Chapter

Water Management in Irrigation Systems by Using Satellite Information

Gema Marco Dos Santos, Ignacio Meléndez Pastor, Jose Navarro Pedreño and Ignacio Gómez Lucas

Abstract

Changes in agriculture are associated to the availability of resources and the economic and social demands. One of the more important transformations is to change rainfed into irrigated crops to increase the yield. In most of the cases, water resource and irrigation reservoirs are needed to maintain the yield. However, evaporation from ponds can be an important economic loss and an unsustainable strategy for water management, especially in arid and semiarid regions. Efficient methods for water storage should be established. In this study, a selected area located close to the city of Cartagena (Murcia) and the south of Alicante (Spain) has been studied, where there was an important transformation from rainfed to irrigated crops. Because of the high temperatures and insolation, the increment of the number of reservoirs detected by using remote sensing data and GIS tools may be inefficient for water management. The characterization of these reservoirs, to quantify the potential loss of water due to evaporation, has been done. The use of these tools for analysis could be interesting to find more efficient storage solutions (i.e., better spatial distribution of reservoirs, an increment of depth, and reduction of surface exposure) for improving the water storage and management.

Keywords: arid environments, evaporation, irrigated agriculture, spatial distribution, water storage

1. Introduction

Water management is one of the most important problems for future decades. Although there are areas of the planet where the water availability is naturally scarce due to the rain and temperature patterns, human pressure on this resource is accentuating the problem of scarcity. As reflected in the World Water Assessment Program published by UNESCO [1], there are three types of pressures or "drivers" on water systems: demographic, economic, and social. Population growth increases not only water consumption but also pollution, which is another way to decrease water availability. Furthermore, land occupation and urbanization affect the dynamics of the ecosystem due to soil sealing, and consequently, the hydrological cycle is altered (infiltration processes, aquifer recharge, etc.). Protecting ecosystems is highly important to maintain the goods and services they offer us, and it is so necessary for life. Economic growth has allowed the development of modern extraction and production techniques that aggravate water scarcity. Natural dynamics of water is affected; i.e., river flows are altered or the water table is reduced. The building of infrastructures that benefits the commerce of both products and services associated to water management has been increased. The change in the lifestyle of many countries is reflected in the amount of water consumed, principally in those in which access to drinking water is easy and immediate. In contrast, in developing countries where there is scarcity and water pollution, it is a great challenge. Therefore, there is a social inequality that must be resolved.

For example, in the case of arid and semiarid areas [2], in which the amount of available water is limited due to the shortage and irregularity of rainfall, the development of irrigated agriculture has caused an increase in pressure on water resources. This affects highly negatively the agriculture, which is one of the biggest users of water with respect to the total demand of water (almost 80%) [3]. In these areas, where water is a limited resource, population growth exerts a great negative pressure on it. Agriculture must be able to supply the population even though the availability of water is the limiting factor for food production [4]. To guarantee the continuous supply of water for irrigation, small ponds are built to store the water and manage it according to their needs [5]. These ponds are usually shallow constructions located near the crops that will supply. However, it seems that the management of these small reservoirs is based on the experience of the farmer and not on contrasted technical criteria [6]. Water is a limited and essential resource for life that has to be managed efficiently, equitably, and allow future generations to have access to it. Therefore, the current management model should be changed to make sustainable use of available water resources and develop strategies that promote savings and minimize losses in irrigation [7].

Evaporation is defined as a process by which liquid water turns to vapor state by heating it (energy breaks the bonds of the molecules) [8]. The main factors that influence evaporation are local climatic conditions such as air and water temperature, solar radiation, relative humidity, wind speed [9], and the geometry of the ponds, for example, evaporation is greater if the relationship between area and volume is large [10]. In areas with high insolation, the evaporation from the sheet of water represents a significant loss from the environmental and also economic point of view [11]. Different methods are being developed to avoid evaporation: there are chemical methods such as stearyl alcohol [12], floating modular systems that have different shapes and materials [13], floating photovoltaic panels [14], canvas, or suspended coverages [15]. Each method may be appropriate depending on the characteristics of the place where it will be installed (amount of water stored, area, costs, etc.) [16]. Therefore, it is necessary to study tools and develop management strategies that improve the efficiency of water consumption and obtain the potential evaporation from the ponds and reservoirs.

The use of Geographic Information Systems (GIS) in the study of water resources allows us to know the dynamics of them, and therefore, models with different scenarios of water availability or demands can be developed [17]. With these models, different projections can be made in order to develop management scenarios more suited to the state of resources. This technology, GIS, is very suitable due to the amount of information that can be incorporated into the models, and the possibility of viewing the information in the form of maps [18]. In developing countries, this tool can help the management of its resources with a relative low cost and the large number of free images obtained over many years from remote sensing. Moreover, in those countries in which it is not possible to collect data in situ because of the cost, time, or access due to legal causes or because of war conflicts.

GIS combining remote sensing help to solve many problems related to resources management.

Remote sensing is being a very useful method to delimit and study water bodies, especially due to the difficulty of obtaining continuous information. Due to the contrast between the reflectance of the sheet of water and that of the earth surface [10], it is possible, through satellite images, to study and monitor the water storage [19], to observe the changes in the surface of water bodies over time, study the evolution of the irrigation reservoirs of an area [20], estimate its evaporation (important in arid and semiarid zones) and volume. The water absorbs the energy in wavelengths of the near and medium infrared; therefore, the reflected energy of these is low and the water bodies appear in dark color in both the multispectral images and the grayscale images [21]. Moreover, satellite images facilitate the composition of RGB or false color images where water sheets can be detected and analyzed.

Facing of future scenarios of climate change [22], in which the availability and quality of water can be seriously affected [23], it is necessary to improve the use of water resources through the incorporation of new techniques and the modernization of infrastructures. This includes the application of regulations [24] that support integrated management techniques that guarantee a better resource quality and also promote citizen participation [25].

In this work, the combined use of remote sensing data and GIS tools, demonstrated with the example, the possibilities of managing and controlling water infrastructures and the evaporation of water in agriculture, is one of the major consumers of water.

2. A study case: Campo de Cartagena, southeast of the Iberian Peninsula

2.1 Study area

The study area is located beside the Mar Menor in Murcia and south of Alicante (**Figure 1**), Spain. This basin is a sedimentary plain formed by conglomerates, marls, sandstones, and clays [26] with approximately 152,000 ha. The Mar Menor is the biggest coastal lagoon of Spain that is included in the RAMSAR convention. It is in serious danger of pollution as a result of nitrogen and phosphate contributions from agriculture that cause the loss of its water's quality, the decrease of the diversity and elimination of autochthonous species, and induce the proliferation of algae blooms. The two factors that most affect this wetland are tourism (population growth) and agriculture; both generate polluting inputs that reach the Mar Menor through the different watercourses and infiltration processes. The climate is Bsh according to the Köppen classification, with low rainfalls (around 300 mm per year) of torrential type especially during the autumn. The average annual temperature is about 18°C, with hot summer (about 32–35°C in August) and mild winters (the temperature usually does not drop below 5°C) [27]. Precisely, the weather is one of the main reasons why so many tourists (both Spanish and foreign) come every year to visit the Region of Murcia (more than 1 million people in 2015–2016) [28], especially near the coast.

Different improvements, mainly since the second half of the twentieth century in the region of Murcia and Alicante province, have favored the growth of population, principally located in coastal areas. This increase may be due to the improvement of communication channels (roads) and greater availability of water resources, which has allowed the development of agriculture. Agriculture is very important in the Region of Murcia, because of the good climate and a fertile soil

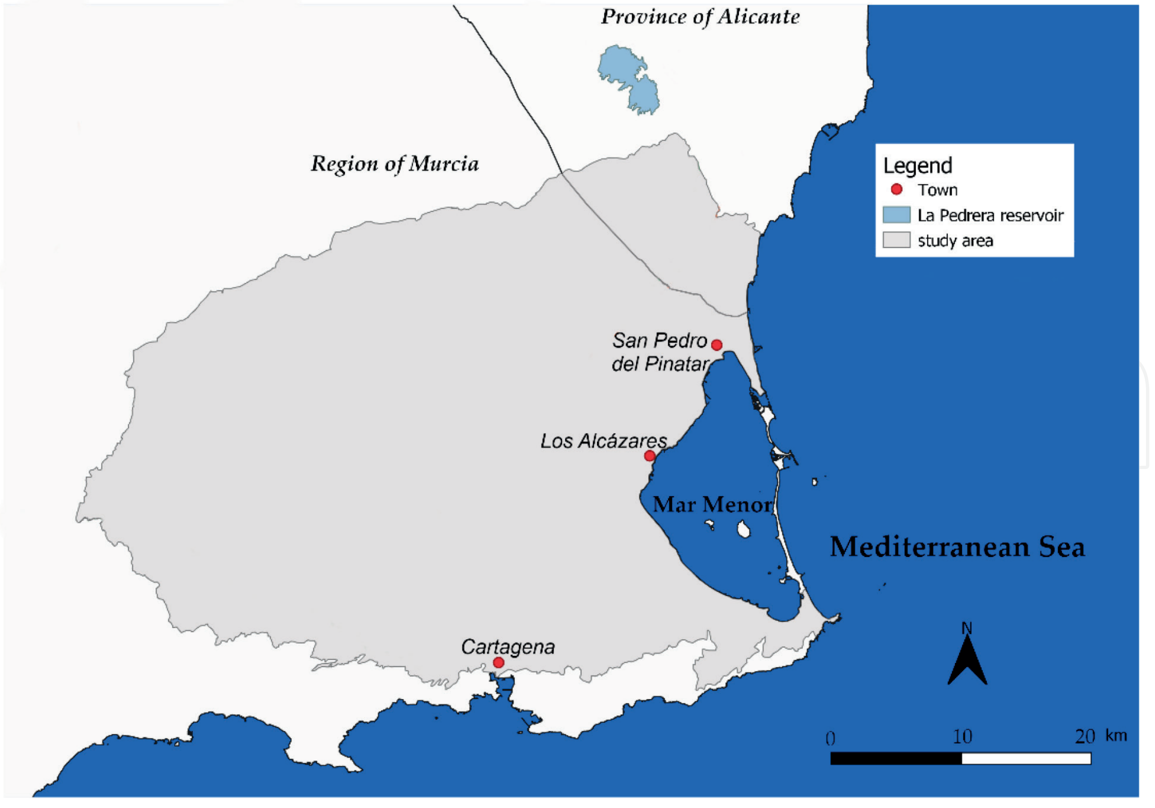

Figure 1.
Location of study area (Campo de Cartagena, Mar Menor watershed) in the region of Murcia and the south of the province of Alicante.

in many river basins that allows suitable growth of crops, but the lack of water has limited the production. Therefore, the change of rainfed crops to irrigated crops was benefited by the capital investment (the Tajo-Segura water transfer in 1979, the exploitation of the aquifers and the obtaining of desalinated water), which increases the availability of water; the productivity of the crops has improved in spite of the severe shortage suffered by the area. La Pedrera reservoir (built in 1985), located in the province of Alicante, is responsible for regulating the water, which comes from the Tajo-Segura transfer canal (agricultural and urban supply). This reservoir maintains adequate water availability despite the severe scarcity suffered in the area [29]. In fact, Murcia exports between 20 and 30% of fruits and vegetables in Spain, especially to the European Union [30]. Even with the external contributions of water, it is not enough to supply the water needs of the area that often suffers serious droughts that cause cuts back not only for agriculture but also for urban supply. In addition, during the summer, the demand for water for agriculture is higher because of the large water deficit and high temperatures. This situation also coincides with the period of greatest urban demand in the area due to tourism [31], especially in some areas closer to the coast. For example, it is estimated that on the Costa Cálida, there were almost 4 million visitors in 2016 [28].

2.2 Methodology

The data were obtained from the National Geographic Institute (IGN). We used the geodesic reference system ETRS89 and UTM projection zone 30 [32].

The Mar Menor watershed was delimited with the Digital Terrain Model (MDT25 CC-BY 4.0 scne.es) and the GRASS software using the flow lines that run along the maximum slope. The basin covers 151,641 ha and is located mainly in the Region of Murcia and a part in the province of Alicante. All the reservoirs of the basin were digitized, one by one by, using high-quality orthophotos from the Plan

Figure 2.
Old mills and the new irrigation systems in the Campo de Cartagena.

Nacional de Ortofotografía Aérea (PNOA) (FotoPNOA 2004–2016 CC-BY 4.0 scne.es, pixel size of 25 cm). The same process was followed with old photographs taken from a photogrammetric flight along the period from 1973 to 1986 (Fotol 1973–1986 CC-BY 4.0 scne.es, scale 1: 18,000, pixel size between 27 and 45 cm). The digitization process was done with QGIS v.3.2. The ponds and reservoirs were marked with points to locate them, and then, they were digitalized to determine their surface taking into account the limits of the structure, when they were at maximum capacity. A field trip was also done to compare the results obtained from the images with the disposition in fact, checking close to a hundred elements (old mills, ponds, and small reservoirs) (**Figure 2**).

A heat map was developed from the density of points that identify the location of each irrigation ponds/reservoirs to better understand their distribution. Point interpolation aids to visualize in a map the concentration of these in a continuous surface. Three parameters are used to create a heat map: the cell size, the bandwidth, and the type of calculation used in the interpolation. The cell size will determine the degree of detail on the surface. The larger the cell size, the less continuous the color gradient that represents the concentration of points will be. The bandwidth (or search radius) is the area around each point that the GIS will take into account for density calculation. The type of calculation used in the most common interpolation is inverse distance weighting (IDW), which assigns more importance to the functions that are closer than to those that are furthest away [33]. In this case, we used a search radius of 5 km and 15 pixels of cell size.

To estimate annual evaporation losses in the study area, we have used as reference the evaporation values published in the article "Regional assessment of evaporation from agricultural irrigation reservoirs in a semiarid climate" by Martínez Alvarez et al. [34]. They use measures done in the 2003 for the entire Segura River basin (located in the southeast of Spain, including the study area). In this article, authors estimate the evaporation losses using daily, monthly, and annual data on temperature, precipitation, relative humidity, wind speed, wind direction, and solar radiation of 74 agro-meteorological stations for the period 2000–2006. In addition, some of them have class-A pan evaporometer in which evaporation was calculated by a sensor that determinate the difference in water level. The class-A pan evaporometer standardized by the US National Weather Service is a 120.7-cm diameter and 15-cm-deep cylinder made of galvanized iron. It is elevated about 15 cm from the ground by a wooden platform. It must be located where the air circulates freely so that it does not affect the measurements [35]. They use 14,145 irrigation reservoirs for the entire Segura basin, which occupied 4901 ha. They obtain as a result the annual evaporation loss in the Segura basin taking into account the maximum surface area, which was 68.8 hm^3. Based upon this value and considering the surface, the evaporation value of water used as a reference is 0.014 hm^3 year/ha. This helps us to estimate the evaporation loss estimation in our study area.

3. Results and discussion

Figure 3 presents the digitized points that indicate the location of the irrigation ponds for both periods. There is a clear increase in the number of points currently with respect to the previous period.

In the image a (**Figure 3**), the points do not appear distributed following any regular pattern; they are dispersed throughout the basin but especially near the coast and the urban cores, some of them forming small groups. In the top of the basin (NW), in the foothills of the Sierra de Carrascoy and El Valle, there are no irrigation ponds because at that time, mechanization and cultivation techniques did not allow working the land in areas with steep slopes. In the image b, there is a greater increase of irrigation ponds and small reservoirs. Grouping of points can be observed mainly in the center of the basin, which is quite flat, and in the top near La Pedrera reservoir. There is also a tendency for a high density of points near the coast as in the first image. In this case, due to the modern techniques, the irrigated crops occupy the foothills of the mountains.

In order to understand and visualize better the irrigation ponds distribution patterns in the area and compare them between two periods, a heat map (**Figure 4**) was created from the density of points. These maps confirm in a very clear way the changes produced in the area.

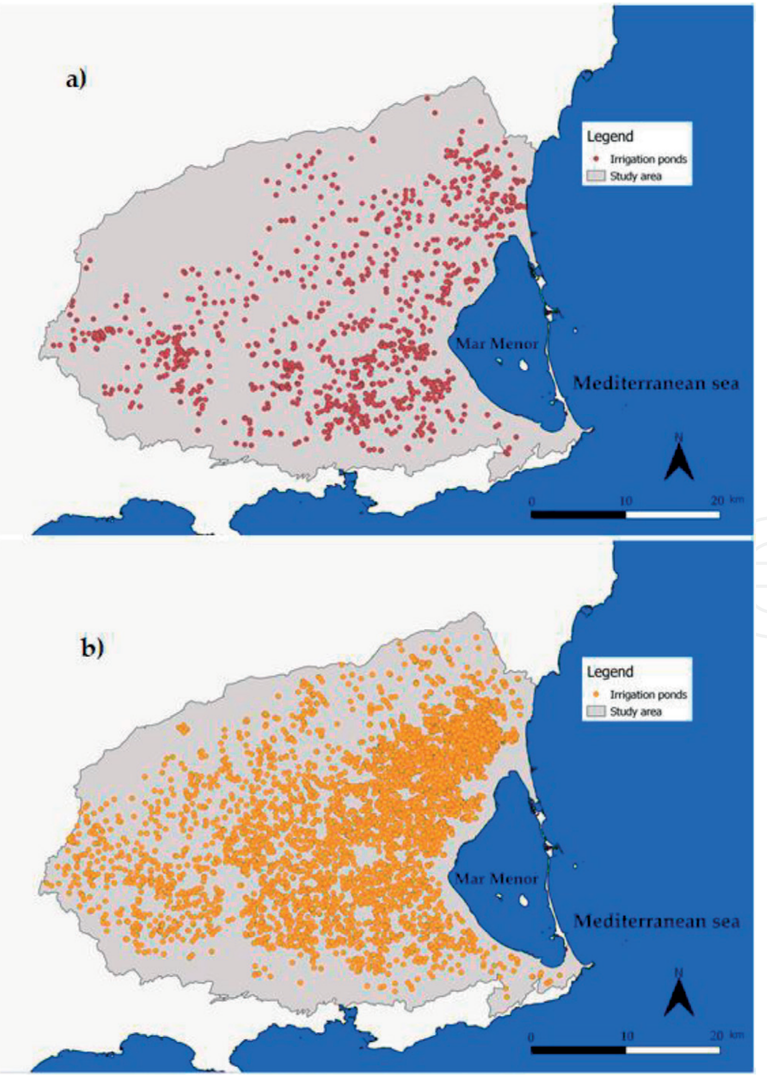

Figure 3.
Points marking the location of irrigation ponds in the Mar Menor basin in the 1973–1986 period (a) and nowadays (2016–2017) (b).

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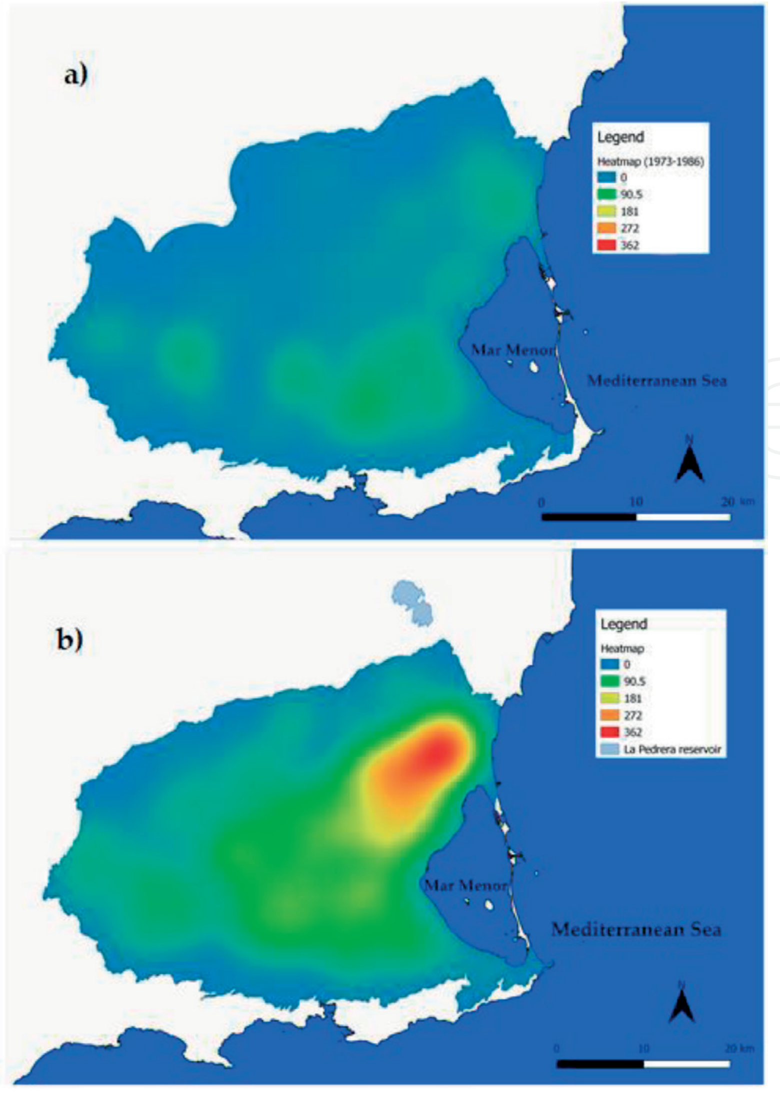

Figure 4.
Heat maps from dot density of the identified ponds with old photographs (a) and those with current ones (b).

In the first image (**Figure 4a**), high density of points (in green) is observed in the lower part of the basin and following the coastline. This location may be associated with the extraction of water from the subsurface aquifers, following the pattern of the traditional systems such as windmills. (A pond was situated near the mill so that the water could fall into it.) Moreover, extraction that is more efficient with pumps made possible to obtain water from the aquifers at a larger depth coming to cause an overexploitation of aquifers.

The arrival of water from the Tajo-Segura transfer in 1979 increased the availability of water and relieved the pressure on groundwater [36]. This situation benefited production and the expansion of intensive agriculture (with the corresponding construction of small reservoirs to store and supply water).

In the second image (**Figure 4b**), there is a generalized increment near the coast and a great increase in the upper part of the basin (NE). This difference could be explained by the construction in 1985 of the La Pedrera reservoir. It has 1272 ha and can store 246 hm^3. This reservoir receives water from the Tajo-Segura transfer and distributed to the Campo de Cartagena by a great canal and others supplied conductions.

La Pedrera reservoir is also used for urban water supply through the Taibilla canal. Therefore, it is easier to supply the crop fields closest to the reservoir. Consequently, it has favored a greater development of greenhouses (**Figure 5**). They are grouped near the towns of San Pedro del Pinatar (Murcia) and Pilar de la Horadada in the south of Alicante.

Figure 5.
Group of greenhouses near San Pedro del Pinatar in the study area (source: derived from FotoPNOA 2004–2016 CC-BY 4.0 scne.es).

	Number of ponds	Total area occupied (m^2)	Mean area per pond (m^2)	Estimated evaporation (hm^3/year)
1973–1986 period	971	886,349	318	1.24
2016–2017 period	3846	12,013,189	1631	16.82

Table 1.
Values obtained from the irrigation pond digitalization and estimated values of evaporation in the study area for both periods.

After the analysis of the data and the digitalization of the irrigation ponds from the images in both periods, **Table 1** shows a summary of them. A total of 971 reservoirs were digitized from the data of the period 1973–1986. The sheet of water, according to the sum of the surface of all them, accounted to 88.63 ha. The average surface area of the reservoir/pond was 318 m^2.

In the second period (2016–2017), 3846 irrigation ponds were digitized from PNOA images. The total water surfaces were 1201.32 ha. The average surface area of the reservoirs increased to 1631 m^2.

These values indicate that the number of reservoirs in this area has almost incremented four times. For the average surface of ponds, the size at present is five times higher than before, however not necessarily deeper than the oldest. Therefore, the total area occupied by the reservoirs has increased fourteen times and the size of the surface of the reservoirs only five times for the last four decades.

To estimate the possible evaporation losses from the sheet of water of the small reservoirs/ponds, we took as reference the value given for the area of 0.014 hm^3 year/ha [34]. Considering all the reservoirs to their maximum capacity, the values estimated for each period were as follows:

- For the 971 ponds in the first period (determined from the images obtained between 1973 and 1986), the annual losses would be close to 1.24 hm^3/year,

- and for the second one (mages of PNOA 2016–2017), it would be close to 16.82 hm^3/year.

This means that there is a difference of approximately 15.62 hm^3/year, parallel to the increment of the surface exposure of reservoirs and ponds. This amount of water that can be lost is equal to that needed for the supply of a city of 300,000 inhabitants for a year considering the average water consumption in Spain for inhabitants [37].

Water scarcity in this area has always been a main concern for agricultural production. However, with the transfer from other river basins (i.e., Tajo river), water availability has been increased and along with the population growth and agricultural yield. This was reflected in the construction of reservoirs/ponds in the last years, which has been increased. With this increment, the potential evaporation of water from reservoirs and ponds has been dramatically increased by the way.

According to a report managed by the Ministry of Agriculture and Water of the Region of Murcia with data from the Space Agency of Meteorology (AEMET), and with the collaboration of different universities and institutions, the evolution of rainfall does not follow a clear trend, which is a normal situation in that area with such irregularities. For temperatures, a slight tendency to increase is observed. In fact, according to this report from 1971 to 2009, the average annual temperature of the entire Region of Murcia increased from 15.5 to 17°C [38]. Therefore, the evaporation loss could be aggravated considering the scenarios based on the climate change and the increase in temperature. In this sense, evaporation can be over the values estimated in this work.

In this line, it is important to study and develop measures to avoid water evaporation and improve the efficiency of the irrigation system. For this reason, it is convenient to study a better spatial distribution of reservoirs and reduce the number of them. Moreover, an increment of depth in their construction can facilitate to store the same amount of water with less surface exposure to evaporation. Finally, the use of some techniques to cover the ponds can reduce the water surface exposure.

4. Conclusions

Remote sensing data are very useful to study and analyze the amount of water stored and the management of irrigation systems. The use of these technologies, both GIS and remote sensing, can help in the management of decision-making about water resources.

The example given shows that the amount of water that could evaporate represents a significant loss. In this case, the amount of water that could evaporate is almost 14 times higher now. This matches with the increase in the total surface occupied by the irrigation ponds. With only a four-time increment in the number of reservoirs, the amount of water that could evaporate increases by 350%. Although it is an estimation, it is clear that water losses due to evaporation represent a high cost, especially in areas where this resource is scarce.

Despite the water limitations of the area, in the Mar Menor basin, there are many agricultural fields that generate tons of fruits and vegetables that provide a great social and economic benefit to region. Even with the different sources of water, there is still a water deficit that generates (especially during droughts periods) economic, social, and environmental instability.

In addition, with the possible effects of climate change that indicates less precipitation and higher temperatures, it is expected that the amount of water resources available can be seriously affected especially in arid and semiarid areas such as Murcia and Alicante, which already suffer the effects of scarcity. Efforts should be done applying techniques to reduce the evaporation. Therefore, saving the resource to avoid losses as much as possible and be able to supply a growing population is a priority.

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Conflict of interest

Authors expressed that there is no conflict of interest.

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