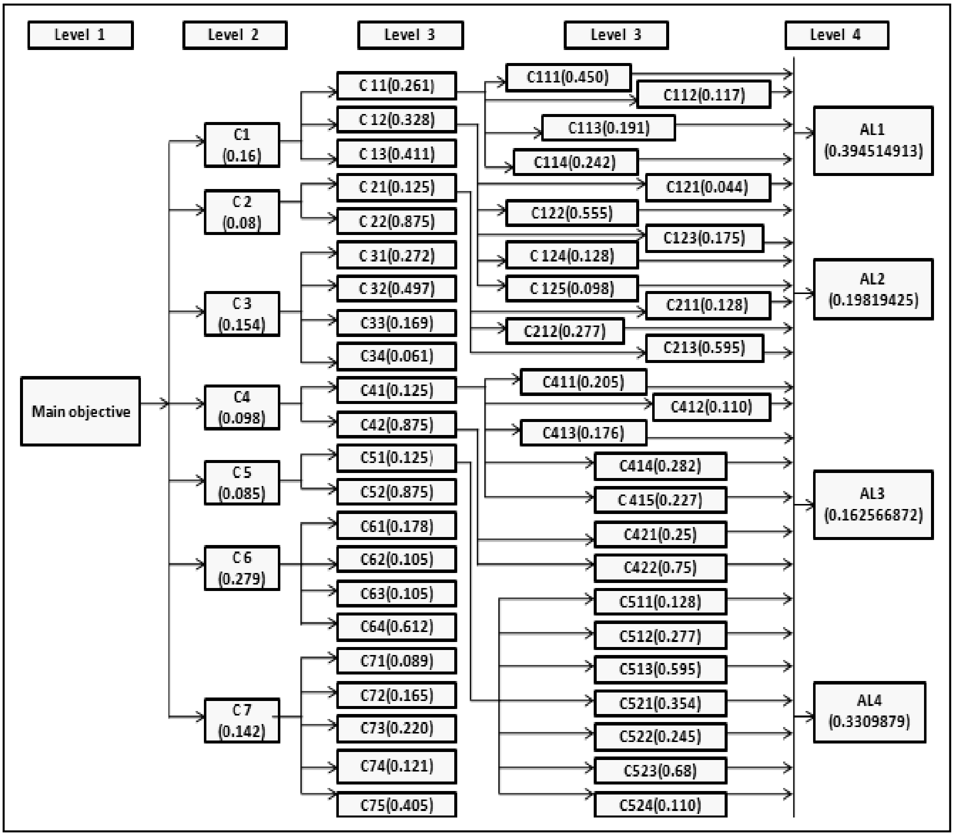

Figure 9: Presentation of the weights of the criteria, subcriteria and alternatives for Expert 3

Nevertheless, since several experts have been contacted and provided different information, the implementation of their information in the AHP method brings about different and even contradictory results. In order to reduce the contradiction and ambiguity, we should combine all the obtained results. The combination must take into account the degree of importance of each expert. For that, Shannon's entropy must be used to calculate the experts' weights.

We calculate the weights of all criteria, subcriteria, as well as the weights of alternatives with respect to each criterion. Then, we multiply the sum of each criterion weight by the alternative one, according to this criterion. Thus we obtain a vector that indicates the impact of the criterion i on each alternative. This vector represents the main eigenvector of the $m \times n$ reciprocal matrix. The results obtained for each expert are shown in Table 7.

Table 7: Weights of irrigation alternatives according to different experts

Experts	w_j	AL1	AL2	AL3	AL4
Expert 1	w_j	3. 478792956	1.343721133	1.511164155	4.666321756
	$w_{jnormalized}$	0.316253905	0.122156467	0.13737856	0.424211069
Expert 2	w_j	2.6289787795	1.642643392	1.612734043	4.315285859
	$w_{j\,normalized}$	0.257752063	0.161049121	0.158116729	0.423082087
Expert 3	w_j	4.33256669	1.206038011	1.785311004	3.658094211
	$w_{j\,normalized}$	0.394514913	0.19819425	0.162566872	0.3309879
Expert 4	w_j	2.567468293	1.42787949	1.822872115	5.392475158
	$w_{j\,normalized}$	0.229019546	0.127367615	0.162601168	0.48101167

Using these results, we can rank alternatives, according to different experts.

From the results of Expert 1, we find that AL4 ≻ AL1 ≻ AL3 ≻ AL2. The use of well water (AL4) is the best choice with the weight of 0.424. It is followed by the reuse of treated wastewater (AL1) (0.316) which is followed by the use of desalinated brackish water (AL3) (0.137) and, finally, by the use of desalinated marine waters (AL2) (0.122). For this expert, the result of the analysis suggests that the use of well water is preferred because it has the highest coefficient of importance (Figure 10).

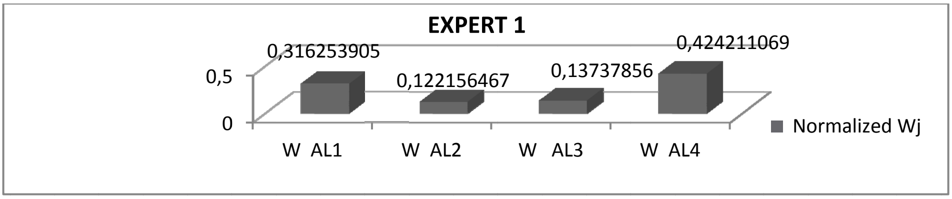

Figure 10: Ranking of water types according to the judgments of Expert 1

From the judgments provided by Expert 2, we obtain the following ranking:

AL4 ≻ AL1 ≻ AL2 ≻ AL3. According to the results obtained from the second expert, the preference of AL4 and AL1 is similar to the first one. Thus, the use of well water and the reuse of treated wastewater are the best types of water for the irrigation of olive trees. The use of desalinated marine waters is preferred to the use of desalinated brackish water according to the judgments provided by Expert 2, which is unlike the rank of Expert 1. We also note that the weights of the two best alternatives are much larger than those of the two others (Figure 11).

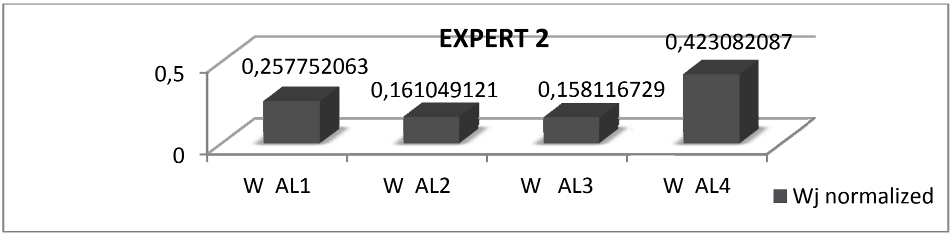

Figure 11: Ranking of water types according to the judgments of Expert 2

Applying the AHP method to the data provided by Expert 3, we obtain the following results:

AL1 ≻ AL4 ≻ AL3 ≻ AL2. According to Expert 3 the best type of water for irrigation is different as compared to the first two experts. Namely, the reuse of treated wastewater turns out to be the best choice with the weight of 39.45%. The use of desalinated brackish or marine waters are the least preferred by all experts (Figure 12).

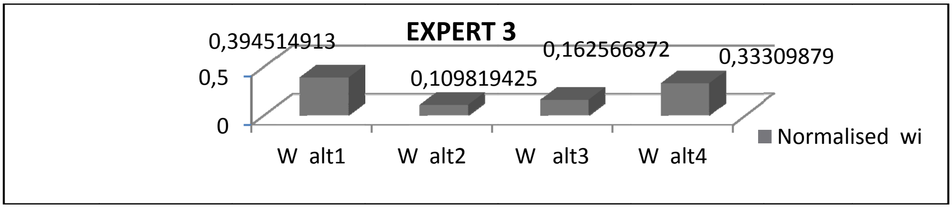

Figure 12: Ranking of water types according to the judgments of Expert 3

The ranking obtained on the basis of the pairwise comparisons provided by Expert 4 is the same as that obtained by Expert 1. However, the use of well water is by far preferred over the other types of water for the irrigation of olive trees with a coefficient of importance of almost 50%, against the other 50% divided among the other three types of water (Figure 13).

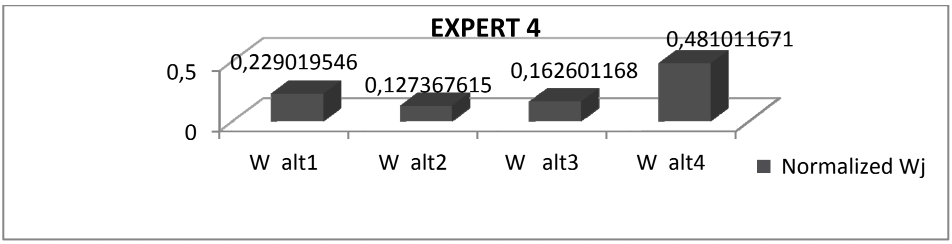

Figure 13: Ranking of water types according to the judgments of Expert 4

4.2 Shannon's entropy for aggregating the experts' rankings

The data provided by the different experts are contradictory and uncertain. In other words, judgments provided by experts are often imprecise, incomplete, uncertain and therefore unreliable due to the inherently limited precision of human evaluations. In this context, unreliability is not synonymous with a total lack of reliability, but it implies partial reliability. In order to cope with heterogeneity, Sandri et al. (1995) have argued that uncertainty models play a crucial role in assessing expertise, since no one can provide absolute certainty of his judgment or advice.

According to our study, since the data provided are uncertain, imprecise, imperfect and conflicting, the weights of the criteria and alternatives determined by the AHP method are also uncertain. These weights are assumed to be subjective probability distributions. This raises the question of how to combine the information from several experts to obtain a better specific result. We cannot regard all the information provided as having the same importance; it must depend on the reliability of the expert. Hence, the aggregation of information should be weighted according to the importance of each expert. In conclusion, to reduce conflict and manage imperfection, we use Shannon's entropy (Shannon, 1948) in order to determine the experts' weights and combine judgments. It is a mathematical function that corresponds to the quantity of information contained or delivered from an informed source, and has the properties of a suitable measure of uncertainty in a random experiment. The more different the information emitted by the source, the larger the entropy (or uncertainty about what the source emits).

4.2.1 Determination of the uncertainty (H_n) of the experts

Shannon's entropy ($\boldsymbol{H_n}$) can serve as a very convenient measure of uncertainty and information that corresponds to a finite probability space or a random experiment. This function has the properties of a suitable measure of uncertainty in a random experiment. We calculate the amount of uncertainty ($\boldsymbol{H_n}$) provided by each expert *i*.

$$H_i = H_i(P_1.....P_n) = -\sum_{j=1}^{n} W_{ij}\, Log_n\left(W_{ij}\right) \tag{3}$$

where W_{ij} is the weight of the alternative *j* according to expert *i*, *i* = 1, ..., *m* and *j* = 1, …, *n*.

$$W_{ij} \geq 0 \text{ and} \sum_{n=1}^{n} W_{ij} \geq 1$$

Shannon's entropy is a decreasing function because the higher $\boldsymbol{H_i}$, the less informative the expert is and the more uncertainty his opinion contains. Therefore, $\boldsymbol{H_i}$ is a function to be minimized. It is then necessary to normalize $\boldsymbol{H_i}$ to find the weights $\boldsymbol{w_i}$ of expert *i, i* = 1, …, *m*.

In our case, alternative weights are assumed to be probabilities. We use Shannon's entropy method to reduce conflict and manage imperfection. This method is based on the theory of probabilities that allows to solve a problem with uncertain data. Since experts do not have the same degree of reliability and the same level of importance, we must determine their weights. The information derived from the data provided by the experts are the weights of the standardized alternatives presented in Table 8.

Table 8: Weights of water types according to each expert

	E1	**E2**	**E3**	**E4**
AL1	0,31625391	0,25775206	0,39451491	0,22901955
AL2	0,12215647	0,16104912	0,10981942	0,12736761
AL3	0,13737856	0,15811673	0,16256687	0,16260117
AL4	0,42421107	0,42308209	0,33309879	0,48101167

These weights are used in a probability distribution. In this case, we can determine the amount of information or uncertainty of each expert using Shannon's entropy. The results are summarized in Table 9.

Table 9: Amount of uncertainty provided by the experts

	$\boldsymbol{H_1}$	$\boldsymbol{H_2}$	$\boldsymbol{H_3}$	$\boldsymbol{H_4}$	**Sum**
H_i	-0,54606995	-0,56419057	-0,55200145	-0,54174727	-2,20400925

We must then normalize the uncertainty quantities of each expert. The obtained data are then summarized in Table 10.

Table 10: The standard uncertainty amount provided by the experts

	$\boldsymbol{H_1}$	$\boldsymbol{H_2}$	$\boldsymbol{H_3}$	$\boldsymbol{H_4}$
$H_{i\ normalized}$	0,2477621	0,25598376	0,25045333	0,24580082

4.2.2 Determination of the experts' weights

When aggregating the opinions of the experts, we cannot regard them as equally important and their judgments, as having the same importance. Indeed, these experts have different degrees of reliability. The more reliable the expert is, the more important his judgment will be. Therefore, to be able to aggregate the opinions of all the experts, we must calculate their weights, which express their coefficients of relative importance.

Since $\boldsymbol{H_i}$ expresses the amount of uncertainty, the higher it is, the more unreliable the expert is and the less his judgments will be considered. This function is then decreasing with the weight of the experts. We obtain:

$$\boldsymbol{w_i}=1 - \boldsymbol{H_{i\,normalized}} \quad (4)$$

Given that $\boldsymbol{H_i}$ expresses the amount of uncertainty, it follows that the higher the uncertainty, the less reliable the expert is and the lower the weight will be. The weight will then be a decreasing function of the amount of uncertainty (Equation 4).

The weights are summarized in Table 11.

Table 11: Determination of the experts' weights

	H_1	H_2	H_3	H_4
W_i	0,7522379	0,74401624	0,74954667	0,75419918

4.2.3 Aggregation of the experts' opinions

To be able to classify the different types of water for the irrigation of olive trees, according to all the experts, we must aggregate all the weights of each alternative determined by the AHP method while considering the degree of reliability of each expert. This aggregation is based on the weighted average method. For each type of olive trees irrigation water, we calculate the priority $\boldsymbol{W'_j}$.

$$\boldsymbol{W'_j} = \sum_{i=1}^{m} \boldsymbol{w_i w_{ij}} \ \forall j = 1, \ldots, n \quad (5)$$

The results are shown in Table 12.

Table 12: Weights of water types

	E1	E2	E3	E4	W_j'
W$_i$	0,7522379	0,74401624	0,74954667	0,75419918	
AL1	0,31625391	0,25775206	0,39451491	0,22901955	0,7522379
AL2	0,12215647	0,16104912	0,10981942	0,12736761	0,74401624
AL3	0,13737856	0,25775206	0,16256687	0,16260117	0,74954667
AL4	0,42421107	0,42308209	0,33309879	0,48101167	0,75419918

On the basis of the determined weight values $\boldsymbol{W'_j}$, we rank the alternatives in a descending order of importance to obtain an outranking graph. The best alternative is the one with the highest $\boldsymbol{W'_j}$, and so on. The alternatives are ranked according to the weights from Table 12.

$$W_j'(E4) > W_j'(E1) > W_j'(E3) > W_j'(E2)$$

Then the ranking of the alternatives is:

AL4 ≻AL1 ≻ AL3 ≻ AL2

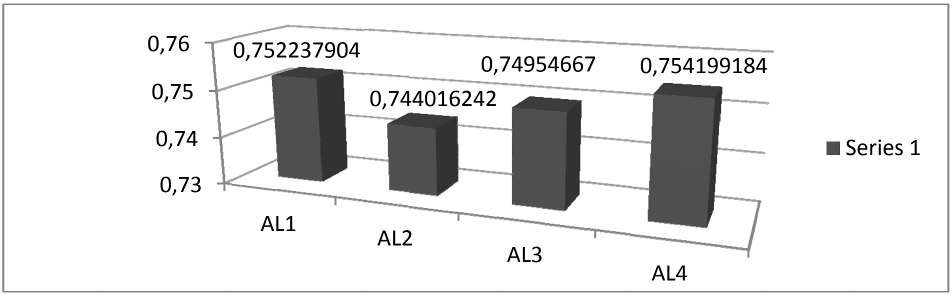

Figure 14: Ranking of alternatives according to the judgments of all experts

From the results provided by Shannon's entropy (Figure 5), we obtain that well water proves to be the best type of water for the irrigation of olive trees in the Sfax region. This alternative minimizes the impact on the environment (contamination) and demonstrates a commitment to public health. Additionally, well water offers an opportunity to enjoy free and healthy water. Hence, well water irrigation can increase olive productivity at the lowest cost. On the other hand, it is obvious that the seawater desalination alternative is considered as the worst technique, mainly because it requires a lot of time and money. So it can have environmental impact. Reuse of treated wastewater is ranked second, followed by desalination of brackish water. In fact, it has the major advantage of providing an alternative resource at a lower cost to limit water shortage, preserve natural resources and contribute to the integrated water management.

5 Conclusion and future research

Tunisia has limited water resources distributed over time and space. In this context, better allocation and valuation of irrigation water are required. In Tunisia, olive growing is of paramount importance in our agriculture in social and economic terms. In fact, irrigation of olive trees is an effective management tool against the hazards of rainfall. Therefore the selection of the best alternative water for the irrigation of olive trees is essential to establish an effective management system. This assessment must be based on the collection of a large amount of information, obtained from several experts. In this context, we hybridized two methods: AHP and Shannon's entropy. Firstly, we used the AHP method to determine the priorities of all criteria of different hierarchical levels and alternatives, and a classification of choice of water alternatives according to each of the four experts is determined. Secondly, we used Shannon's probabilistic entropy method, since the data provided by the experts are contradictory and uncertain and therefore unreliable. Thus, we determined the importance of each expert using Shannon's entropy in order to be able to aggregate all the rankings by the experts and then determine a unique result. The proposed approach has shown that well water irrigation is the best water alternative. Among the most promising prospects, it would be interesting to analyze and measure the uncertainty of the results obtained by the AHP method in a simulation model. It is necessary to increase the use of unconventional waters for treating wastewater. It is a solution that seems efficient in the immediate or short term. But it is still insufficient considering the limitations of their use. As for desalination of seawater, it is a solution that could be serious and radical, but the cost of a cubic meter of this type of water still represents a major constraint. Finally, we must consider the desalination of seawater to solve the problem of lack of water resources in the region in the long term.

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