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Global Change: Impacts on Traditional Rainwater Harvesting Systems in Campo de Cartagena (Region of Murcia, Spain)

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Abstract

The effects of global change on the planet are undeniable, especially in terms of climate change, which is alarming in regions with water resource deficiencies, such as arid and semi-arid territories. One such territory is the Region of Murcia (Spain), in the southeast of which lies the Campo de Cartagena region. It is place where rainwater has historically been essential for settlement and traditional agricultural and livestock farming, giving rise to a valuable, now-forgotten water heritage. Through historical, spatial, climatic, and statistical analysis, we aim to demonstrate the significant implementation of these infrastructures in the study area and identify the causes of their abandonment, despite the continued increase in demand for water by all economic sectors, especially the agricultural, urban and tourism sectors. The results demonstrate the existence of five traditional runoff management infrastructures (cisterns, dams, runoff water channels, terracing and benching), and that the effects of global change have been decisive in their neglect, especially those related to climate change and land use modifications, in addition to increased demographic and socioeconomic pressure.

Keywords: global change; rainwater; traditional water management; agriculture; hydraulic heritage; GIS; CORINE land cover

1. Introduction

Located in the southeast of the Region of Murcia (Spain) and measuring nearly 1500 km^2, the natural region of Campo de Cartagena is a plain bordered on all sides by mountain ranges, except for the eastern sector, where it slopes downwards and where the Mar Menor is located (Figure 1). Thus, the greatest differences in elevation exist in the area where it meets these reliefs, where the terrain is steeper and more difficult to adapt for agricultural exploitation, while the rest of the territory constitutes a vast expanse, whose gentle slope determines the direction of its drainage network.

The drainage network is composed entirely of ravines, dry beds and trough of varying length and width, the headwaters of which are located in the aforementioned surrounding mountain ranges [1]. Thus, these channels generally descend from these elevations toward the center of the basin, tracing a hierarchical, tree-like network. The smaller ones converge in the more important ones, and these, finally, with the main collectors. The most important of these is the Fuente Álamo or Albujón ravine, located in the center of the region and draining runoff from west to east, channeling it to the aforementioned lagoon.

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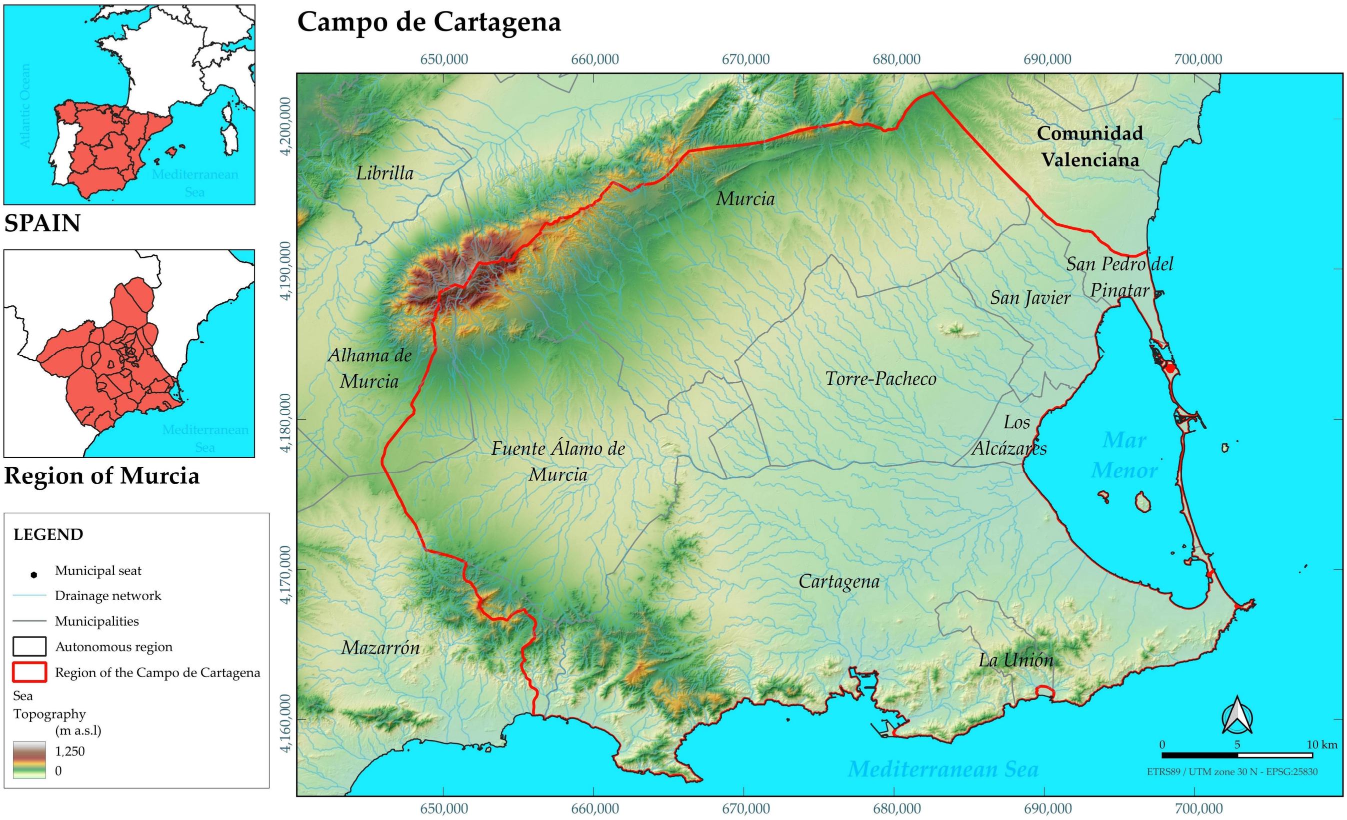

Figure 1. Study area: natural region of Campo de Cartagena, southeast of the Region of Murcia, autonomous community located in the southeast of Spain. Authors.

However, all these channels remain dry for most of the year, and only during episodes of intense rainfall are they capable of transporting considerable flows, which at certain times constitute true water resources. Although they are sporadic and usually mobilized in torrential flows, slowing their flow and diverting it to areas of agricultural interest is essential to allow their agricultural use.

Furthermore, the climatic characteristics of this region are typical of the semi-arid regions of the planet [2]. Consequently, the annual rainfall barely exceeds 300 mm, with peaks in autumn and spring, and an average annual temperature of around 18 °C is recorded, with summer highs exceeding 40 °C.

However, even with this significant limitation, which influences the record of a structural water deficit exceeding 400 mm/year, this is one of the most important agricultural areas in the country in terms of the population dedicated to agricultural activities, as well as the volume and quality of its production. It is also important in terms of the economic wealth generated, with commercial transactions involving agricultural and livestock products, and derivatives, for prominent international destinations, primarily for the European market [3].

A territory with a deep-rooted agricultural tradition that, over the centuries and thanks to technological innovations and acquired knowledge, has evolved from primarily rainfed production until the mid-20th century toward a largely highly technically irrigated one [4]. This transformation has also altered the land use and has been made possible by the implementation of systems of varying complexity that have allowed for the almost continuous and increasing availability of water resources (groundwater, subsurface water, and surface water).

Thus, the systems have progressed from the archaic but efficient use of rainwater to the transfer of foreignwater flows from the Taibilla and Tajo rivers, the desalination of seawater and brackish water, and the application of modern systematic irrigation techniques. These techniques are evidence of an ancient water culture, both tangible and intangible, dedicated to using the minimal resources available to obtain the highest possible returns. In fact, in Spain, the application process for the declaration of "Historic and Traditional Irrigation Systems" as a representative manifestation of Intangible Cultural Heritage has just been initiated[1]. The trend of protection and recognition includes the previous declaration in 2009 as Intangible Cultural Heritage of Humanity of the "Consejo de Hombres Buenos" of the Orchard of Murcia (Murcia, Spain) and the "Tribunal de Aguas" of the Orchard of Valencia (Valencia, Spain)[2]. These two entities have been identified as customary courts, where irrigators resolve their disputes for the use of water in the area they govern in an autonomous, democratic, expeditious and equitable manner.

Considering the above, it is worth asking the following: What infrastructures historically harvested rainwater in this region and what was their spatial distribution? What is the current situation regarding rainwater harvesting (RWH) in this territory? And what has been and is the impact of global change on these infrastructures, especially considering climate and land use changes? These are multiple questions whose resolution constitutes the main purpose of this research. Research that is important in terms of the novel global view it offers of the traditional water harvesting and harvesting systems used and the analysis of their existence or disappearance according to the consequences of so-called global change.

In this sense, "global change" is understood as the set of large-scale transformations occurring on the planet as a result of human activity and natural processes themselves. These changes can be summarized as: climate change, overexploitation of natural resources, land use changes, environmental pollution, biodiversity loss, deforestation, ocean acidification, alteration of biogeochemical cycles, introduction of exotic and invasive species, population growth, and excessive consumption.

From a general to a specific perspective, it is worth noting that the literature on global change is certainly abundant, although mostly developed from a purely biological perspective. At the international level, there are some notable recent examples [5,6], while in the case of Spain, the work coordinated by Dr. Duarte [7][3], the one coordinated by Dr. M. B. García and Dr. P. Jordano [9], and the one recently edited by M. Oliva, J. Martín, C. B. Lozano, J. I. López and J. Bonsoms [10] should be highlighted. Specifically, for the case study, research linked to the availability of water resources stands out, with the predominance of research on the effects of such alteration on the flows of some Spanish rivers being evident [11,12].

Aside from this, the bibliography is scarce; even more so if the search is limited to the Region of Murcia and specifically to Campo de Cartagena. These are territories where research has been conducted, preferably and independently, on issues related to climate change, environmental pollution, and the overexploitation of natural resources. Therefore, the approach proposed in this work is innovative. On the other hand, regarding the analysis of runoff as a resource, one of the most recent and comprehensive approaches was published in 2018 [13], and there are also publications aimed at studying the existence and importance of cisterns in Campo de Cartagena [14,15], as well as some aimed at analyzing slope irrigation [16]. However, it is equally true that most authors have focused their attention on the relevance of these infrastructures, without directly considering their obsolescence and abandonment as a consequence of the effects of global change, as happened in this region with waterwheels and windmills to raise water. In fact, it has generally been pointed out that the main reason for this situation is the technological evolution of hydraulic systems, a matter that is also not uncertain.

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The results obtained demonstrate the historical implementation in the study area and for centuries of different systems of runoff utilization, specifically: cisterns, dams, runoff water channels, terracing and benching. These infrastructures are widely used and their existence and functionality proved essential, first until the beginning of the 20th century, when modern groundwater exploitation techniques made continuous, almost ad hoc irrigation possible, and then with the arrival of the Tajo-Segura Transfer. A water transfer project that involved a green revolution and the gradual abandonment of dryland agriculture and, with it, of the infrastructure that supported it with sporadic but very important irrigation. The effects of global change have also played a key role in this abandonment, with a particular impact of the recent climate change and land use changes resulting from demographic and economic pressure. Runoff water was, in this way, an enormously useful resource in the past, which is why the protection and recovery of the resulting heritage and the re-implementation of these updated techniques are proposed as a measure to obtain new resources in a framework of marked water deficit, and to increase the adaptation capacities to future changes. Future changes make the advance of desertification and the worsening of droughts seem to be unavoidable consequences.

Therefore, the objective of this research is to provide a comprehensive overview of the historical RWH infrastructures in the Campo de Cartagena, to analyze their spatial distribution and current condition, and to assess how climate and land-use changes associated with global change have influenced their persistence, transformation, or disappearance.

2. Materials and Methods

Firstly, for the analysis of the spatial distribution of the infrastructures and works for the use and exploitation of runoff waters in the Campo de Cartagena, of known and proven use, two processes have been carried out.

1. The first involves identifying the region's old cisterns, dams, and drainage channels. Unique runoff water collection infrastructures are recorded in the planimetric sketches. To this end, *Bosquejos planimétricos* (Planimetric sketches) produced by the IGE (Spanish Institute of Geography and Geology) between 1898 and 1901 were used, given that this is the only official, detailed cartography that reflects the existence of these hydraulic elements in a generalized and relatively accurate manner in the territory. Moreover, this was at a time when their implementation and use were probably most important in the study area. This circumstance was influenced both by its population and by the development of hydraulic technology at that time, which was still in its infancy in terms of the motorized exploitation of underground resources and, of course, non-existent in terms of the reception of foreign waters or the treatment of wastewater or saltwater.

This cartography was prepared under the direction of the Central Evaluation and Cadastre Commission, dependent on the Spanish Ministry of Public Works, and pursuant to the *Ley de 24 de Agosto de 1896 sobre rectificación de las cartillas evaluatorias de riqueza rústica y pecuaria y formación del catastro de cultivo y del registro de predios rústicos y ganadería*. Specifically, the documents analyzed were fifty-one, physically held in the archives of the National Geographic Institute (IGN) (Spain). Their production was linked to the development of the National Topographic Map (MTN) at a scale of 1:50,000, which began in the late 19th century. These maps were executed at a scale of 1:25,000 for each municipality and based on field measurements drawn in handwritten form. Furthermore, as a secondary and equally informative source, historical aerial orthophotography made available digitally by the IGN itself has been used: Flights 1929–1930 (Ruiz de Alda), 1945 (Americano Serie A), 1956 (Americano Serie B), 1981 (Nacional), and Plan Nacional de Ortofotografía Aérea (PNOA) 2022. This is cartographic documentation whose review has also been

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implemented as a validation procedure for the identification of hydraulic artifacts made in the Planimetric sketches.

Historical cartography has traditionally been used as a source of information for the analysis of territories and their constituent elements. The development of Geographical Information Systems (GIS) has led in recent decades to the application of standardized and replicable methodologies for generating and managing this historical information which can be incorporated into a Historical-GIS (HGIS) [17,18]. That is, the use of GIS for the digitization and georeferencing of historical maps and their information, a procedure currently on the rise in various disciplines.

Consequently, this work is based, in part, on previous research that has used such Planimetric sketches. However, it does so specifically on those that have established this link between this historical cartography and the elements of the hydraulic heritage represented therein, since it is these that are the subject of this article. This contribution has replicated part of the approach and methodology used in these previous experiences, which, moreover, are few in number.

Along these lines, excellent examples in Spain are the contributions related to the Autonomous Community of Madrid and aimed at the identification and study of its historical hydraulic assets and the preparation of a general inventory [19,20]. Also noteworthy are the studies applied to the Valencian Community, specifically to the province of Alicante, among which one stands out, dedicated to the analysis of the hydro-toponyms of the Vinalopó area [21]; another on the hydraulic mills of Elda fed by this same river [22]; and a third and fourth that focused on traditional floodwater harvesting systems in the Abanilla-Benferri [23] and Sarsa-El Derramador (Agost) [17] ravines. Furthermore, two new works have recently been published, whose methodological basis is equally fundamental to this research: the first is a study of the water mills (or blood norias) that existed in Campo de Cartagena [24], and the second is a study of the water-raising windmills located in this same area [25].

Considering the above, the processes described below constitute the primary methodology applied in this phase of the work:

First, using a GIS, a digital cartographic project was created using layers that serve as an informative support and as a digital tool for representing the identified data, also giving rise to a Historical GIS (HGIS). Thus, the free and open-source software QGIS (version 3.34 Prizren, Switzerland) was used.

Next, using the aforementioned planimetric documents as a reference, a systematic scan was performed of each of the cartographic sheets included in the territorial analysis framework to visually identify and geolocate the desired hydraulic elements[4]. The methodological use of the sheet as a tracking unit instead of searching by bands or grids is due to the greater simplicity of keeping track of the analyzed documents, but also, above all, to the difficulty associated with the fact that many of these sheets overlap in certain areas. This could lead to errors due to a lack of review of hidden areas, either by not alternating viewing of the documents or by not doing so in the correct order. This repetition of mapped areas can lead to duplicates of the identified elements, which was corrected through a second review.

The aforementioned identification of these elements, after validation by means of the aforementioned historical aerial orthophotography, was transferred to the digital project by creating independent shape file layers in vector format and point geometry. Next, the specific distribution of the hydraulic artifacts of interest was analyzed using a Heatmap. This was achieved by graphically representing the values of the smallest radius, a quartic kernel, and a discrete interval, which are more representative of the spatial concentration of these artifacts.

2. Second, the identification of the terracing and terraced infrastructure was carried out through a spatial review of different sources. First, and using the aforementioned GIS, LiDAR (Light Detection and Ranging) mapping, specifically the second coverage published in Spain, as the third will not be published until the second half of 2025; second, historical and current aerial orthophotographs made digitally available by the IGN; and finally, through fieldwork. This identification was transferred to the GIS by creating independent shape file layers in vector format and polygonal geometry.

Likewise, using the indicated GIS and the Qgis2threejs plugin, three-dimensional (3 D) terrain models have been generated of certain representative enclaves of the historical construction of terracing and terraces in the study area. To this end, Digital Terrain Models (DTMs) developed by the CNIG with a 2-m height resolution (DTM02) and aerial orthophotographs from the Ruiz de Alda Flight from 1929 were used.

Furthermore, the analysis of land uses applied to the study area was carried out using GIS and statistical analysis, performing a comparative study of the Spanish land use maps (*Mapas de ocupación del suelo*) corresponding to the European CORINE[5] Land Cover project (CLC), versions 1990, 2000, and 2018. Unfortunately, the new version of this cartography has not yet been published, as work began in 2025 and is scheduled for completion in 2026.

Finally, regarding the analysis of the climate dataset, the following should be noted. Monthly climatic data were obtained from the TerraClimate database, which provides global gridded fields of near-surface meteorological variables and derived water-balance components at ~4 km (1/24°) spatial resolution for the period 1958–2024.

The following variables were downloaded from the official THREDDS server of the Northwest Knowledge Network (University of Idaho):

- Precipitation (PPT, mm month^{-1})
- Potential evapotranspiration (PET, mm month^{-1})
- Surface runoff (q, mm month^{-1})
- Maximum and minimum air temperature (TMAX, TMIN, °C)
- Standardized Precipitation-Evaporation Index (SPEI)

The Standardized Precipitation–Evapotranspiration Index (SPEI) is a multiscalar drought index that quantifies anomalies in climatic water balance by combining precipitation (P) and potential evapotranspiration (PET). It's computed from the accumulated difference between P and PET over a given timescale and then standardized to allow comparison across regions and periods. Unlike precipitation-only indices, SPEI explicitly incorporates atmospheric evaporative demand, making it particularly sensitive to temperature-driven drying under climate warming. This characteristic renders SPEI especially suitable for Mediterranean and semi-arid environments, where increasing PET plays a major role in drought intensification. In this study, SPEI-12 is used to characterize long-term hydrological drought conditions and to link observed climatic trends with changes in water availability relevant to traditional rainwater-harvesting systems [26].

Potential evapotranspiration was obtained from the TerraClimate dataset, which estimates PET using a modified Penman–Monteith formulation that integrates near-surface air temperature, radiation, humidity, and wind speed at monthly resolution. This physically based approach provides a robust representation of atmospheric evaporative demand and has been widely applied in regional and global hydroclimatic analyses, particularly in drought studies. The use of TerraClimate PET ensures internal consistency between precipitation, temperature, and evaporative demand, allowing reliable assessment of long-term climatic water balance trends in the Campo de Cartagena basin [27]

Each variable was retrieved as annual NetCDF files (TerraClimate_<var>_<year>.nc) via the fileServer access protocol and subsequently merged into multi-year datasets using xarray (version 2024.6). For each variable, the mean conditions of the 1961–1990 and

1991–2020 reference periods were derived, and the inter-period difference (Δ) was calculated to illustrate the long-term climatic shifts. Temporal trends were quantified for both the basin-averaged series and individual grid cells.

Despite its advantages, the use of TerraClimate entails several limitations that are relevant when interpreting local-scale climatic trends. TerraClimate is produced through a combination of CRU climatologies, WorldClim high-resolution surfaces, and reanalysis fields from JRA-55. Although the resulting 1/24° (4 km) monthly dataset offers one of the finest global resolutions currently available, it still incorporates legacy inconsistencies in the station density (particularly in earlier decades), spatial smoothing inherent to the downscaling process, and uncertainties inherited from the parent datasets.

These factors may attenuate extreme values and partially smooth spatial gradients within relatively small basins such as Campo de Cartagena. However, monthly aggregation strongly reduces day-to-day noise, making TerraClimate appropriate for long-term trend analysis (as recommended by Abatzoglou et al. 2018 [27]). All the analyses were therefore performed at the monthly scale to minimize error propagation, and trends are interpreted as regional climatic signals rather than point-scale estimates.

At the pixel scale, ordinary least-squares (OLS) linear regression was applied to the annual values to estimate the slope (per decade) and the associated p-value, testing the null hypothesis of no trend.

Significant trends at the 95% confidence level were highlighted using stippling in the maps.

For the basin-averaged annual series, the Theil–Sen slopes and OLS fits were cross-checked for robustness, and 95% confidence intervals were computed following standard error propagation.

To highlight the low-frequency variability, the annual time series were smoothed using both an 11-year centered running mean and a LOWESS (Locally Weighted Scatterplot Smoothing) filter with a fractional window of 0.25.

The spatial domain was cropped to the Campo de Cartagena basin using the shapefile mask in GeoPandas/Rasterio, and the data were resampled to monthly and annual means or sums, depending on the variable's physical meaning.

3. Results

3.1. Geolocation and Spatial Analysis of the Location Records of Traditional Rainwater Harvesting (RWH) Systems in Campo De Cartagena

3.1.1. Cisterns

For centuries, cisterns were essential to ensuring the settlement of Campo de Cartagena, as in the general absence of other potable water resources, they were used to meet the population's water supply needs. In fact, there is evidence of their use as such since the pre-classical period, although their use in world history can even be traced back to the Neolithic [28].

They thus constitute one of the main RWH and harvesting infrastructures implemented in this region, remaining essential until the construction of the public water supply network in the mid-20th century, a project linked to bringing water from the Taibilla River. This was amajor undertaking that began in 1932 and that provided water to Cartagena in 1939; to San Javier, San Pedro del Pinatar and Torre Pacheco in 1952, to Murcia in 1956, to Fuente Álamo de Murcia in 1959 and to La Unión in 1961 [29]. Through the aforementioned geolocation efforts, a total of 390 cisterns have been identified in the study area (Figure 2): 122 in Torre Pacheco, 92 in Cartagena, 62 in Fuente Álamo de Murcia, 56 in Murcia (in the area corresponding to Campo de Cartagena), 26 in San Javier, 17 in San Pedro del Pinatar, 10 in

Los Alcázares (independent since 1983), 4 in Alhama de Murcia (in the area corresponding to Campo de Cartagena), and 0 in La Unión.

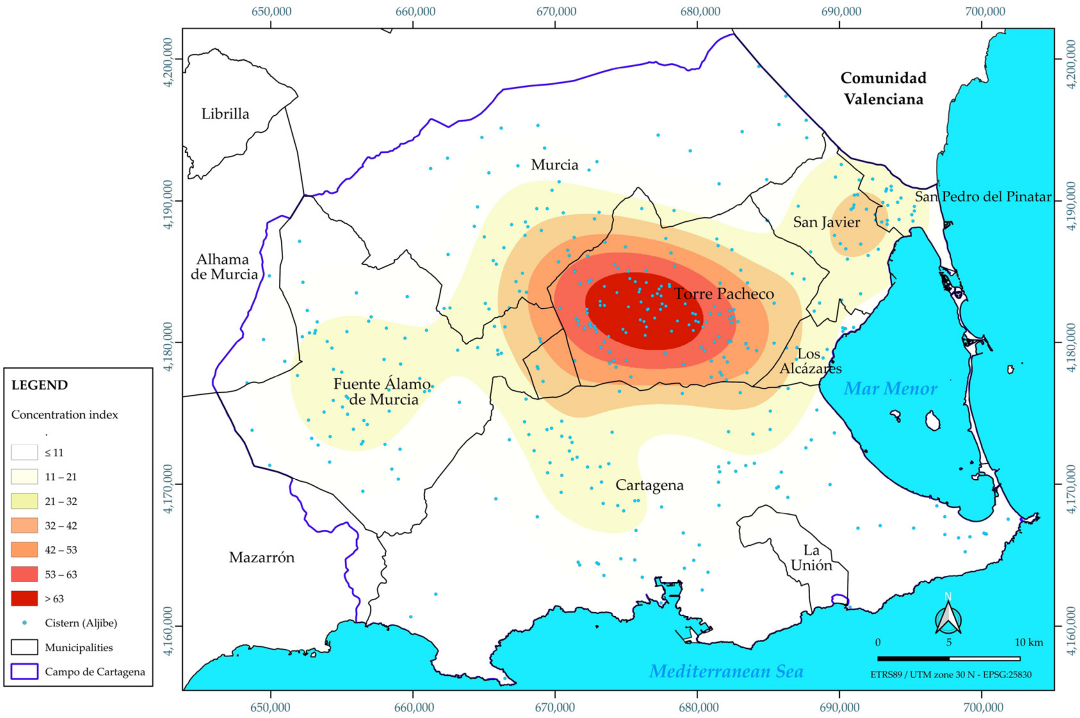


Figure 2. Distribution and concentration analysis of the documented cisterns in Campo de Cartagena based on the analysis of Planimetric sketches. Authors.

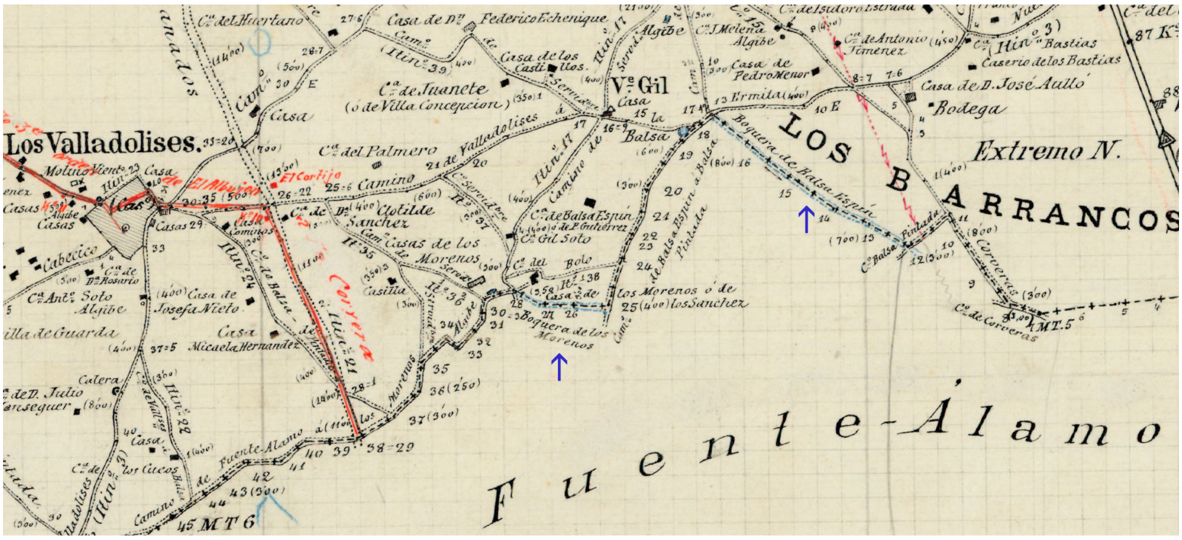
The typology of these artifacts is generally not differentiated in the aforementioned historical cartography, although they can be distinguished in most cases when studying the orthophotographs of historical areas, allowing us to affirm that three types of cistern existed in the study area: rectangular cistern (or barrel-vaulted cistern), circular cistern (domed or hemispherical cistern) and vertical cistern (or bottle cistern). These typologies were also observable during fieldwork, with visits to those that survived (Figure 3). The spatial analysis of the distribution of these ancient hydraulic infrastructures offers a clear interpretation. Despite their widespread distribution in practically all the municipalities that make up Campo de Cartagena, their greatest concentration is located in Torre Pacheco, with a secondary area between San Javier and San Pedro del Pinatar, and with two other areas of notable importance located in the central area of the municipality of Fuente Álamo de Murcia and the northwest of Cartagena. These infraestructures had an average capacity of between 50 and 60 m^3, which in the late 19th and early 20th centuries added up to an approximate rainwater storage capacity of between 19,500 and 23,400 m^3 in the Campo de Cartagena; regenerable as long as rainfall was repeated.

3.1.2. Derivation Dums and Rainfall Channels

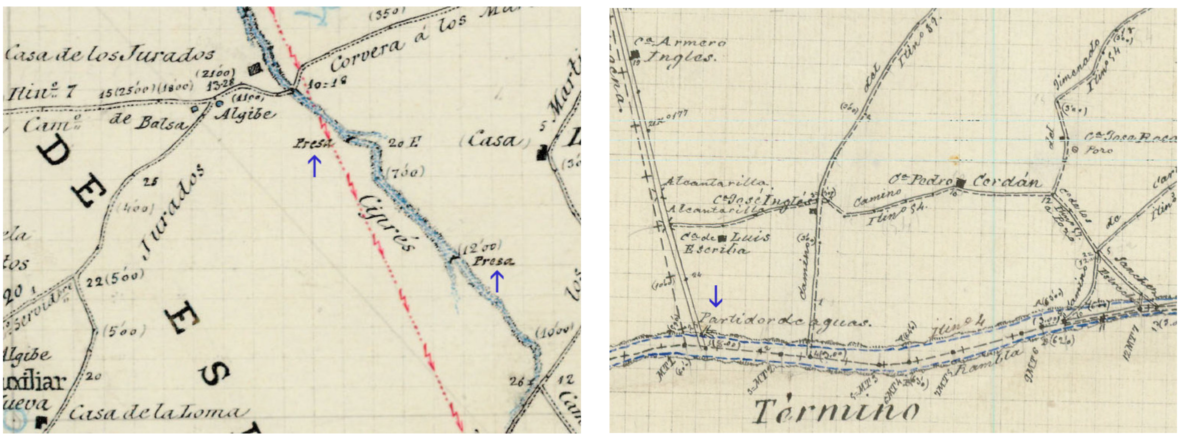
The representation of diversion dams and runoff dams in the planimetric sketches is somewhat more unusual. This is due to the fact that, despite their widespread existence and use, they were primarily earthen conduits and used sporadically. Therefore, they were far removed from the territorial imprint of construction irrigation ditches with almost permanent flow, as well as from other construction infrastructure, such as cisterns. However, important runoff water ditches have been documented in historical cartography, such as Pescado, Alarcón, Los Morenos, and Balsa Espín (Figure 4).

(**a**) (**b**)

Figure 3. (**a**) Rectangular cistern and water rainfall channel of Los Morenos (Valladolises, Murcia); and (**b**) circular cistern in La Carrasca (Fuente Álamo de Murcia). Authors.



(**a**)



(**b**) (**c**)

Figure 4. (**a**) Rainfall channels of Los Morenos and of Balsa Espín represented in the Bosquejos planimétricos; (**b**) dams in the Cypress ravine; and (**c**) direct water intake at the Fuente Álamo ravine. The blue arrows identify the elements of interest identified. Source: Planimetric sketches 300295 (**a**,**b**) and 300355 (**c**), CNIG of Spain.

The last two are of great interest for two reasons. The first is that an interesting Roman-era site dating from the 1st to 3rd centuries AD was located in the space between these two canals. This one was located in the Balsa Espín area (Valladolises, Murcia), although it was called "Balsapintada," and it seems to have been a villae or agricultural facility, associated with a thermal complex fed by a canal whose origin is unknown [30]. Unfortunately, its remains have now been destroyed.

Secondly, there were two large hydraulic infrastructures associated with these runoff water ditches. Thus, next to the first and in the Los Morenos area, there is a large cistern with three wells, unique in the Campo de Cartagena, built very close to the aforementioned site. The second, was associated with a now-disappeared water reservoir, probably known as Balsa Espín, which gave its name to the house and the area.

In addition to these runoff water ditches, which channeled surface runoff by conditioning topographically depressed areas, there are also runoff water channels, albeit fed by water diverted from trough, ravines and watercourse. This was made possible by the construction of both diversion dams and water dividers.

The earliest infrastructure consisted of earth or stone structures built perpendicularly or obliquely to the channel of gullies and ravines. Thus, they diverted part of the floodwater to one or both sides of the channel, where it entered a water runoff ditch, usually made of earth, which transported it to water reservoirs and cisterns or to cultivated fields. On the other hand, water dividers (partidor) were direct intakes built on the sides of these channels, which only captured floodwater when it reached their height and position. In fact, the RAE (Royal Spanish Academy) defines a "partidor" as: "A structure designed to distribute, by means of floodgates into different conduits, the waters running through a channel".

Regarding dams, cartographic analysis has allowed the identification of constructions of this type linked to the del Ciprés, del Charco, del Cementerio y del Miedo, de Ponce, and de la Murta ravines. The latter is of greater interest, as it depicts two successive dams that first diverted water to the right bank of the channel and later to the left.

Finally, regarding the dividers, they are barely reflected in the planimetric sketches consulted. In fact, only one of them is recorded, although it is linked to the largest channel in the hydrographic network that drains the Campo de Cartagena basin: the Fuente Álamo or Albujón ravine. This corresponds to a dividing channel built on the left bank of the riverbed north of El Albujón (Cartagena) and must have supplied floodwaters to at least this sector of the Las Colonias area. This ravine was extensively exploited in this regard, as evidenced, for example, by the request issued by Juan de Velasco in 1876 for the use of its floodwaters through a large sluiceway intended to irrigate his Villa Antonia Estate [31].

Likewise, in the old municipal council minutes of the region's municipalities, references are frequently found to the turbid water sluiceways that existed within their boundaries. One example is the sluiceway that fed the Las Ánimas Cistern in the town of Fuente Álamo. A cistern of which there is evidence already in 1800. Thus, in the session of the council of this term of 30 July 1887, the following is recorded: "It was noted, based on a request made by Mr. Ginés Hernandez Bermudez, that the rainfall channel whose turbid waters flow into the cistern of his property called 'de las Animas' should be left free and clear for cleaning, offering to make, at his expense, a path to the right of the cistern for the service of the public, leaving the said rainfall channel to the left without passage" (translated from Spanish).

References to runoff water channels that supplied water reservoirs have also been documented. For example, to the water reservoir that gave its name to the town of Balsapintada, whose origin appears to be Roman [32]. Thus, in the session of the municipal council of Fuente Álamo on 20 February 1948, the following was stated: "the Mayor is authorized (. . .) to grant a deed of sale in favor of the aforementioned Francisco Ros Torralba for a plot of land (. . .) with the obligation on the part of the purchaser to cover with an arch the rainfall channel existing between his house and the pond, not to divert the natural course of the waters that flow through the aforementioned rainfall channel, and to carry out (. . .) the repairs that may be necessary in the arch, and also the cleaning of the aforementioned rainfall channel (. . .) so that the beneficiaries of said rainfall channel do not suffer any injury to their rights" (translated from Spanish).

Similarly, historical press references to the runoff water ditches of this region also appear, often linked to the sale of properties. For example, an advertisement in the Eco de Cartagena newspaper of 4 August 1874, mentions the sale of a property with rights to the floodwaters of a ravine, which also bordered the mouth of Lo Ferro (Miranda, Cartagena) to the west: "Román Rodríguez Delgado, Judge of (. . .) this City. I hereby make known: That on Monday the twenty-fourth of this month (. . .) in the Court of this Court, the sale by public auction of the properties belonging to Antonio González took place (. . .) three bushels of land with the right to the ravine in its frontage, located in the area of La Loma, Miranda district (. . .), bordering (. . .) West rainfall channel called Ferro" (Translate form spanish). Announcement similar to the edict published on 21 September 1929 in La Tierra and which said: "Due to non-compliance with certain conditions agreed upon in a mortgage deed, the following properties, located in the municipality of Pacheco, district of Roldán, are sold at public auction. Ten bushels of dryland, intended for cereals in the area of Los Bastidas (. . .) It has the right to half of a rainfall channel of turbid waters" (translated from Spanish).

3.1.3. Terracing

The topographic characteristics of the Campo de Cartagena natural region determine the presence of long, generally gentle slopes that descend from these elevations toward the center of the basin, and from there, toward the aforementioned coastal lagoon. Analysis of historical aerial orthophotographs (1929, 1945, 1956, and 1981), complemented by a review of LiDAR images and fieldwork, has allowed us to identify a multitude of artificial land modifications in the study area. These modifications are the result of traditional anthropogenic interventions, carried out to create cultivable areas and take advantage of the scarce but valuable runoff water. These alterations were carried out primarily in the foothills of the aforementioned mountain ranges and in a significant number of the dry bedrocks of the valleys, gullies, and ravines that make up the drainage network of the region, thus giving rise to important agricultural areas supplied by runoff water irrigation.

Thus, two types of land preparation/conditioning can be distinguished. While they pursue the same purpose, they are often differentiated by the preferred location where they were carried out and the type of work that made them possible. In any case, both are remarkably effective techniques and have been used intensively and widely in this area for centuries. In fact, there is evidence of their use in the Bronze Age, as can be seen, for example, at the site of La Bastida de La Murta (Murcia).

The first technique employed is terracing (Figures 5–7), horizontal land preparation developed in areas with steep slopes. The construction of these terraces gives rise to stepped agricultural terraces that descend down the hillside from the highest point. In this case, the construction of dry-stone walls of considerable height is generally used to stabilize the resulting terraces. This technique was declared Intangible Cultural Heritage of Humanity by UNESCO in 2018, thanks to a multinational candidacy in which Spain participated with other European countries, such as Croatia, Cyprus, France, Greece, Italy, Slovenia, and Switzerland.

https://doi.org/10.3390/land15010098

Figure 5. Terraces between the northern slope of Cabezo de la Panadera and the mouth of the Azohía ravine, east of the town of La Azohía (Cartagena). Source: USAF 1956 Flight. Sitmurcia-IDERM.

Figure 6. Terraces on the western side of Cartagena (Torre de Nicolás Pérez, Cartagena). Authors.

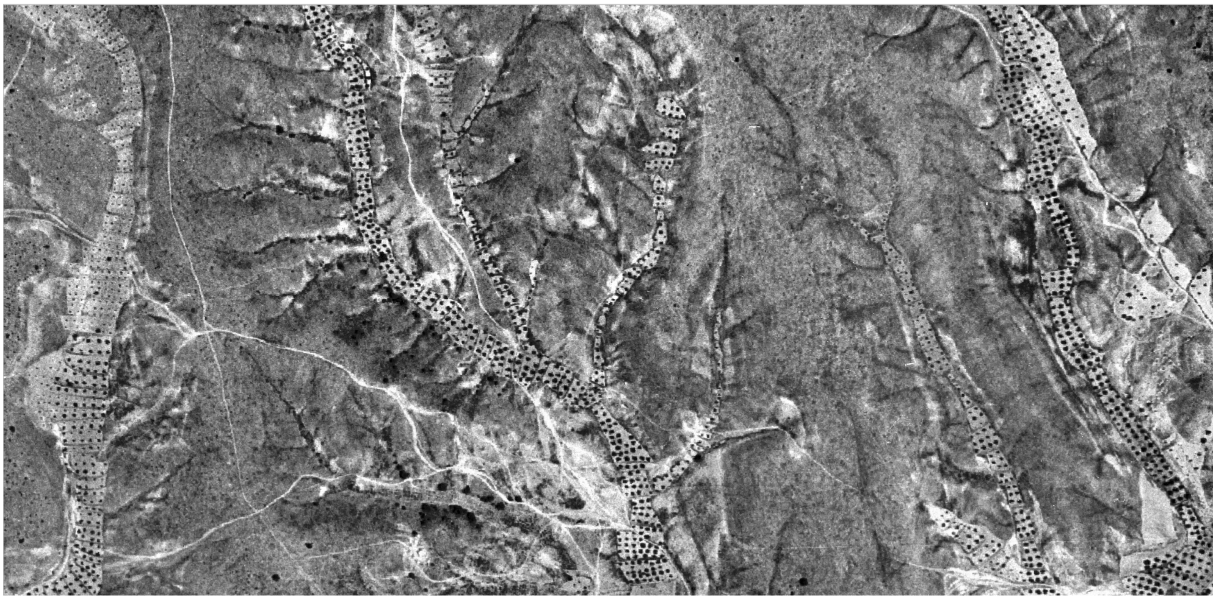


Figure 7. Terracing of the riverbeds of various valleys in the Campo de Cartagena basin. Note how the cultivated areas are adapted to the hydrographic network, thus taking advantage of the natural passage of runoff water. Source: USAF 1956 Flight. Sitmurcia-IDERM.

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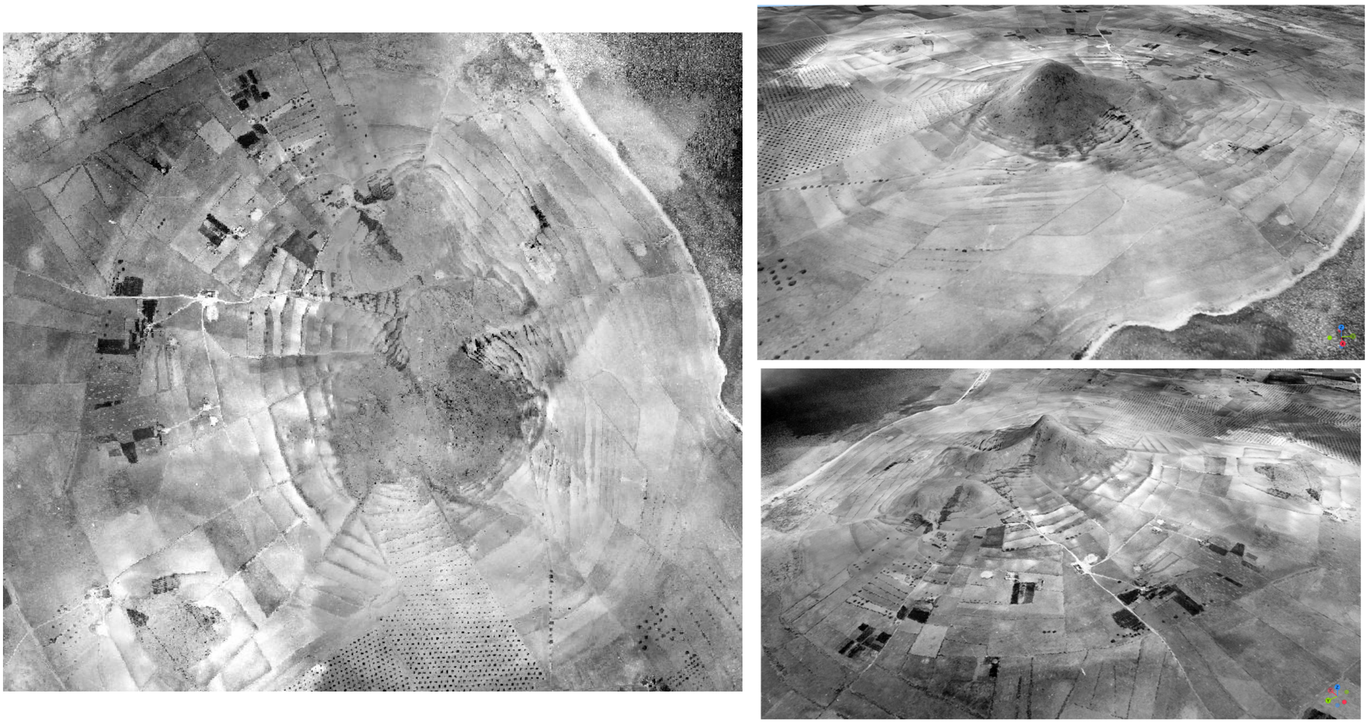
The second technique is benching (Figures 8 and 9), a land preparation technique generally used on hillsides and surfaces with more moderate gradients. This results in simpler and less significant land leveling, but also allows for the creation of successive crop strips. In this case, the steps are usually smaller than terraces, and although they do not usually require the construction of walls—leveling the land is sufficient to retain soil and water—they sometimes include small boulders and water spillways. They are therefore a less costly technique for expanding the cultivable area and taking advantage of rainfall.



(**a**) (**b**)

Figure 8. (**a**) Terraces and terracing around the El Carmolí volcanic cone (Cartagena). The terraces and terracing form a concentric layout, gaining in width and extension as they descend. Ruiz de Alda Flight (CHS) (1929. Sitmurcia-IDERM. (**b**) Three-dimensional modeling of the terraces and terracing around El Carmolí in 1929. Ruiz de Alda Flight (CHS) (1929) and modeling by the authors.

In any case, both structures serve a common goal: to allow greater water retention, contribute to soil conservation, and enable cultivation on steep or sloping terrain that would otherwise be impossible to cultivate or would be very difficult and less profitable.

The analysis also revealed differences in the original agricultural uses associated with both systems, specifically in the types of crops grown. Thus, while the terraced lands were primarily used for the cultivation of dryland tree species (olive, almond, and carob), the terracing offered greater versatility, generally being used for sowing cereals: wheat, barley, and oats. However, these cereals were also grown on these terraces.

However, it is worth mentioning that terracing was also traditionally used in mountain agricultural areas supplied with water from natural springs or mines and water galleries, such as those linked, for example, to the Fuente de La Murta (Corvera, Murcia), the Fuente del Alacrán (Corvera, Murcia), or the Fuente de La Muela (Cartagena). This use became more intensive in more recent times, when the construction of motorized wells ended up supplying many of the documented terraced and banked areas, expanding the crop typologies with the inclusion of various types of herbaceous plants and, occasionally, even fruit and citrus trees.

Figure 9. Terraces and terracing still survive in the vicinity of the Sierra de Carrascoy (Carrascoy and El Valle Regional Park), specifically between the Cortijo de la Al-mazara and the Cortijo de los Jaimes (Murcia). LiDAR image, 2016 (IGN).

3.2. Main Effects of Global Change on Campo De Cartagena

3.2.1. Modification of the Land Uses in Campo De Cartagena

A review and classification of CORINE Land Cover data[6] (Table 1) shows that the most important land use in Campo de Cartagena is “Agricultural areas,” occupying 63.5% of the entire region (Figures 10 and 11). This is followed in importance by “Plant areas with natural vegetation and open spaces,” which constitute 21.6%, and, to a lesser extent, “Artificial surfaces,” at 8%, and “Watersurfaces (excluding seas and oceans),” representing 6.5%. The total area is made up of “Wetlands areas,” which comprise 0.4%.

However, a comparative analysis of this information also reveals a significant change in the land uses identified by this European project, something evident when looking at the cartographic information derived from this data (Figure 12). Thus, the most recent values for “Artificial surfaces” have doubled the 1990 figures; in fact, they have increased by 8685 ha. These positive figures also affect “Agricultural surfaces,” although to a lesser extent, by 4400 ha. In contrast, “Wetland areas” have suffered a significant decrease of 5328 ha, and “Plant areas with natural vegetation and open spaces” have decreased by 244 ha compared to the initial year.

Table 1. Land uses identified in Campo de Cartagena, Level 1 CLC.

Level 1 CLC	1990 (ha)	2000 (ha)	2018 (ha)	Difference	Variation Rate (%)
Artificial surfaces	7719.8	10,260.6	16,405.7	8685.9	112.5
Agricultural areas	126,189.7	130,046.0	130,590.4	4400.7	3.5
Plant areas with natural vegetation and open spaces	49,671.8	47,261.8	44,343.5	−5328.3	−10.7
Wetland areas	974.9	938.0	730.8	−244.1	−25.0
Water surfaces *	13,502.1	13,502.2	13,465.1	−37.0	−0.3

* Seas and oceans are not quantified.

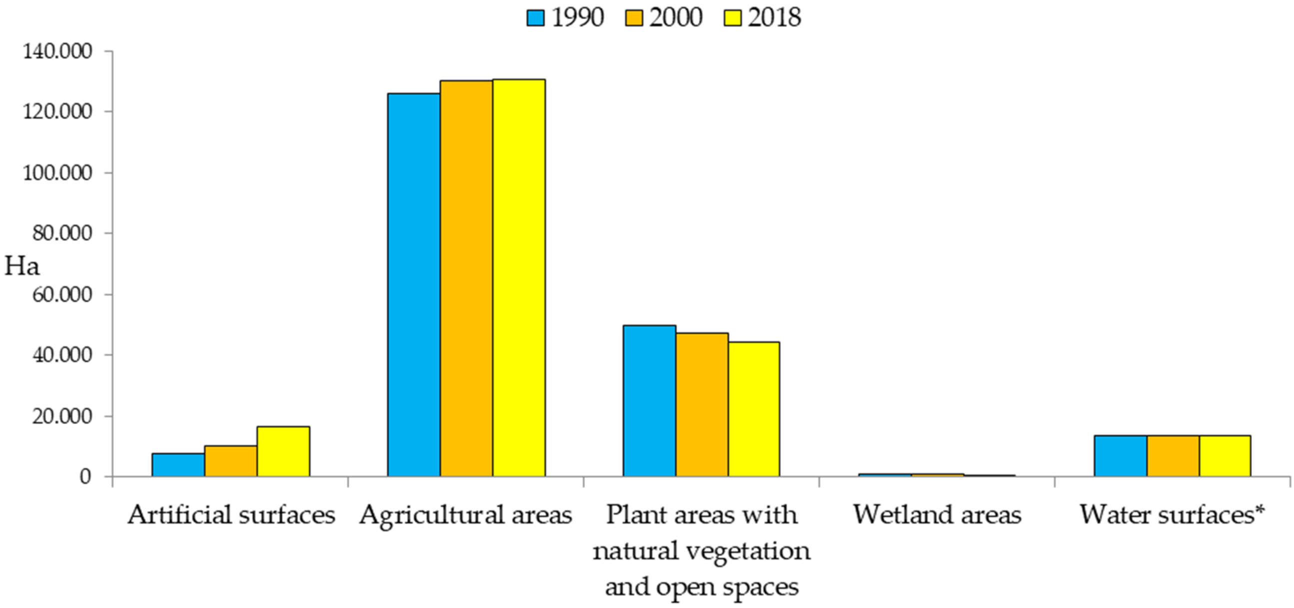


Figure 10. Land use changes in Campo de Cartagena 1990–2018, data relating to Level 1. Source: Prepared by the authors using CORINE Land Cover information from the National Geographic Institute of Spain (IGN). Derived work de CLC 19990, 2000 y 2018 CC-BY 4.0 scne.es. *Seas and oceans are not quantified. Authors.

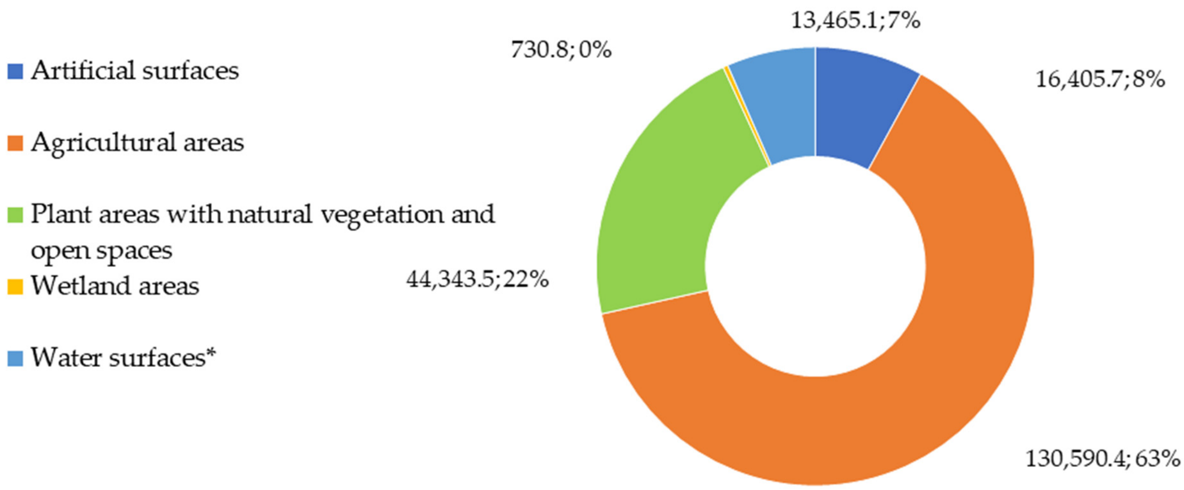


Figure 11. Land use distribution in Campo de Cartagena in 2018 according to CORINE Land Cover 2018 data. Source: Prepared by the authors based on CORINE Land Cover information from the National Geographic Institute of Spain (IGN). * Seas and oceans are not quantified. Derived work de CLC 2018 CC-BY 4.0 scne.es.

These variations offer more interesting information if, instead of analyzing the data grouped by main categories (Level 1 of detail), the study is conducted at the highest level of precision available, that is, Level 3 (Table 2) (Figure 13).

Thus, in the "Artificial surfaces" group, the greatest increase is in "Industrial or commercial zones" (121) and "Sports and recreational zones" (142), the former with 2538.5 ha and the latter with 2362.9 ha. They add 1375.8 ha plus "Continuous urban fabric" (111), 941.3 ha plus "Discontinuous urban fabric" (112), and 812.7 ha plus "Mining extraction areas" (131); therefore, these values are equally important. The surface area of "Airports" (124) has also increased significantly, exceeding the 535 ha, undoubtedly affected by the construction of the Region of Murcia International Airport (RMU). The increase of 214.3 ha in "Road and rail networks and adjacent land" (122) is close to the 203.9 ha of "Construction areas" (133). Far from these values, there was also an increase of 75.8 ha in "Green urban zones" (141), a commitment to environmental improvement that coincides with the significant reduction in the surface area of "Landfills and dumps" (132), with 350.2 ha less. A decrease was also observed in "Port areas" (123), with a reduction of just over 24.4 ha.

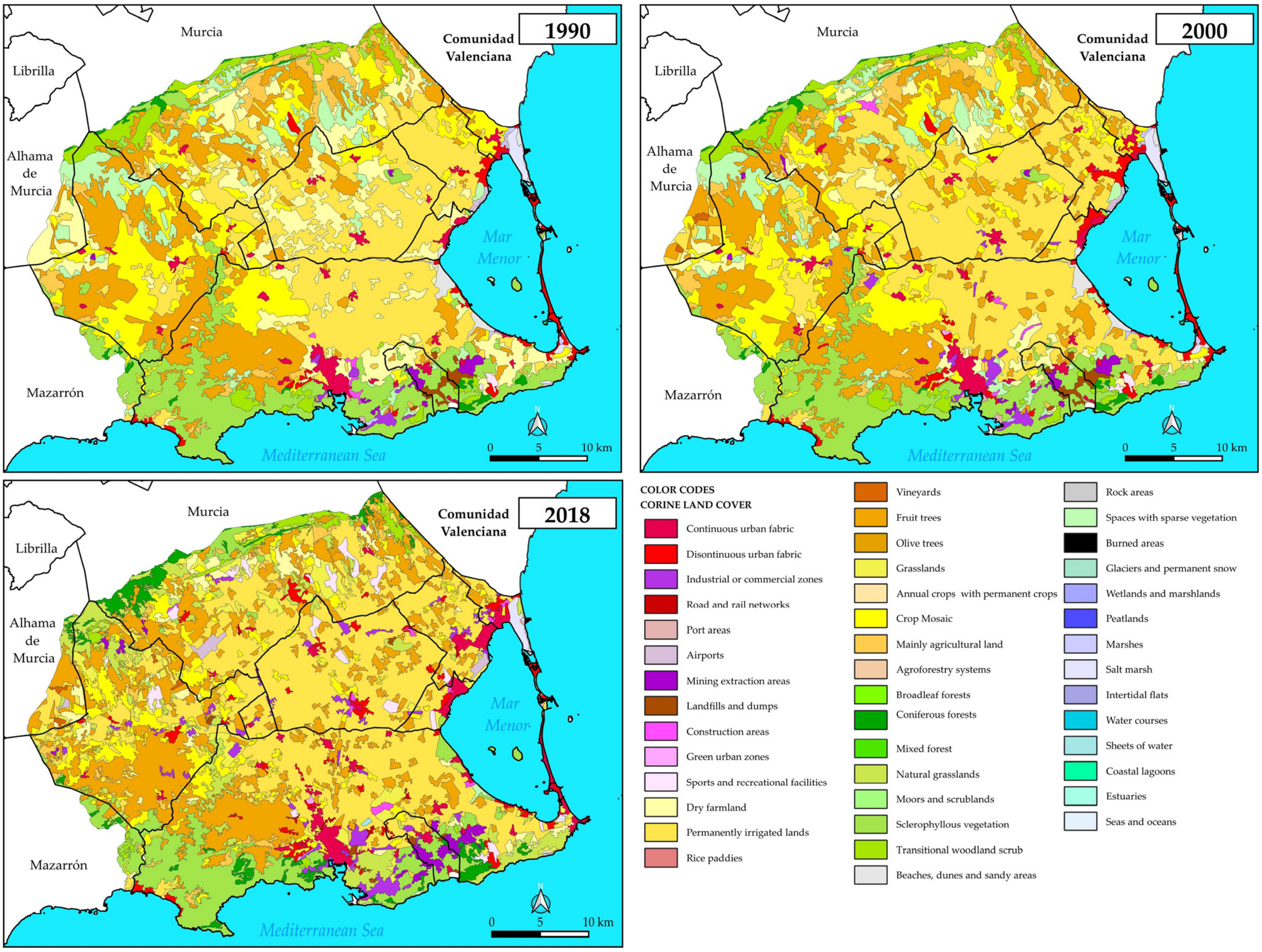


Figure 12. Land use changes in Campo de Cartagena 1990–2018. Source: Prepared by the authors using CORINE Land Cover information from the National Geographic Institute of Spain (IGN). This work is derived from CLC 19990, 2000 y 2018 CC-BY 4.0 scne.es. Authors.

As regards the group of "Agricultural surfaces", a notable dichotomy is evident, since while those dedicated to "Dry farmland (211)" have decreased by 85.1%, specifically about 22,157.2 ha, those occupied by "Permanently irrigated land" (212) have increased by 18,844.8 ha, and those of "Fruit trees" (222) by 18,149 ha. Dry farmland where traditional RWH systems are analyzed in this work were applied for centuries and, therefore, have seen their survival affected.

A very significant decrease is also seen in the "Crop mosaic" (242) and "Mainly agricultural land but with significant areas of natural and semi-natural vegetation" (243) categories, the former with a reduction of 55.9% and the latter of 61.4%, 13,814.7 ha in the first case and 3572.4 ha in the second. This increase has been very significant for the "Natural grasslands" (321) areas, as they registered a total of 6729.9 ha more in 2018. Finally, "Vineyard" (221) and "Olive trees" (223) have seen their surface area grow significantly, the former by 35% between 2000 and 2018, and the latter by 9.3% in the period 1990–2018, specifically, 217.7 ha and 34.7 ha, respectively. Finally, "Annual crops associated with permanent crops" (241) have also seen their number of hectares reduced, in this case, by just over 30.8 ha.

Table 2. Land uses identified in Campo de Cartagena, Level 3 CLC.

Id—Level 3 CLC	CODE 90	1990	2000	2018	TV%	Difference 1990–2018
Continuous urban fabric	111	2925.6	3263.0	4301.4	47.0	1375.8
Discontinuous urban fabric	112	2046.0	3094.6	2987.2	46.0	941.3
Industrial and commercial zones	121	534.0	1247.6	3072.5	475.4	2538.5
Road and rail networks	122	-	-	214.3	-	214.3
Port areas	123	25.3	282.0	225.9	−9.7	−24.4
Airports	124	128.2	128.2	663.5	417.5	535.3
Mining extraction areas	131	693.4	782.3	1506.1	117.2	812.7
Landfills and dumps	132	754.4	780.5	404.2	−46.4	−350.2
Construction areas	133	229.9	373.9	433.8	88.7	203.9
Green urban zones	141	-	31.5	75.8	-	75.8
Sports and recreational zones	142	157.9	276.9	2520.9	1496.0	2362.9
Dry farmland	211	26,031.9	11,688.3	3874.7	−85.1	−22,157.2
Permanently irrigated lands	212	36,985.9	48,441.7	55,830.7	51.0	18,844.8
Vineyards	221	-	160.2	217.1	35.5	217.1
Fruit trees	222	32,245.4	41,501.6	50,394.6	56.3	18,149.2
Olive trees	223	372.3	103.5	407.0	9.3	34.7
Grasslands	231	-	-	6729.9	-	6729.9
Annual crops with permanent crops	241	30.8	30.8	-	−100.0	−30.8
Cropmosaic	242	24,704.3	23,577.3	10,889.6	−55.9	−13,814.7
Mainly agricultural land	243	5819.2	4542.6	2246.8	−61.4	−3572.4
Coniferous forest	312	8072.9	8076.0	11,976.3	48,4	3903.4
Mixed forest	313	231.7	231.7	-	−100,0	−231.7
Natural grasslands	321	-	80.3	11,140.3	-	11,140.3
Sclerophyllous vegetation	323	23,770.9	22,819.6	18,257.6	−23.2	−5513.3
Transitional woodland scrub	324	7272.6	7034.5	2534.7	−65.1	−4737.8
Beaches, dunes and sandy areas	331	1329.2	1,272.4	95.1	−92.8	−1234.2
Rock areas	332	-	-	26.0	-	26.0
Spaces with sparse vegetation	333	8994.6	7747.5	313.6	−96.5	−8681.0
Marshes	421	211.0	174.1	-	−100.0	−211.0
Salt marsh	422	629.1	629.1	597.6	−5.0	−31.6
Intertidal flats	423	134.9	134.9	133.2	−1.2	−1.6
Sheets of water	512	-	-	49.5	-	49.5
Coastal lagoons	521	13,502.1	13,502.2	13,415.5	−0.6	−86.6
	TOTAL	184,556.3	188,506.5	192,070.4	4.1	7514.100

Thirdly, in the group of "Plant areas with natural vegetation and open spaces," the increase in the area of "Natural grasslands" (321) and "Coniferous forest" (312) is significant. The first case with 11,060 hectares more than in the year 2000, while in the latter, this increase has been 3903.4 ha, 48.4% more than in 1990. In contrast, the rest of the categories have seen a decrease in their numbers. Thus, the most significant reduction is linked to the loss of 8681 ha of "Spaces with sparse vegetation" (333), followed by 5513.3 ha fewer of "Sclerophyllous vegetation" (323) and 4737.8 ha fewer of "Transitional wooded scrub" (324). The area of "Beaches, dunes and sandbanks" (331) decreased by 92.8%, specifically by 1234.2 ha. Similarly, the area of "Mixed forest" disappeared from the 2018 records, despite having totaled 231.7 ha in 1990 and 2000.

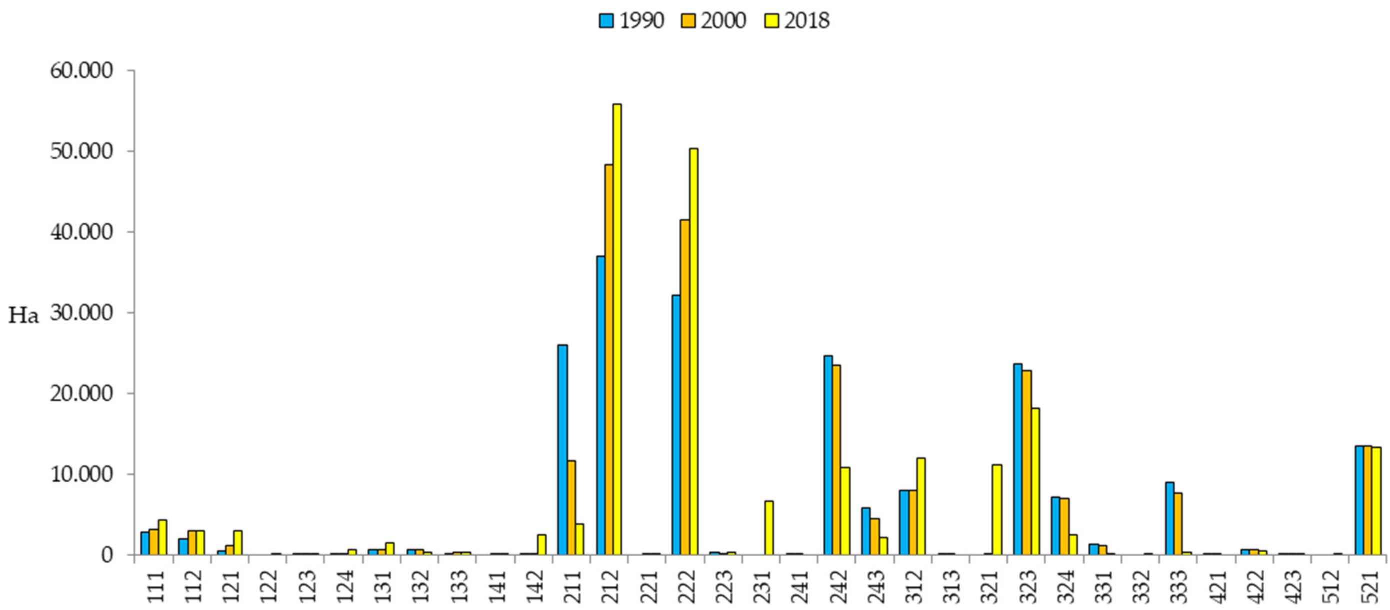


Figure 13. Land use changes in Campo de Cartagena 1990–2018. Source: Prepared by the authors using CORINE Land Cover information from the National Geographic Institute of Spain (IGN). This work is derived from CLC 19990, 2000 y 2018 CC-BY 4.0 scne.es. Own elaboration.

Finally, in the "Wetland areas" group, both "Marshes" (421) and "Salt marshes" (422) have seen their area reduced, the former by 211 ha and the latter by 31.6 ha. The "Intertidal flats" (423) remain, however, with practically with the same values, just 1.6 ha less than in 1990.

3.2.2. Climate Alteration

The Campo de Cartagena basin has experienced a clear alteration of its climatic balance over the last seven decades. Analysis of the TerraClimate dataset (1958–2024) reveals statistically significant trends in the PET, together with spatially homogeneous changes in the regional water balance. These changes are consistent with the generalized warming trend observed in the southeastern Iberian Peninsula and the progressive intensification of atmospheric aridity documented in Mediterranean environments during recent decades.

- Potential evapotranspiration (PET)

The annual PET series shows a robust and statistically significant upward trend of +12.1 mm·dec^{-1} ($p < 0.001$), confirming a sustained increase in the atmospheric evaporative demand since the late 1950s (Figure 14). The year-to-year variability remains high, but the long-term evolution is unequivocally upward, with the highest annual PET values recorded in the most recent decade. This increase in the PET translates into a net intensification of the regional evaporative regime, particularly during the warm season, which represents the critical period for water scarcity and crop stress in the area.

Spatial analyses corroborate this pattern. The mean PET for 1991–2020 is approximately 30–50 mm yr^{-1} higher than during 1961–1990 across the entire basin. The change is spatially coherent, indicating that the process is driven by broad-scale atmospheric forcing rather than by local surface modifications. The resulting map of the PET difference (ΔPET_B−A) highlights a uniform positive anomaly, with the largest increments in the central and northeastern sectors of the basin. This behavior reflects a combination of increased air temperature, higher vapor pressure deficit, and lengthening of the warm season—all typical manifestations of climate warming in semi-arid Mediterranean domains.

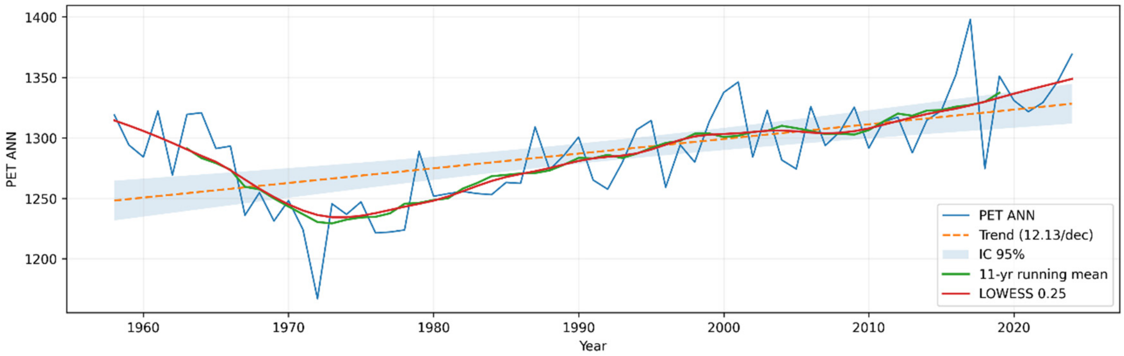


Figure 14. Annual potential evapotranspiration (PET) over the Campo de Cartagena basin for the 1958–2024 period. The dashed orange line represents the linear trend (+12.1 mm·dec^{-1}), with the shaded area showing the 95% confidence interval. The green line corresponds to the 11-year running mean, while the red line shows a LOWESS smoother (frac = 0.25), emphasizing the low-frequency variability and decadal fluctuations. Note: The *Y*-axis represents the PET (mm/month). Own elaboration.

Seasonal trend analyses reveal a marked summer (JJA) enhancement, with widespread positive and significant trends across the basin. Spring (MAM) and autumn (SON) show moderate but consistent increases, while winter (DJF) remains nearly stationary or slightly negative (Figure 15). This confirms that the long-term rise in the PET is primarily driven by the intensification of summer heat and dryness, consistent with the progressive warming of surface air temperature observed in southeastern Spain

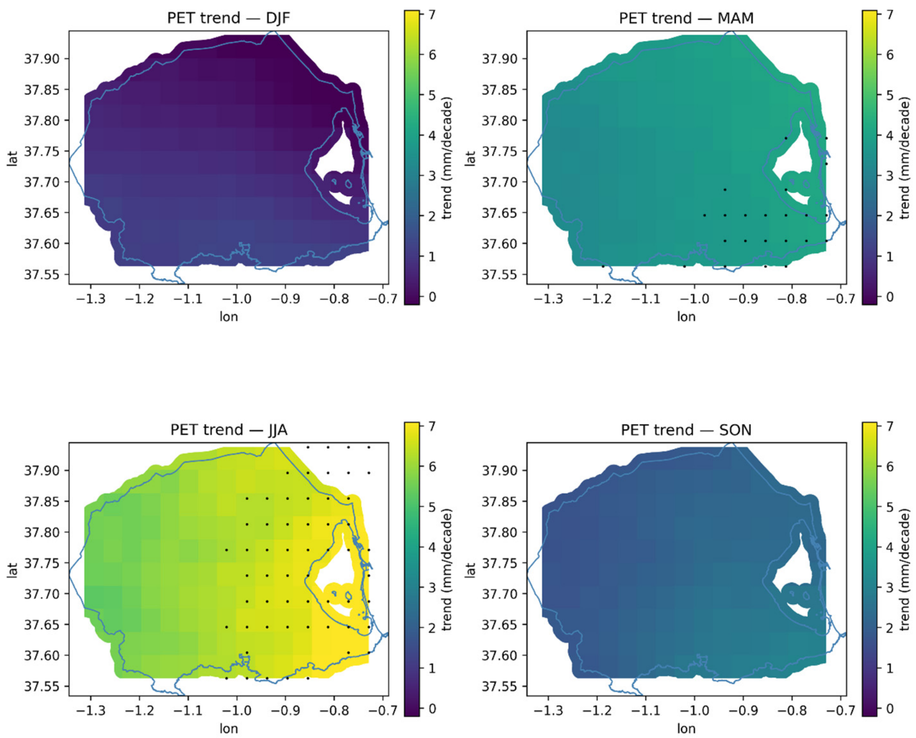


Figure 15. Spatial distribution of seasonal trends in the potential evapotranspiration (PET) over the Campo de Cartagena basin for the 1958–2024 period. Dots indicate grid cells with statistically significant trends ($p < 0.05$). A consistent color scale (mm·dec^{-1}) was applied to all the panels to highlight the magnitude and spatial variability of the PET increases across seasons. Own elaboration.

From a hydroclimatic perspective, this evolution implies a progressive widening of the potential evapotranspiration–precipitation gap, that is, a long-term increase in the climatic water deficit. Even if the precipitation remained stable, the rise in PET alone would reduce the effective water availability for soils, vegetation, and aquifers. However, the preliminary results for precipitation (P) and temperature (T)—presented in the following subsections—indicate a dual pattern: decreasing rainfall totals and increasing temperatures. The combined effect of both factors amplifies the negative water balance and reinforces the propagation of drought conditions at multiple timescales, as will be demonstrated by the analysis of the Standardized Precipitation–Evapotranspiration Index (SPEI).

The homogeneity of the PET trend across Campo de Cartagena suggests a basin-wide forcing linked to large-scale atmospheric dynamics rather than to local land-use changes. The influence of subtropical high-pressure persistence, combined with a higher frequency of blocking and warm-advection episodes from North Africa, may have contributed to the observed pattern.

Taken together, the basin-averaged PET increase of approximately 1.2 mm yr^{-1} implies an additional evaporative demand of nearly 12 mm per decade, equivalent to roughly 60–70 mm more potential water loss per hydrological year compared to the 1960s. Overall, the climatic alteration of Campo de Cartagena is characterized by an unequivocal strengthening of the evaporative component of the hydrological cycle, superimposed on a regime of high interannual variability. The combined increase in the PET and air temperature, together with the declining or stagnant rainfall, points to a transition to a more arid state. This process entails profound implications for groundwater recharge, soil-moisture dynamics, and agricultural sustainability in one of the most intensively cultivated areas of southeastern Spain.

Our results are consistent with the broader evidence of long-term "wind stilling" over mid-latitudes, that is, a widespread decline in near-surface wind speeds since the 1970s. This phenomenon has been documented at the hemispheric scale [33] and, more specifically, over Spain and Portugal, where homogenized observations reveal significant negative trends in the mean winds and in the frequency and intensity of strong wind gusts during 1961–2011. Recent analyses further indicate that wind stilling has weakened or even ceased over the Iberian Peninsula since the early 2000s, although the near-surface winds remain lower an in the mid-20th century [34].

The next sections analyze the evolution of the precipitation, temperature, and composite drought indicators (SPEI) to contextualize the PET trend within the broader framework of hydroclimatic change in Campo de Cartagena, quantifying the extent to which the observed evaporative intensification contributes to the ongoing depletion of the regional water balance.

- Runoff variability and hydrological implications

While the PET trends reveal an intensification of the atmospheric water demand, the runoff patterns highlight the hydrological consequences of this drying tendency.

Runoff (Q) over the Campo de Cartagena basin reveals a marked low-flow regime, characteristic of Mediterranean semi-arid catchments with strong precipitation seasonality and limited storage capacity. The annual runoff series (Figure 16) exhibits pronounced interannual variability, punctuated by a few high-flow years (e.g., mid-1970s and early 2020s) and extended dry intervals. The long-term linear trend is nearly null (-0.0 mm·dec^{-1}), indicating the absence of a statistically significant monotonic trend. Nevertheless, both the 11-year running mean and the LOWESS smoother point to a non-linear evolution with a gradual decline from the late 1970s until the early 2000s, followed by a weak recovery over the most recent decade. This temporal pattern aligns with the general drying signal observed in southeastern Iberia, where the higher evaporative demand and more irregular rainfall have altered the hydrological response of low-relief basins.

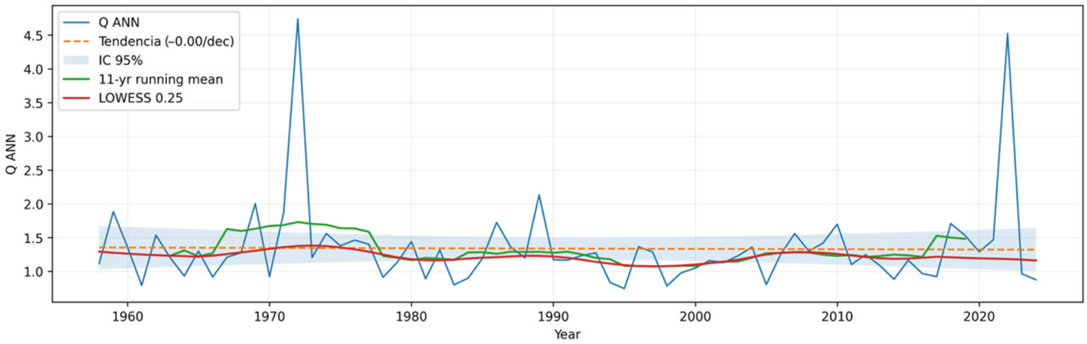


Figure 16. Surface runoff (Q) over the Campo de Cartagena basin for the 1958–2024 period. The dashed orange line represents the linear trend (-0.0 mm·decade^{-1}), with the shaded area showing the 95% confidence interval. The green line corresponds to the 11-year running mean, while the red line shows a LOWESS smoother (frac = 0.25), emphasizing the low-frequency variability and decadal fluctuations. Note: The *Y*-axis represents the monthly precipitation in mm/month. Own elaboration.

Spatially, the annual trend map (Figure 17) reveals a heterogeneous distribution of changes, with weak positive slopes across the northwestern headwaters and negative tendencies toward the southern and coastal sectors. The seasonal trends (Figure 17) emphasize this contrast. During spring (MAM), a mild positive trend is observed over the northern and central areas of the basin, possibly related to localized convective activity or residual frontal systems. Conversely, autumn (SON) shows the most pronounced negative signals, reaching -0.3 to -0.4 mm·dec^{-1}, consistent with the decline in autumnal precipitation—the main recharge season in this region. Winter (DJF) and summer (JJA) exhibit negligible changes, suggesting that runoff alterations are primarily concentrated during transition seasons, when soil moisture preconditioning and rainfall intensity play a dominant role in generating flow.

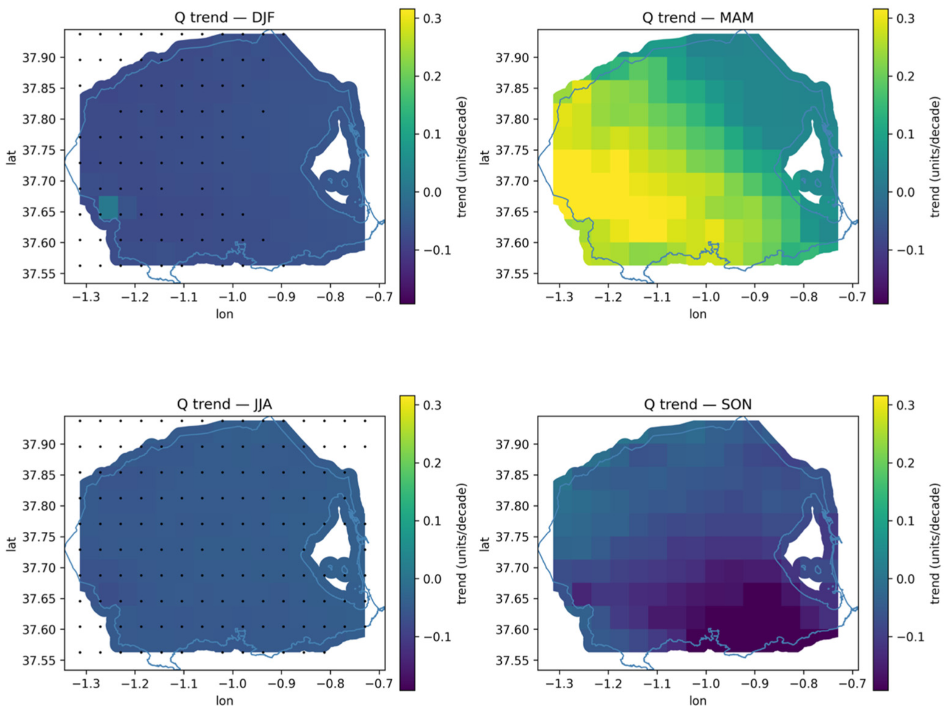


Figure 17. Spatial distribution of the seasonal trends in surface runoff (Q) over the Campo de Cartagena basin for the 1958–2024 period. Dots indicate grid cells with statistically significant trends ($p < 0.05$). A consistent color scale (mm·decade^{-1}) was applied to all the panels to highlight the magnitude and spatial variability of Q increases across seasons. Own elaboration.

A comparison between the reference period 1961–1990 and the recent period 1991–2020 reveals a generalized reduction in the mean annual runoff. The average values decreased from approximately 15–20 mm·yr^{-1} in the earlier period to below 15 mm·yr^{-1} in recent decades. The difference highlights negative anomalies of -3 to -4 mm·yr^{-1} across most of the basin, particularly in its southern and coastal sectors. These areas coincide with zones of intensified PET and land degradation processes, underscoring the coupled influence of climatic and land-surface drivers.

Overall, the spatial and temporal patterns indicate a progressive reduction in effective runoff generation and surface water availability, despite the weak linear trend detected at the basin scale. The combined evidence suggests that hydrological processes in the Campo de Cartagena basin have become increasingly flashy and episodic, reflecting the combined effect of climatic warming, enhanced PET, and declining rainfall efficiency. This pattern is consistent with other Mediterranean basins of southeastern Spain, where the imbalance between precipitation inputs and the atmospheric evaporative demand has led to a contraction of blue-water resources and a growing frequency of hydrological droughts (e.g., [35,36]).

These findings demonstrate that, while the PET increase reflects the intensification of the atmospheric water demand, the runoff trends quantify its hydrological manifestation through reduced water yield and storage capacity. Such coupled signals provide robust evidence of a long-term hydroclimatic desiccation in the Campo de Cartagena basin and contribute to understanding how semi-arid Mediterranean catchments respond to compounded climate and land-use pressures.

- Precipitation variability and long-term trends

Precipitation across the Campo de Cartagena basin shows a general downward tendency during 1958–2024, averaging -4.3 mm·decade^{-1}, though not statistically significant at the 95% level. The annual series (Figure 18) reveals pronounced interannual variability, with exceptionally wet years in the 1960s–1970s and markedly dry phases in the 1980s and early 2000s. The 11-year running mean and LOWESS smoother display a clear multidecadal signal: a progressive decline from the late 1970s to about 2000, followed by partial recovery but without reaching former totals.

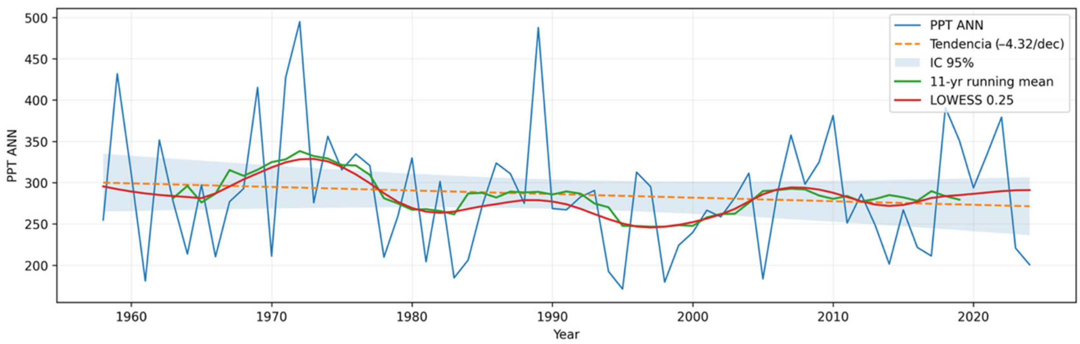


Figure 18. Annual precipitation (PPT) over the Campo de Cartagena basin for the 1958–2024 period. The dashed orange line marks the linear trend (-4.3 mm·decade^{-1}), with the shaded area showing the 95% confidence interval. The green curve shows the 11-year running mean, and the red line a LOWESS smoother (frac = 0.25), emphasizing the low-frequency variability. Note: The *Y*-axis shows runoff values in mm/month. Own elaboration.

Spatially, negative precipitation trends dominate most of the basin (Figure 19). The declines are strongest toward the southeastern lowlands, where the rates locally exceed –4 mm·decade^{-1}, while weak positive signals appear in the northwestern uplands.

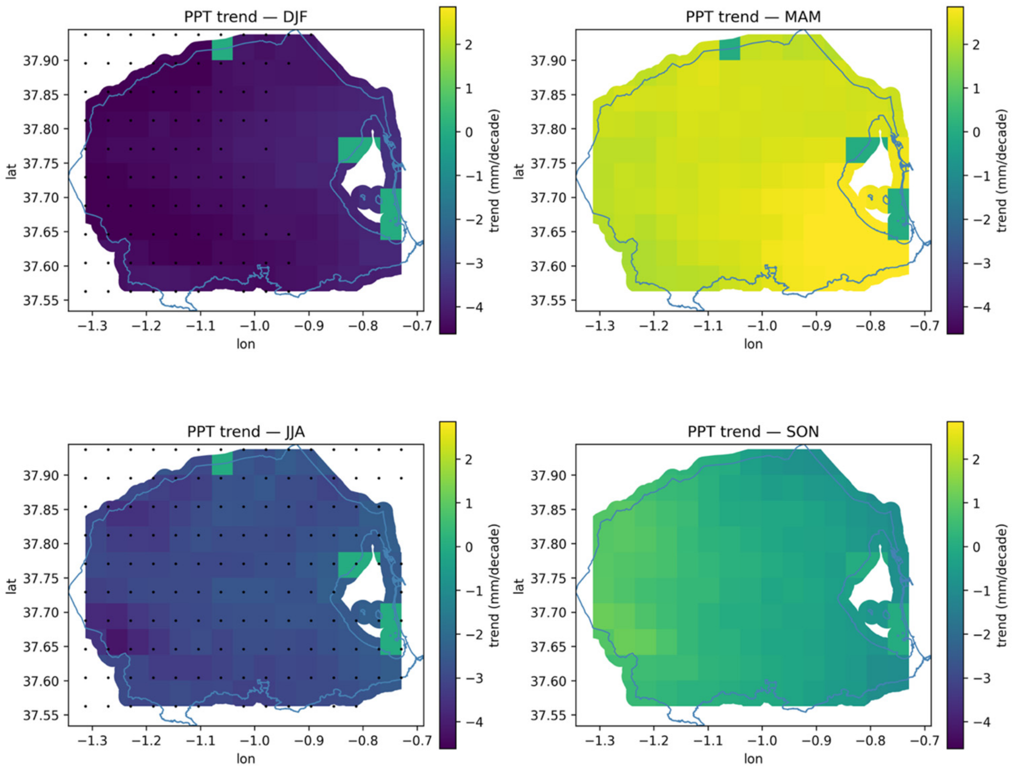


Figure 19. Spatial distribution of seasonal precipitation trends (1958–2024). Dots indicate grid cells with statistically significant trends ($p < 0.05$). A consistent color scale (mm·decade^{-1}) was applied to all the panels to highlight the magnitude and spatial variability of the PPT increases across seasons. Own elaboration.

Seasonally, winter (DJF) and summer (JJA) exhibit statistically significant reductions (≈ -4 and -2.7 mm·decade^{-1}, $p < 0.05$), confirming a contraction of rainfall in both the cool and dry halves of the year. Spring (MAM) shows a slight increase (~+2 mm·decade^{-1}) and autumn (SON) remains nearly stationary. These patterns imply that the basin's modest annual decrease arises mainly from losses in winter and summer precipitation rather than from autumn, which retains high interannual irregularity linked to convective activity.

The spatial coherence of the drying points to a regional atmospheric control, likely associated with the reduced Atlantic frontal influence in winter and the increasing prevalence of subtropical subsidence and high-pressure persistence in summer. In contrast, the neutral autumn trend suggests that isolated Mediterranean convective episodes still offset longer-term decline.

Overall, rainfall variability remains the dominant feature, yet the multi-decadal downward drift reinforces the transition toward greater aridity already inferred from the PET trends.

- Trends in Maximum Temperature (TMAX).

The analysis of the annual maximum temperature (TMAX) over the Campo de Cartagena basin for the period 1958–2024 reveals a robust and statistically significant warming signal. The basin-averaged annual series (Figure 20) exhibits a linear increase of approximately +0.28 °C dec^{-1}, confirming a strong warming trend consistent with the regional signal observed across southeastern Spain and the western Mediterranean. The LOWESS smoother highlights an acceleration of warming since the late 1980s, coinciding with the onset of persistently positive temperature anomalies and the transition toward a drier, more stable climatic regime dominated by subtropical high-pressure systems.

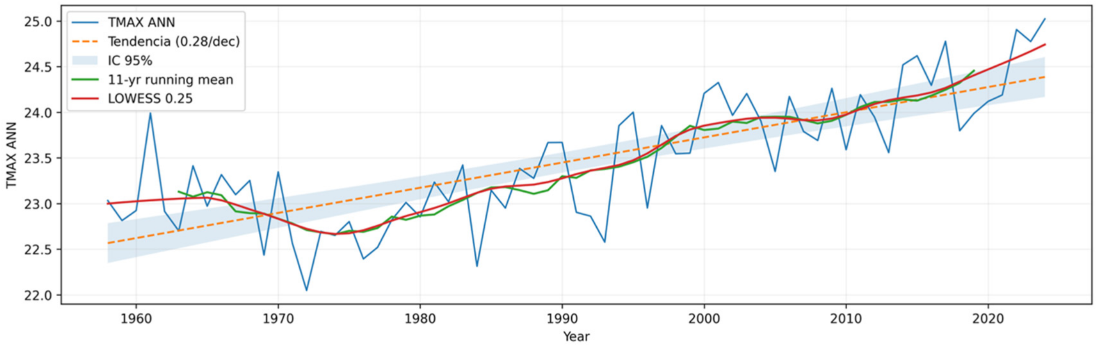


Figure 20. Mean maximum temperature (TMAX) over the Campo de Cartagena basin for the 1958–2024 period. The dashed orange line represents the linear trend (+0.28 °C·decade^{-1}), with the shaded area showing the 95% confidence interval. The green line corresponds to the 11-year running mean, while the red line shows a LOWESS smoother (frac = 0.25), emphasizing the low-frequency variability and decadal fluctuations. Note: The *Y*-axis shows maximum temperature expressed in °C. Own elaboration.

The spatial pattern of the annual trends (Figure 21) indicates a moderate south–southwest gradient, with the highest positive anomalies concentrated over the southern and southwestern sectors of the basin and comparatively weaker or near-neutral trends toward the coastal fringe. Although the magnitude of the warming remains spatially coherent, local topographic and maritime influences modulate the temperature response, particularly near the coast, where the sea exerts a partial buffering effect. The stippling pattern demonstrates that the majority of grid cells show significant ($p < 0.05$) positive trends, confirming the statistical robustness of the basin-wide warming.

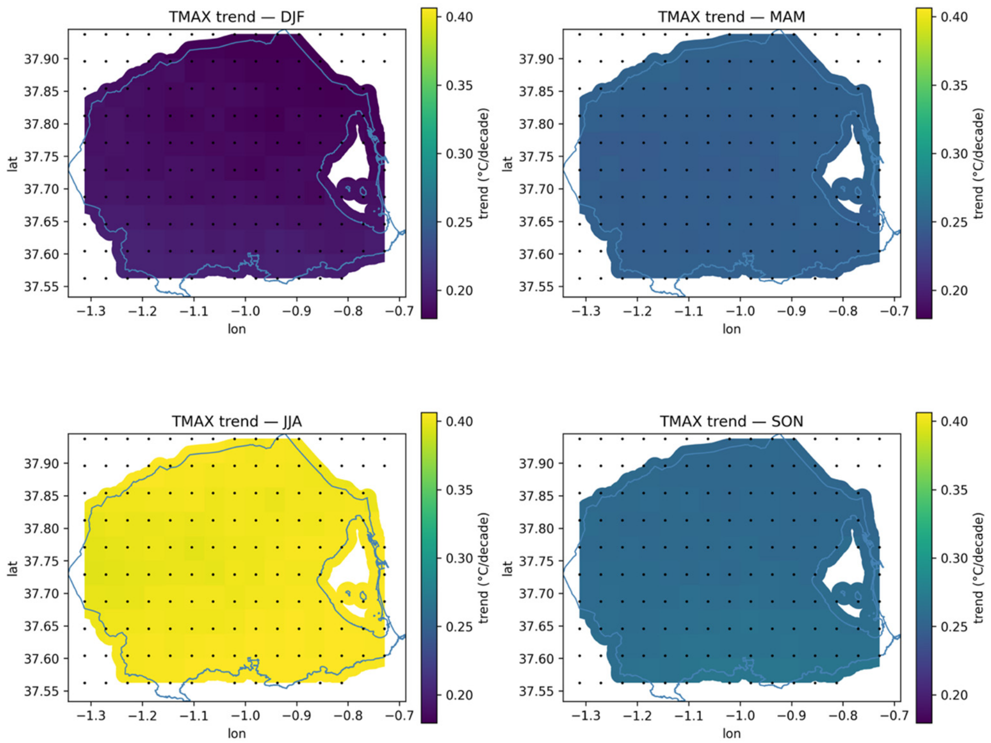


Figure 21. Spatial distribution of seasonal trends in the mean maximum temperature (TMAX) over the Campo de Cartagena basin for the 1958–2024 period. Dots indicate grid cells with statistically significant trends ($p < 0.05$). A consistent color scale (mm·decade^{-1}) was applied to all the panels to highlight the magnitude and spatial variability of the TMAX increases across seasons. Own elaboration.

The seasonal breakdown reinforces this signal. The strongest increase is observed during summer (JJA), exceeding +0.40 °C dec^{-1}, followed by spring (MAM) (~+0.25 °C dec^{-1}) and autumn (SON) (~+0.26 °C dec^{-1}). In contrast, winter (DJF) exhibits a comparatively weaker trend (~+0.19 °C dec^{-1}), reflecting the greater interannual variability and the occasional influence of Mediterranean cold advections and nocturnal radiative cooling still affecting the cold season. This intra-annual asymmetry highlights an amplification of summer heat extremes and the progressive extension of the warm season, in agreement with the broader Euro-Mediterranean pattern of intensified summer warming and increased heatwave frequency since the late 20th century.

From a climatic perspective, these results confirm the progressive intensification of thermal stress across the Campo de Cartagena basin, with potential implications for evapotranspiration rates, irrigation demand, and agro-ecosystem resilience. The magnitude, spatial coherence, and statistical significance of the observed TMAX trends emphasize the need for continued monitoring and regional climate modeling efforts to better anticipate temperature-driven hydrological changes under sustained anthropogenic forcing in this semi-arid Mediterranean environment.

- Trends in Minimum Temperature (TMIN).

The analysis of the annual minimum temperature (TMIN) across the Campo de Cartagena basin for the period 1958–2024 indicates a statistically significant and spatially coherent warming trend. The basin-averaged annual series (Figure 22) exhibits a linear increase of approximately +0.26 °C dec^{-1}, reflecting a persistent rise in the nighttime and early-morning temperatures. The LOWESS smoother reveals a sustained upward trajectory since the early 1980s, with the most intense warming occurring after the 1990s, consistent with the general acceleration of the regional minimum-temperature increases observed across the Mediterranean.

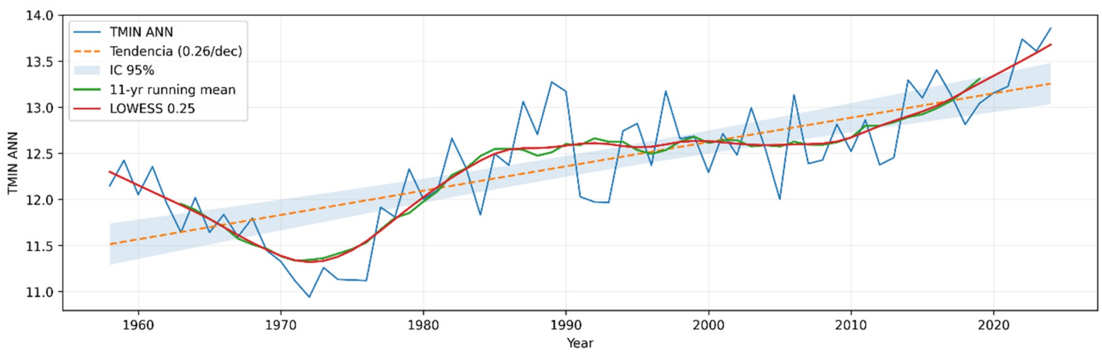


Figure 22. Mean minimum temperature (TMIN) over the Campo de Cartagena basin for the 1958–2024 period. The dashed orange line represents the linear trend (+0.22 °C·decade^{-1}, corregido), with the shaded area showing the 95% confidence interval. The green line corresponds to the 11-year running mean, while the red line shows a LOWESS smoother (frac = 0.25), emphasizing the low-frequency variability and decadal fluctuations. Note: The *Y*-axis shows minimum temperature expressed in °C. Own elaboration.

The spatial distribution of the annual trends (Figure 23) shows a gentle north–south gradient, with the strongest positive anomalies concentrated over the southern and south-eastern sectors of the basin, while the northern areas display slightly lower but still positive values. The relative uniformity of the warming signal across the basin suggests a basin-wide increase in nocturnal heat retention, probably enhanced by both large-scale radiative forcing and local land-use factors that reduce the nocturnal cooling efficiency. The stippling pattern confirms that most grid cells exhibit significant ($p < 0.05$) positive trends, consolidating the robustness of the observed signal.

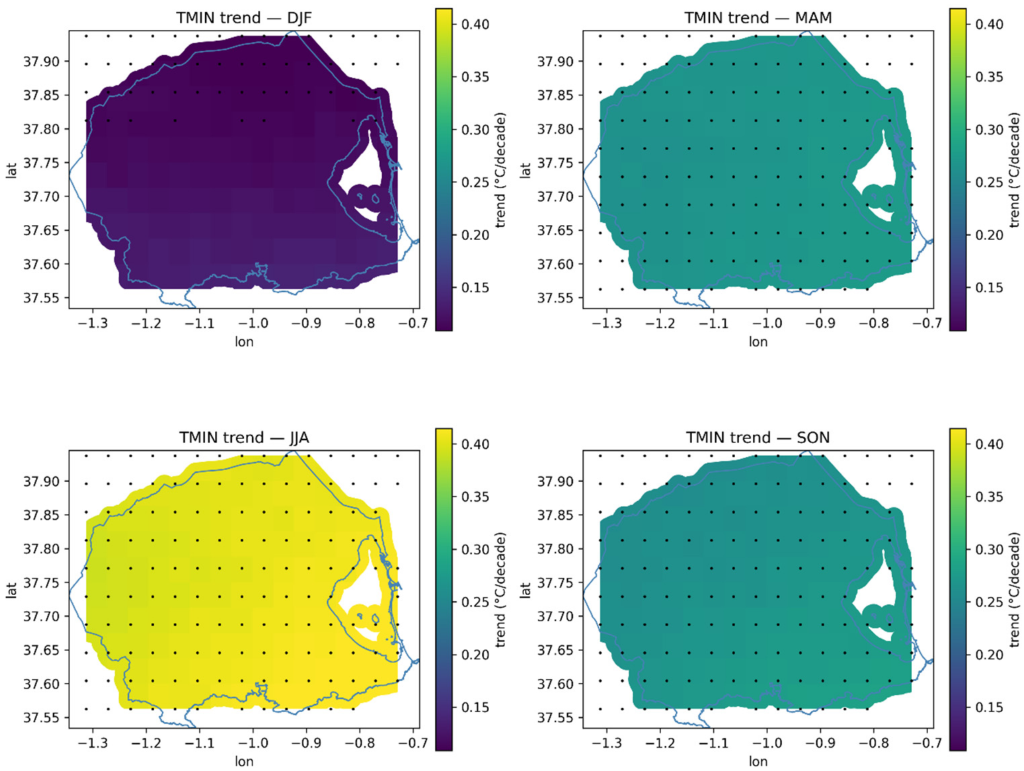


Figure 23. Spatial distribution of seasonal trends in the mean minimum temperature (TMIN) over the Campo de Cartagena basin for the 1958–2024 period. Dots indicate grid cells with statistically significant trends ($p < 0.05$). A consistent color scale (mm·decade^{-1}) was applied to all the panels to highlight the magnitude and spatial variability of the TMIN increases across seasons. Own elaboration.

The seasonal behavior (Figure 23) confirms that the summer (JJA) months experience the most intense warming, exceeding +0.40 °C dec^{-1}, followed by spring (MAM) and autumn (SON), both around +0.27 °C dec^{-1}. The winter (DJF) season presents the weakest trend (+0.12 °C dec^{-1}) and the highest interannual variability, likely modulated by occasional cold intrusions and radiative inversion events that still occur during the cold season. Overall, the seasonal asymmetry highlights a marked amplification of summer nocturnal heat, consistent with the Euro-Mediterranean pattern of asymmetric warming, where the nighttime minima increase faster than the daytime maxima.

From a climatic and environmental standpoint, these results imply a substantial reduction in the diurnal temperature range (DTR) and a progressive increase in the baseline nighttime temperatures, which may affect the evapotranspiration dynamics, soil-water balance, and crop phenology. The coherence and magnitude of the observed TMIN trends underscore the growing relevance of nocturnal warming as a component of regional climate change, emphasizing the need for integrated analyses that link thermal behavior, humidity feedbacks, and local land-surface processes in this semi-arid Mediterranean basin.

- Long-term meteorological drought conditions (SPEI-12).

The basin-averaged SPEI-12 series for Campo de Cartagena (1958–2024) reveals a persistent and statistically significant drying trend of −0.17 index·dec^{-1} (Figure 24). This signal reflects a sustained long-term imbalance between the atmospheric water demand and the effective precipitation, consistent with the observed warming and evapotranspiration increases described in previous sections. The LOWESS smoother and the 11-year running mean both indicate a shift toward negative anomalies after the early 1990s, confirming the prevalence of moderate to severe drought conditions during recent decades. This temporal evolution mirrors the Mediterranean-wide decline in the climatic water balance, which has been particularly evident since the late 20th century.

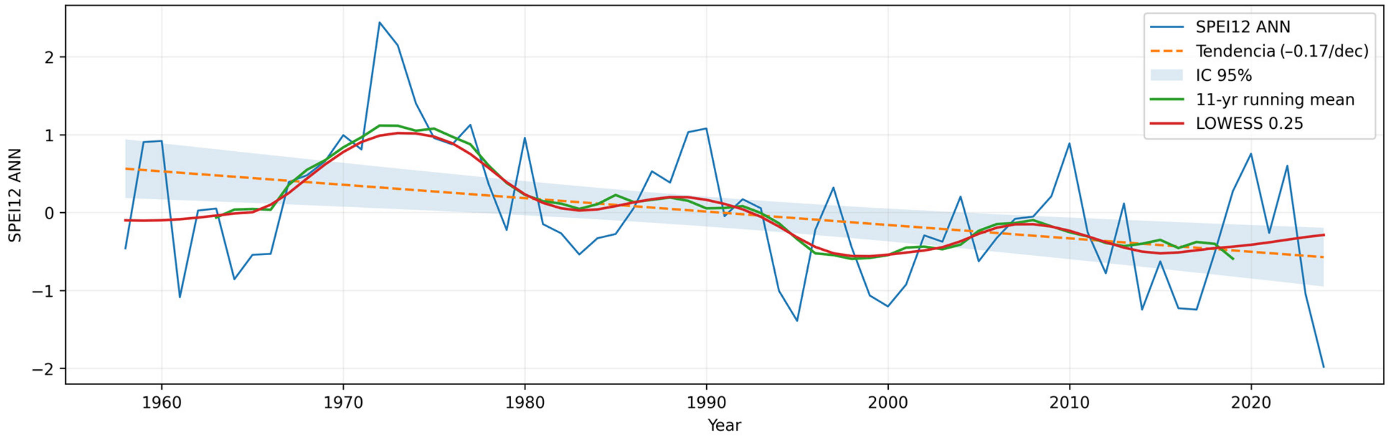


Figure 24. SPEI-12 over the Campo de Cartagena basin for the 1958–2024 period over the Campo de Cartagena basin for the 1958–2024 period. The dashed orange line represents the linear trend (-0.14 index·decade^{-1}), with the shaded area showing the 95% confidence interval. The green line corresponds to the 11-year running mean, while the red line shows a LOWESS smoother (frac = 0.25), highlighting long-term drought intensification. Note: The *Y*-axis represents the standardized SPEI values (dimensionless index). Own elaboration.

The spatial distribution of annual trends (Figure 25) exhibits a clear west-to-east contrast across the basin. The western and northwestern zones show relatively stable or slightly positive SPEI-12 values, while the eastern and southeastern coastal areas display marked negative trends (-0.18 to -0.20 index·dec^{-1}). This spatial gradient suggests the combined influence of topographic effects, coastal aridity, and intensified evapotranspiration linked to higher land-surface temperatures. Most grid cells exhibit statistically significant declines ($p < 0.05$), underscoring the robustness of the drying signal and its basin-wide consistency.

At the seasonal scale (Figure 25), negative trends are observed throughout the year but are strongest during spring (MAM) and summer (JJA), both near -0.19 index·dec^{-1}, reflecting the compounding influence of reduced rainfall and enhanced potential evapotranspiration during the warm season. The winter (DJF) and autumn (SON) periods also show drying tendencies (-0.17 to -0.18 index·dec^{-1}), though with greater interannual variability. The seasonal coherence of the negative trends indicates that the basin's hydrological stress is becoming chronic, with fewer wet recovery periods interrupting prolonged deficits.

From a hydroclimatic perspective, the progressive decline in the SPEI-12 values points to a transition toward more persistent multi-year drought regimes. This has direct implications for groundwater recharge, irrigated agriculture, and ecosystem resilience, particularly given the strong dependence of regional water availability on winter–spring precipitation. The consistent SPEI-12 decrease across both the annual and seasonal timescales underscores that warming-induced evapotranspiration increases are outpacing rainfall variability, amplifying water deficits even without a pronounced decline in the total precipitation. These results reinforce the critical role of temperature-driven aridification in shaping the future hydroclimate of the Campo de Cartagena basin.

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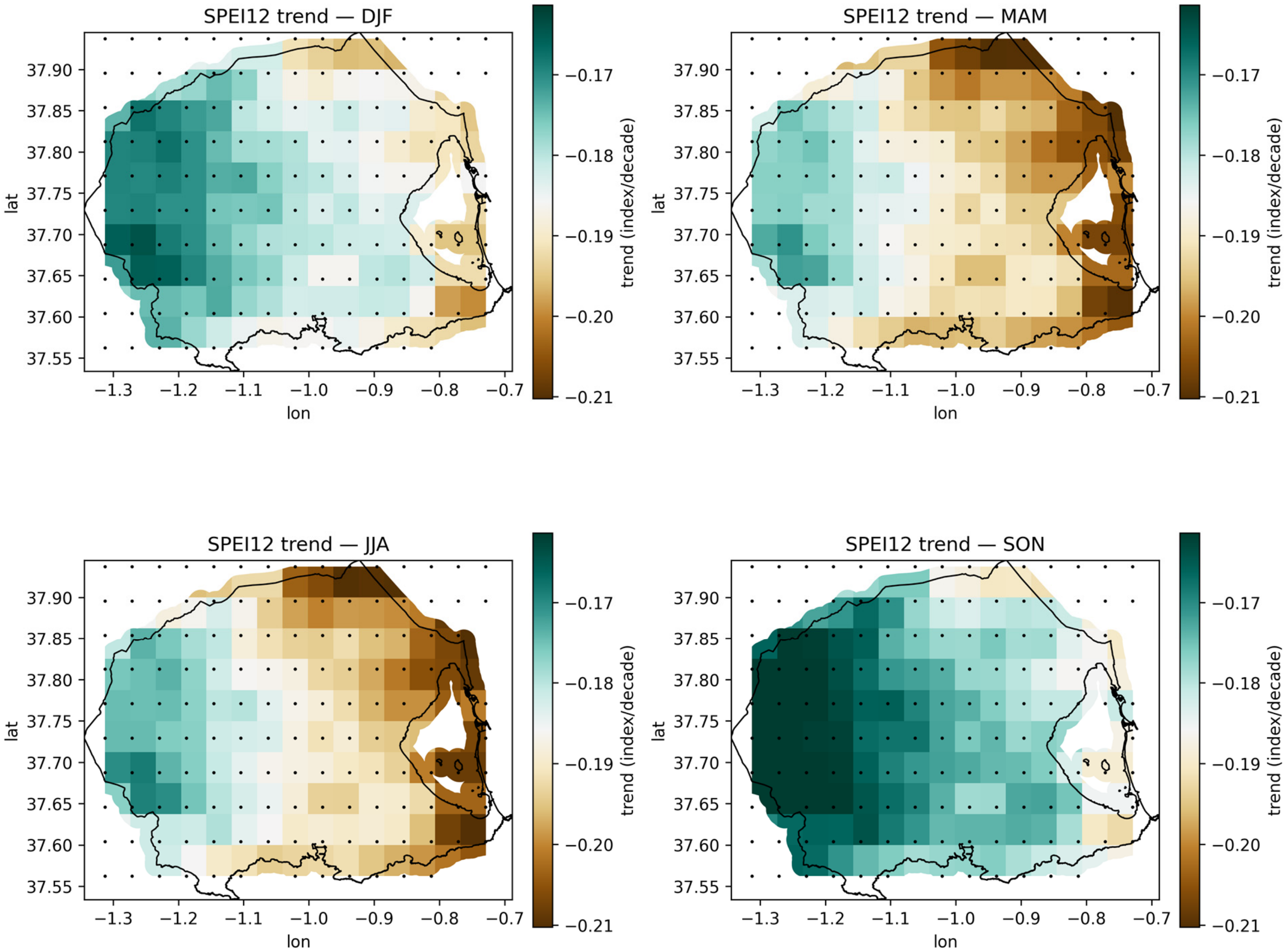

Figure 25. Spatial distribution of seasonal trends in the SPEI-12 over the Campo de Cartagena basin for the 1958–2024 period. Dots indicate grid cells with statistically significant trends ($p < 0.05$). A consistent color scale (mm·decade^{-1}) was applied to all the panels to highlight the magnitude and spatial variability of the SPEI-12 increases across seasons. Own elaboration.

Figure 26 summarizes the spatial patterns of the annual trends in the main hydroclimatic variables across the Campo de Cartagena basin for the period 1958–2024. A coherent signal emerges between the intensification of the water deficit (PET, SPEI-12) and the progressive decline in precipitation and streamflow, while both the maximum and minimum temperatures exhibit widespread increases (Table 3). Overall, the maps reveal a clear shift toward more arid and thermally contrasted conditions, confirming the basin's increasing hydrological vulnerability and its transition toward a climate regime dominated by enhanced evaporative demand and reduced water availability. To address potential uncertainties in the trend estimates, all the linear regressions were computed with 95% confidence intervals and assessed for statistical robustness. Te confidence bands are displayed in every time-series figure, while the trend significance (p-values) is provided in the text. These measures ensure that the reported trends represent robust basin-scale climatic signals rather than artefacts of interannual variability.

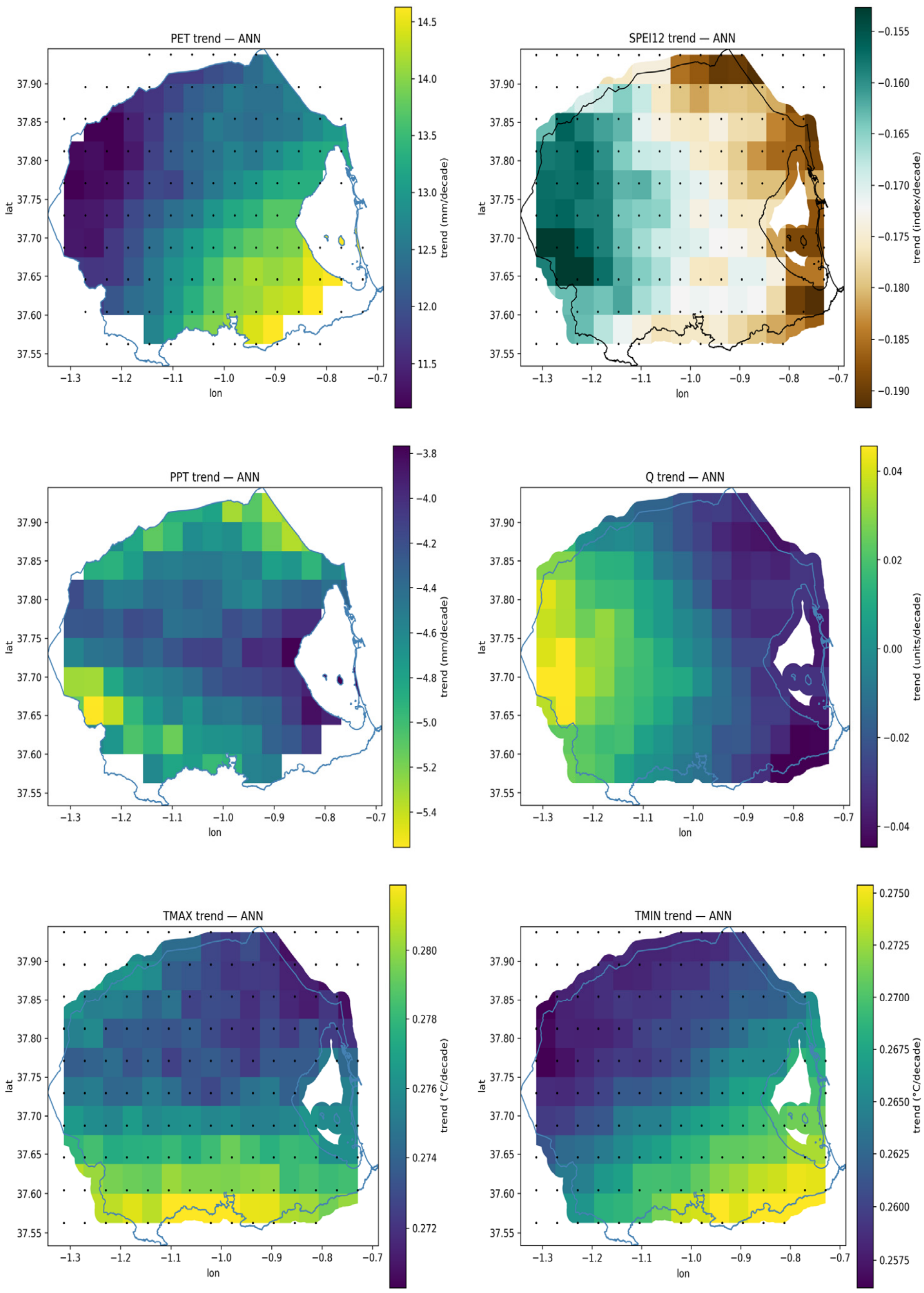

Figure 26. Spatial distribution of annual trends in Campo de Cartagena basin for the 1958–2024 period. Dots indicate grid cells with statistically significant trends ($p < 0.05$). A consistent color scale (mm·decade^{-1}) was applied to all panels to highlight the magnitude and spatial variability of SPEI-12 increases across seasons. Own elaboration.

Table 3. Summary table showing the temporal statistical trends for each analyzed variable (trend·dec^{-1}) and the corresponding *p*-value. Statistically significant trends ($p < 0.05$) are shown in bold and are additionally marked with two asterisks (<0.01) and one asterisk (0.01–0.05).

		Trend/dec	*p* Value
PET	DJF	0.70	0.079
	MAM	**3.54** **	0.000
	JJA	**5.97** **	0.000
	SON	**2.09** **	0.000
	ANN	**12.13** **	0.000

Table 3. *Cont.*

		Trend/dec	*p* Value
Q	DJF	−0.07	0.054
	MAM	0.18	0.139
	JJA	**−0.04** *	0.003
	SON	−0.09	0.472
	ANN	−0.01	0.906
PPT	DJF	**−4.05** *	0.048
	MAM	2.29	0.430
	JJA	**−2.74** *	0.002
	SON	0.00	0.998
	ANN	−4.32	0.348
TMAX	DJF	**0.19** **	0.000
	MAM	**0.24** **	0.000
	JJA	**0.40** **	0.000
	SON	**0.26** **	0.000
	ANN	**0.27** **	0.000
TMIN	DJF	0.12	0.055
	MAM	**0.27** **	0.000
	JJA	**0.40** **	0.000
	SON	**0.27** **	0.000
	ANN	**0.26** **	0.000
SPEI−12	DJF	**−0.18** *	0.003
	MAM	**−0.19** *	0.001
	JJA	**−0.19** *	0.002
	SON	**−0.17** *	0.003
	ANN	**−0.17**	0.001

4. Discussion

Experts from all continents have confirmed the importance and potential offered by the application of the various historical RWH techniques analyzed here in different regions of the planet, especially in areas with water resource deficiencies [37], with some measures even being potentially applicable to cover part of the current urban demand [38]. This circumstance not only enables methodological comparisons but also the exchange of practices and knowledge that can be not only useful but also transcendental in saving lives [39] and entire ecosystems, such as that of the Mar Menor. This relevance is even greater when scientific evidence demonstrates the significant changes to which these territories are subject and those they are expected to endure in the future. These changes are mainly derived from climate change and continued population growth and the pressure on resources, including the soil.

In this sense, cisterns once constituted true landmarks of the rural and urban landscape. Today, they have practically disappeared, and their existence is limited, for the most part, to isolated regions or those without the possibility of connection to the public supply network. Their implementation in southeastern Spain was truly significant [40], and this current situation of detachment and neglect is more than evident in Campo de Cartagena, where the remains of these hydraulic infrastructures generally await inexorable disappearance. This abandonment and risk have been denounced on more than one occasion by researchers who have approached their regional analysis.

However, there are also notable examples of their conservation around the world, generally in spaces where, due to their characteristics, they continue to be essential infrastructures after millennia of history, especially in the arid rural areas of Africa and

Asia [41,42]. Tere are actions and artifacts of widespread global dissemination since times as remote as the Neolithic. The circumstance leads researchers to continue considering them as a sustainable, efficient, and recommendable technique for present and future hydraulics.

The situation of the runoff water ditches and the diversion dams of is equally dramatic in the study area, which is severely affected by land clearing and land use transformation. The only known example of their restoration for agricultural purposes is the one developed by Bejo Iberica at the experimental farm "El Aljibe," located in Los Carrascos (Murcia). It is based on capturing runoff water from the Los Bastidas runoff water channel and subsequently storing it in a water reservoir of approximately 8500 m^2.

Sadly, the usefulness and effectiveness demonstrated by these structures over the centuries, as well as their cultural and heritage importance, has not been sufficient for their optimal preservation. Their fragile architecture, combined with the rapid and profound transformation of the territory, affected by agricultural mechanization and industrialization and the application of modern hydraulic techniques, has condemned them to obsolescence and virtually erased their footprint from the land. Despite all this, in recent decades, very interesting studies and inventories have been carried out in Spain, demonstrating their widespread use over the centuries, as well as their cultural and environmental value [43–47], especially in the southeast and in the face of advancing desertification processes. Some of these studies have even compared them with international examples, concurring in defending their value and relevance anywhere in the world [48,49]. However, in the international context, it is not easy to find studies on these watershed irrigation infrastructures, which in the case of Campo de Cartagena may also be a measure to combat environmental pollution and the massive transport of nutrients that alters the ecological balance of the Mar Menor.

On the other hand, terracing and benching are an unmistakable feature of this use of rainwater and of adaptation to a significantly hostile environment, whether due to the lack of resources or the ruggedness of the territory. There are many studies that have addressed their study, with important examples referring to territories in South America, Europe (especially the Mediterranean area), Africa and Asia. The research concurs in highlighting the relevance for reducing runoff, increasing rainfall infiltration values, and decreasing soil erosion [50–53]. Therefore, as global climate patterns change, water resources are reduced and demand increases, the application and recovery of this agricultural technique makes more and more sense, especially in arid and semi-arid regions [54–58]. Furthermore, it constitutes a step towards to supporting the transition towards a sustainable and resilient future [59].

The abandonment of these systems is not only a sign of changing land use, but also poses a serious risk, given that the lack of maintenance of the terraces—especially their stone walls—and their subsequent collapse, accelerate hillside erosion. This is also the case in Campo de Cartagena, where the difficulties in incorporating machinery for their exploitation and the abandonment of dry land in favor of more profitable irrigation have generally turned these terraced systems into agricultural relics of a practically forgotten past. The terraced and benching systems have not fared any better, with many of them being razed and leveled to create extensive plots characterized by mechanized and highly technological exploitation.

Nevertheless, it should be noted that, in addition to being part of distinctive and attractive landscapes, these infraestructures are culturally valued by the academic world, which considers them examples of adaptation and sustainable use of resources. Likewise, and in this evaluative sense, their connection with the construction of "dry stone" walls distinguishes them as Intangible Cultural Heritage of Humanity by UNESCO. Dry stone construction that the "La Pedrisa" Cultural Association is being enhanced in the western area of the municipality of Cartagena through interesting activities. These activities look to recover the technique, the tangible and intangible heritage linked to it, and the valuable landscapes associated with its use.

But the degradation of tangible hydraulic heritage becomes even more serious when linked to the deterioration of the intangible cultural heritage associated with these infrastructures. This is because they not only fulfill technical functions but also sustain practices, knowledge systems, and forms of social organization that have been transmitted intergenerationally for centuries, all of which are likewise at risk.

Thus, this article complements other recent studies that link intangible heritage to climate change, demonstrating that the alteration of climate cycles directly affects the continuity of cultural practices dependent on traditional hydraulic systems [60]. Investigations that, likewise, rightly point out that the loss or transformation of water environments due to these causes compromises cultural rights, ancestral knowledge, and transmission processes intrinsically linked to the physical environment [61]. They also note that climate governance frameworks do not yet adequately incorporate these intangible dimensions, creating significant gaps in the protection of water-related heritage [62]. In this sense, the cited works, demonstrate, from different points of view, the effect of climate change on heritage, and that the deterioration of hydraulic infrastructures is not only a problem of material conservation, but a factor that accelerates the erosion of intangible heritage linked to water. Heritage whose safeguarding requires coherently articulated climate, legal and community approaches.

On another note, regarding land use changes, the agricultural data are unquestionable and confirm what was recently expressed. Thus, the reduction in the area used for dry land in the Region of Murcia is a proven fact, as is the reduction in the area devoted to cropland, with the loss of 192,282 hectares between 1999 and 2020. A circumstance in which the abandonment of low-profit plots for modern agriculture, many of which can only be cultivated under dry land conditions, and also the urbanization process, marked by the promotion of multiple residential development plans in rural areas, has been particularly relevant [63]. Furthermore, the European Union's renewable energy promotion policies, as well as the availability of abundant solar radiation, have also led to an increase in the use of rural land for the installation of photovoltaic solar power plants in recent decades [64], including the study area.

Thus, during this period, the decrease in land dedicated to dryland crops was almost 50 %, specifically, 193,840 ha less than in 1999. In contrast, the land dedicated to irrigated production has remained stable over time, with records close to 190,000 ha. This has, in turn, led to a change in the percentage representation of each of the production systems in the total, varying from a distribution of 69% rainfed and 31% irrigated in 1999, to 54–46% in 2020. This trend is symptomatic of agricultural intensification and modernization. This fact is reinforced by studying the values of the crop area produced in greenhouses and through localized irrigation, in both cases with a clear increase in their areas, which affects both herbaceous and woody production. It is also a consequence of the commitment to optimize the use of scarce water resources.

The long-term hydroclimatic evolution of the Campo de Cartagena basin reflects the broader trajectory of aridification observed across the southeastern Iberian Peninsula and the western Mediterranean. Our SPEI-12 trends reveal a persistent decline in multi-scale water availability, particularly during spring and summer, consistent with the progressive desiccation reported for southern Spain and the Mediterranean Basin. The combination of decreasing precipitation totals and a significant rise in the atmospheric evaporative demand has amplified the regional climatic water deficit, confirming an ongoing drying tendency. This imbalance is coherent with documented declines in streamflow and runoff generation across Iberian catchments [65–67], a fact indicating that warming and enhanced evapotranspiration have become dominant drivers of hydrological drought propagation. Overall, these findings suggest that the Campo de Cartagena basin exemplifies the accelerated transition of Mediterranean semiarid systems toward higher evaporative regimes, prolonged droughts, and reduced hydrological resilience.

To assess the statistical robustness of the temporal trends, we computed the coefficient of determination (R^2), p-values, and 95% confidence intervals of the fitted linear models. All the robustness metrics are provided in Supplementary Table S1.

Although TerraClimate provides monthly data rather than daily series, its use is fully justified in the context of long-term trend analysis. TerraClimate is one of the highest-resolution global climate reanalysis datasets currently available, delivering 4-km spatial resolution—considerably finer than other widely used products such as ERA5-Land, whose grid spacing at the study latitude is 8.8 km. This higher spatial detail is particularly relevant in heterogeneous Mediterranean landscapes, where topographic and land-surface contrasts strongly modulate climatic gradients. Moreover, the objective of this research is to assess the multi-decadal climate tendencies, for which monthly aggregation is the standard temporal scale in climatological studies. Even when daily data are available, long-term trend detection typically requires monthly or annual integrators to avoid the influence of short-term variability and to ensure the statistical robustness of the slope estimates. Therefore, the use of TerraClimate monthly fields offers the best balance between high spatial precision and appropriate temporal aggregation for trend detection.

From a socio-environmental perspective, these hydroclimatic trends contribute to explaining the gradual abandonment of traditional water-harvesting and field-terracing systems in Mediterranean agrarian landscapes. The increasing irregularity of rainfall and the diminishing frequency and intensity of runoff events reduce the effectiveness of infrastructures like cisterns, terraced fields, and dykes—originally designed for capturing episodic flows under more stable precipitation conditions. Over time, farmers perceive these systems as less reliable, especially when modern irrigation technologies and external water transfers become available, leading to their disuse and neglect.

This process is analogous to the documented abandonment of soil and water conservation structures in southeast Spain, driven by mechanization, changing land use, and shifts in agricultural strategies [68]. Similarly, studies of medieval and ancestral irrigation networks in Spain reveal that these systems persist under stress, yet they struggle with efficiency and maintenance burdens under changing hydrological regimes [69]. Moreover, research on citrus plantation abandonment in eastern Spain shows how land neglect can sharply reduce runoff generation and degrade hydraulic connectivity in local hydrosystems [70]. The intersection of climate-induced aridification and socio-technological substitution thus underlies the dual trajectory of hydraulic infrastructure decay and cultural loss. Reviving or adapting these ancestral systems—by combining traditional methods with modern storage and water management tools—could offer viable pathways to enhance resilience under increasing climate stress.

5. Conclusions

This study has allowed us to comprehensively document and analyze the set of traditional hydraulic infrastructures in Campo de Cartagena that, for centuries, enabled the capture, storage, and use of runoff water in its territory, characterized by its aridity and markedly irregular rainfall. Using historical cartographic sources, aerial orthophotography, and geospatial data, we have verified their widespread use, typological diversity, and functionality, revealing the complex network of cisterns, runoff water ditches, dams and agricultural terraces that supported the dryland economy and shaped the cultural landscape of the region. These systems, in addition to their technical value, represent material

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expressions of ancestral hydraulic knowledge and the close relationship between society and the environment, based on sustainability and the rational use of scarce resources. However, agricultural modernization, agricultural mechanization, urban development pressure, and the alteration of land use, combined with the effects of climate change, have led to their abandonment, destruction, or replacement by contemporary infrastructure and techniques, contributing to the loss of hydraulic heritage and the associated cultural memory.

The results of the spatial and temporal analysis of the land use confirm this profound transformation experienced by Campo de Cartagena, with a substantial increase in artificial and industrial surfaces and a drastic reduction in dryland areas in favor of intensive irrigation and urbanization. This dynamic has directly affected the survival of traditional infrastructure, the remains of which are now fragmented or in an advanced state of degradation. Despite this, their technical, heritage, and environmental value justifies their recovery and conservation, not only as testimonies of the past, but also as sustainable solutions that constitute present and future benchmarks in the face of the current water and climate crisis. In this sense, the restoration, enhancement, and modernization of runoff water ditches, dams, cisterns and terraces, could contribute to mitigating erosion, improving infiltration, and recharging aquifers, thereby strengthening territorial resilience. As Emeritus Professor Francisco López Bermúdez pointed out, "the frequent droughts experienced in the Murcia region and the Campo de Cartagena region would make it advisable to recover these systems to adapt to adverse rainfall, and also for their heritage and cultural value." Ultimately, the research demonstrates that the ancient hydraulic technologies of the study region should be understood not only as historical heritage, but also as models of sustainable water management applicable to the present and future in contexts of global change. This reflection can be extended to other water-deficient territories around the world.

Therefore, this analysis contributes new insights to existing studies, because, for the first time, it integrates a simultaneous historical, territorial, climatic and socioeconomic approach to explain the evolution and abandonment of traditional RWH infrastructure in the Campo de Cartagena region. In contrast to previous studies focused on typological descriptions or local research, this approach combines a comprehensive inventory, based on HGIS, historical mapping, LiDAR and orthophotos, with climate series and land-use change data. This demonstrates, quantitatively, that aridification, increased evapotranspiration, agricultural transformation, and the expansion of artificial soil have been key factors in the obsolescence of these systems. Thus, the study introduces an innovative perspective that directly links global change to the disappearance of this hydraulic heritage and its potential importance for future water resilience.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land15010098/s1, Table S1: Summary of linear trend statistics, including slope, *p*-value, R^2, and 95% confidence intervals (CI95%), for all climatic variables and annual analysed in the Campo de Cartagena basin (1958–2024).

Author Contributions: Conceptualization, G.C.-P., D.E.-S. and R.G.-M.; methodology, G.C.-P. and D.E.-S.; software, G.C.-P. and D.E.-S.; validation, G.C.-P. and D.E.-S.; formal analysis, G.C.-P., D.E.-S. and R.G.-M.; investigation, G.C.-P., D.E.-S. and R.G.-M.; resources, G.C.-P., D.E.-S. and R.G.-M.; writing—original draft preparation, G.C.-P., D.E.-S. and R.G.-M.; writing—review and editing, G.C.-P., D.E.-S. and R.G.-M.; visualization, G.C.-P. and D.E.-S.; supervision, G.C.-P. and R.G.-M.; project administration, G.C.-P.; funding acquisition, G.C.-P. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Corine Land Cover data of the territory of Spain can consult and download from the website of the National Geographic Information Center (CNIG) of Spain: https://centrodedescargas.cnig.es/CentroDescargas/corine-land-cover (accessed on 26 December 2025). TerraClimate data is available to the public through an unrestricted data repository hosted by the University of Idaho's Northwest Knowledge Network: https://www.climatologylab.org/terraclimate.html (accessed on 26 December 2025).

Conflicts of Interest: The authors declare no conflicts of interest.

Notes

1. Boletín Oficial del Estado (BOE). Núm. 221. Sábado 13 September 2025. Resolución de 4 de septiembre de 2025.
2. UNESCO: https://ich.unesco.org/es/ (accesed on 1 December 2025)
3. A concept that has recently evolved into "Anthropogenic global change" [8].
4. Georeferenced cartographic sheets that have been downloaded from the CNIG and subsequently loaded into the GIS, thus renouncing the use of the orthocomposite mosaic available via WMS connection, since this alters part of what is represented in the original documents.
5. Coordination of Information on the Environment (CORINE).
6. These are classified into Level 1, Level 2 and Level 3, increasing in detail from the first to the last.

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