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Research Article

High Resolution of Water Availability for Emilia-Romagna Region over 1961–2015

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In this study, monthly time series of precipitations and temperatures from 1024 controlled and homogeneous meteorological stations located in the Emilia-Romagna region (northern Italy) are processed in order to assess potential climate changes that occurred during the period 1961–2015. Normal period as baseline between 1961 and 1990 (1990s) and recent period between 1991 and 2015 (2010s) were adopted in this study to analyse the possible effect of climate change on water availability during long-term period. Based on monthly and annual temperature (TT), precipitation (PP), and potential (ET0), the actual evapotranspiration (AET0) and water availability (WA) were computed at high spatial resolution. Between the two analysed periods, during the 2010s, it was found an increase in the maximum mean annual temperature by 1.08°C while the maximum mean annual precipitation saw a slight decrease (from 2222 mm to 2086 mm). The precipitation decrease is more intense in the South and West sectors of area (8%) and mainly depends on negative changes taking place during the winter and the beginning of spring (from December to March). The maximum mean annual ET0 and AET0 reached values of 663 mm and 565 mm during the 1990s, while during the 2010s, the found values were 668 mm and 572 mm, respectively. Because of the decrease in precipitation and increase in the ET0 and AET0, the WA (the proportion of precipitation that is available at the soil surface for subsequent infiltration and runoff processes) shows a reduction (about 10–20%) in the whole region, with exception of the North-East part of the Emilia-Romagna region. The decrease in the mean annual water availability induces severe issues concerning the water resources management across the whole Emilia-Romagna region.

1. Introduction

Surface water and groundwater are precious resources that are exploited worldwide for drinking, agricultural, industrial, and energetic purposes. Being directly recharged by solid and liquid precipitations, both surface water and groundwater are dependent on climate changes. The latter can cause variability in inter- and intra-annual discharges of springs and rivers because of changes in the total amount and pattern of rainfall and/or snowfall occurring in the corresponding recharge areas and catchments. Moreover, temperature controls the evapotranspiration processes taking place at the soil surface; thus, an increase or a decrease in temperature leads to different precipitation quotas that return to the atmosphere by means of plants transpiration.

Water availability has been widely exploited worldwide for evaluating the potential effect of climate changes on surface water and groundwater at different time-periods (Čenčur Curk et al., 2014; [1]. It represents the proportion of precipitation that is available at the soil surface for subsequent infiltration and runoff and can be easily calculated in a spatially distributed analysis starting from the monthly precipitation and temperature datasets alone.

It is noteworthy that, for a selected time period, lower precipitations or/and higher evapotranspiration than those characterizing the reference period would lead to a deficit of water availability. On the contrary, higher precipitation amounts and/or lower evapotranspiration would result in a surplus of water availability.

The aim of this paper is to assess the potential changes of water availability in the Emilia-Romagna region (northern Italy) that may have occurred during the period 1961–2015.

Here, several authors have highlighted a precipitation reduction in the last century [1–3] that has mainly affected the winter and spring seasons [4]. Although this decrement was not uniform across the area, it has been found to be more intense since the 1990s [2, 5, 6]. Moreover, and by considering the period 1958–2000, Tomozeiu et al. [7] demonstrated an increase in seasonal minimum and maximum temperatures, which was more marked in the summer period. Antolini et al. [5] confirmed this trend also for mean annual temperatures by evidencing increases up to 0.5°C/decade for the period 1961–2010.

These conditions acted on an area where the water management is very complex. Although the mountainous sector of the region is characterized by the highest values of precipitation, the wide outcropping of poorly permeable rock units promotes runoff instead of infiltration [8, 9]. This means that relatively superficial and short groundwater circuits feed the majority of the springs and rivers, and the corresponding discharges closely follow meteoric water recharge patterns [10, 11]. Thus, in case of prolonged periods with no precipitation, river and spring flow rates may reach an almost nil value within a few months.

The hydrological behaviour of rivers strongly controls water management in the lowlands areas as well. Here, river diversions provide water for intensive agricultural activities, while the water needs of hundreds of thousands of people and industrial activities are satisfied by wells [12]. These exploit the porous aquifers of the alluvial plain of the river Po, which are in turn fed by the runoff dispersion from the stream beds [12–14]. As evidenced in [15], the reduction in runoff into the river network induces negative changes to the recharge of these porous aquifers; the latter can be therefore affected by reduction in water availability in the mountainous areas [16].

As a consequence, the Emilia-Romagna region experienced has several droughts that have caused serious water management issues, as in the case of 2003, 2006/2007, and 2017 [16], when water for human consumption was rationed and wells incremented their flow rates to satisfy the agricultural water demand.

In this work, we have started with a dataset consisting of monthly values of precipitation and minimum and maximum temperatures obtained from controlled and homogeneous 1024 weather stations that are 5 × 5 km distributed across the territory. The dataset is split into reference period 1961–1990 and recent period 1991–2015. Furthermore, monthly and annual ET0, annual AET0, and annual WA were computed on raster grid data at high spatial resolution. Relative changes of these metrics between the two analysed periods were evaluated.

The results represent a starting point for the further adaptation measures that should be pursued by stakeholders in charge of water management to reduce the effects of droughts.

2. Study Area

The Emilia-Romagna region extends from 43°44′ to 45°08′ latitude north and from 9°11′ to 12°45′ longitude east. Elevations range from more than 2000 m a.s.l. at the southern boundary to approximately 0 m a.s.l. (Po River), decreasing toward the northeast. The mean annual precipitation exceeds 2000 mm/year in the northern Apennines and decreases below 750 mm/year in the Po River plain [17] (data from 1961 to 2015). Precipitation distribution during the year is characterized by a marked minimum in the summer season and two maximum peaks, with the main one falling in autumn and the secondary one in spring. Cumulative annual snow cover is extremely variable from year to year, but in the uppermost part of region, it can reach 2–3 m in winter [18]. ET0 is concentrated in the summer season and closely follows the topography ranging from a few tens of mm per year up to 600–650 mm/year in the lowlands. As anticipated in the Introduction section, flow rate response of rivers and springs to precipitation events is rapid (few hours) because of the lithological characteristics of the northern Apennines, in which clayey materials widely outcrop [10, 11]. Low flows reflect the minimum peak of precipitation occurring in summer and in the beginning of autumn (August, September, and October) when also evapotranspiration and water demand for agricultural purposes are the highest. It is worth noting that agriculture is intensively practiced in the Po Plain and consists of a number of water-demanding crops such as fruit trees (pear trees, cherry trees, peach trees, and vineyards), wheat, beetroots, corns, tomatoes, rice, and forages. As touched upon in Section 1, water demand for agricultural activities is supplied by both river diversions and groundwater pumping. In addition, the lowland area is also densely populated and is the site of many ceramic, food, and engineering industries; water demand for industrial and drinking purposes is here ensured by groundwater pumping. Finally, it should be noted that the mountainous sector is sparsely populated while the total number of inhabitants has been declining steadily since the 1990s along with the percentage of cultivated areas. Here, water supply depends on spring flow rates and may encounter problems during the summer season, when people staying in their holiday homes double the residential population [8].

3. Materials and Methods

Monthly data of maximum and minimum air temperatures and precipitation from 1024 controlled and homogeneous meteorological stations from the Emilia-Romagna region [19] (Supplementary material 2) were used to assess the climate change effect on water availability at spatial scale over 1961–2015. These data are available at high spatial resolution (5 km^2) and are suitable for climatic studies, including both the computation of climatic indices based on daily values and analyses in which averaged values over a sufficiently large time scale are needed. In fact, they derived from the observed measurements of several stations, which were processed by Antolini et al. [5] to verify their temporal homogeneity and synchronicity, consistency, and spatial control. More details about the statistical procedures adopted can be found in [5].

As proposed by Dall'Amico and Hornsteiner [20], the time series of mean monthly air temperatures is calculated from the monthly averages between the corresponding maximum and minimum temperature values.

The final dataset is divided into two average periods of 1961–1990 thereafter defined as 1990s and 1991–2015 respective 2010s. This selection is widely used nowadays for the baseline period (1990s) and next two decades are analysed as more close to present or recent period [21–23].

Annual ET0, AET0, and WA were calculated in ArcGIS using raster grid data. Finally, spatial distribution of each parameter (namely, precipitation, temperature, ET0, AET0, and WA) is computed in ESRI GIS environment for both time-periods.

3.1. Potential Evapotranspiration (ET0). The potential evapotranspiration ET0 is defined as the amount of water that would be removed from the soil by evaporation and transpiration if sufficient water were available. There are several formulas in the literature for calculating this parameter, and the most complex ones (such as, those based on the Penman approach; see [24]) require a large amount of data. In this study, we calculate the annual Potential Evapotranspiration (ET0) for each weather station by using the well-known method [25]. This approach is based on the monthly temperature data and is very reliable in climate and hydrological studies at a spatial scale [26–28]. The formula is expressed as follows:

$$\mathrm{ET0} = b_i 16\left(\frac{10T_i}{I}\right)^{\alpha}, \qquad (1)$$

where ET0 is the monthly potential evapotranspiration (mm); T_i is the average monthly temperature (°C), and it is worth noting that in case of mean monthly temperature <0, ET0 is set equal to 0; I is the heat index; α is a function of the heat index; and b_i is the latitude factor related to sunshine (Table 1).

The heat index I is obtained as

$$I = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)^{1.514}. \qquad (2)$$

The parameter α is given by

$$\alpha = 6.75\times10^{-7}I^3 - 7.71\times10^{-5}I^2 + 1.7912\times10^{-2}I + 0.49239. \qquad (3)$$

3.2. Actual Evapotranspiration (AET0). Unlike ET0, AET0 is the quantity of water that is actually removed from the soil due to the processes of evaporation and transpiration. Being dependent on the soil moisture supply, AET0 is generally lower than ET0 as seldom the soil presents full and constant saturation.

In this work, we calculate the annual AET0 by following the approach proposed by Budyko [29]. This has been widely applied at regional scale to determine the final water balance of the soil by indicating whether the heat energy is sufficient to induce evaporation [30].

The method consists of two steps. Firstly, the aridity index φ is calculated as the ratio between ET0 and precipitation PP with a long-term period dataset:

$$\varphi = \frac{\mathrm{ET0}}{\mathrm{PP}}. \qquad (4)$$

Secondly, the annual AET0 can be obtained as a proportion of the annual precipitation as

$$\frac{\mathrm{AET0}}{\mathrm{PP}} = \left[\left(\varphi\tan\frac{1}{\varphi}\right)\left(1-\exp^{-\varphi}\right)\right]^{0.5}, \qquad (5)$$

where AET0 is the actual land cover evapotranspiration (mm) and PP is the total annual precipitation (mm).

3.3. Water Availability (WA). As anticipated in the Introduction section, the WA represents the precipitation quota that is available at the soil surface for subsequent infiltration and runoff after evaporation and transpiration processes. It has been used in several studies involving estimates of the potential effect of climate change (Čenčur Curk et al., 2014; [22, 28]. For each period time-series, the mean annual WA is obtained as follows:

$$\mathrm{WA\,(mm)} = \text{annual precipitation (mm)} - \text{annual AET0 (mm)}. \qquad (6)$$

3.4. Areal Mapping of the Climate Indices. The mean annual values of the parameters PP, TT, and ET0 from the period time-series are spatially mapped by means of the ESRI-ArcGIS (version 10.5). In detail, the spatial distributions of the parameters TT, PP, ET0, and AET0 are obtained using the Kriging Ordinary method from geostatistical analyst including the digital elevation model at 1 km^2 spatial resolution. Through this method, the accuracy of the climate variables interpolation is better rather than simply spatial analysis interpolation. It consists in a statistical approach in which observed values are interpolated following both a weighted average of the neighbouring points and their overall spatial arrangement to estimate the value of an unobserved point [31]. The results are reported on a regular grid with a cell size of km^2. The calculations of monthly and annual ET0, annual AET0, and WA were computed on a gridded layer using the "Raster Calculator" function in ArcGIS environment.

3.5. Mann-Kendall Test. The homogeneous and controlled daily data of precipitation and temperature (maximum and minimum values) for a subset of 6 meteorological stations are further analysed at the annual scale to better understand the temporal evolution of climate change and its statistical significance. Cumulative annual values of precipitations and mean annual minimum and maximum temperatures are processed for the 6 stations homogeneously distributed over the study area (i.e., Conselice Nord, Reggio Emilia, Vigoleno Verghereto, Bedonia, Abetone; see red dots in Figure 1).

Table 1: Sunshine parameter (expressed in units of 30 days of 12 hours).

Latitude	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
b_i (43°N)	0.81	0.82	1.02	1.12	1.26	1.28	1.29	1.20	1.04	0.95	0.81	0.77
b_i (44°N)	0.81	0.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	0.95	0.80	0.76

Source: [25].

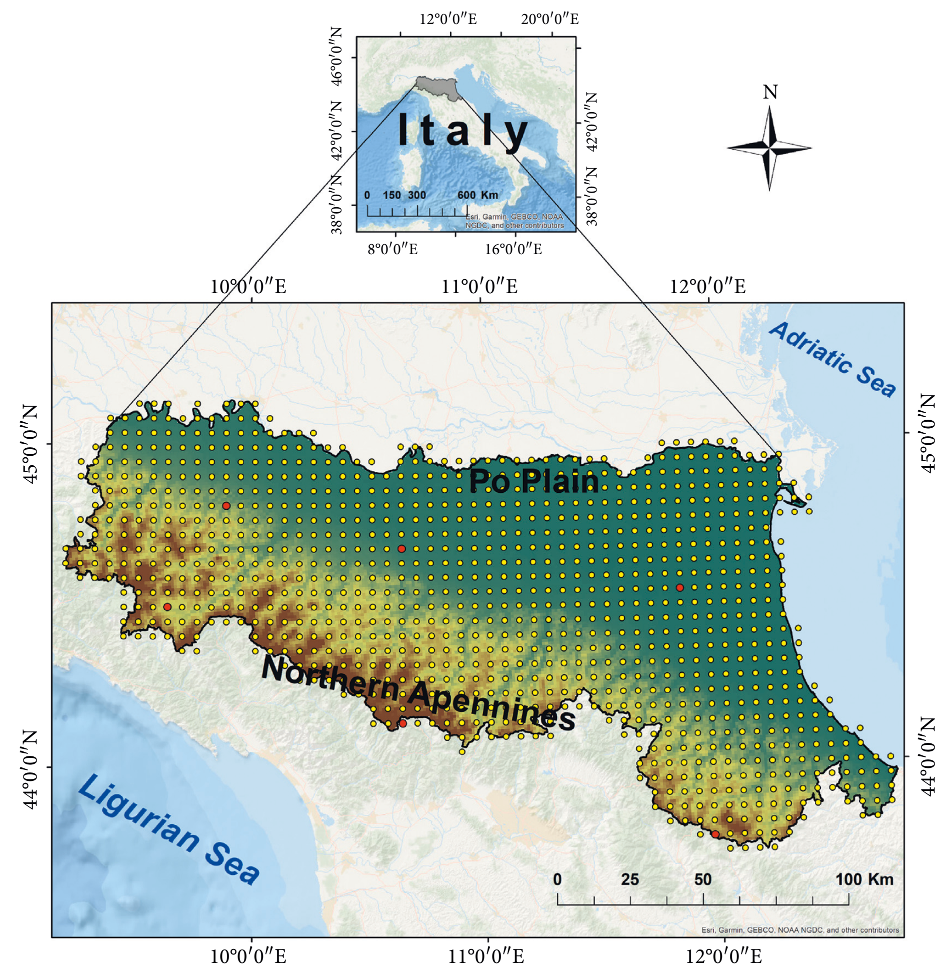


Figure 1: Physical map of the Emilia-Romagna region and distribution weather stations. Red dots represent the stations analysed in detail (e.g., annual trend). Background image source: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

The Mann-Kendall test [32] is then applied to evaluate the statistical significance of the different trends. This method is a nonparametric test that has been widely used in hydrology as it allows us to find the time-series data values [33, 34]. The S statistic value 0 of the Mann-Kendall test indicates no trend in the series. In the time series, the data values are evaluated, and if the more recent data are higher that oldest ones, the S value is incremented indicating a positive trend. On the contrary, if the recent data value is lower than that at the beginning of the series, the S values will decrease.

The Mann-Kendall statistic (S) is given by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sign}\left(x_j - x_k\right), \tag{7}$$

where $\operatorname{sign}(x_j - x_k) = 1$ if $x_j - x_k > 0$, $\operatorname{sign}(x_j - x_k) = 0$ if $x_j - x_k = 0$, and $\operatorname{sign}(x_j - x_k) = -1$ if $x_j - x_k < 0$.

As anticipated above, the higher positive values of S suggest an increasing trend, while the lower negative values of S indicate a decreasing trend. Nil value of S indicates that no trend is statistically significant in the series.

4. Results

4.1. Spatial Data Analysis of TT and PP Metrics. Mean monthly and annual TT and annual PP metrics were analysed at the spatial scale over the Emilia-Romagna region during 1961–2015. Figures 2(a) and 2(b) indicate the spatial variation of the mean annual TT for the 1990s and 2010s

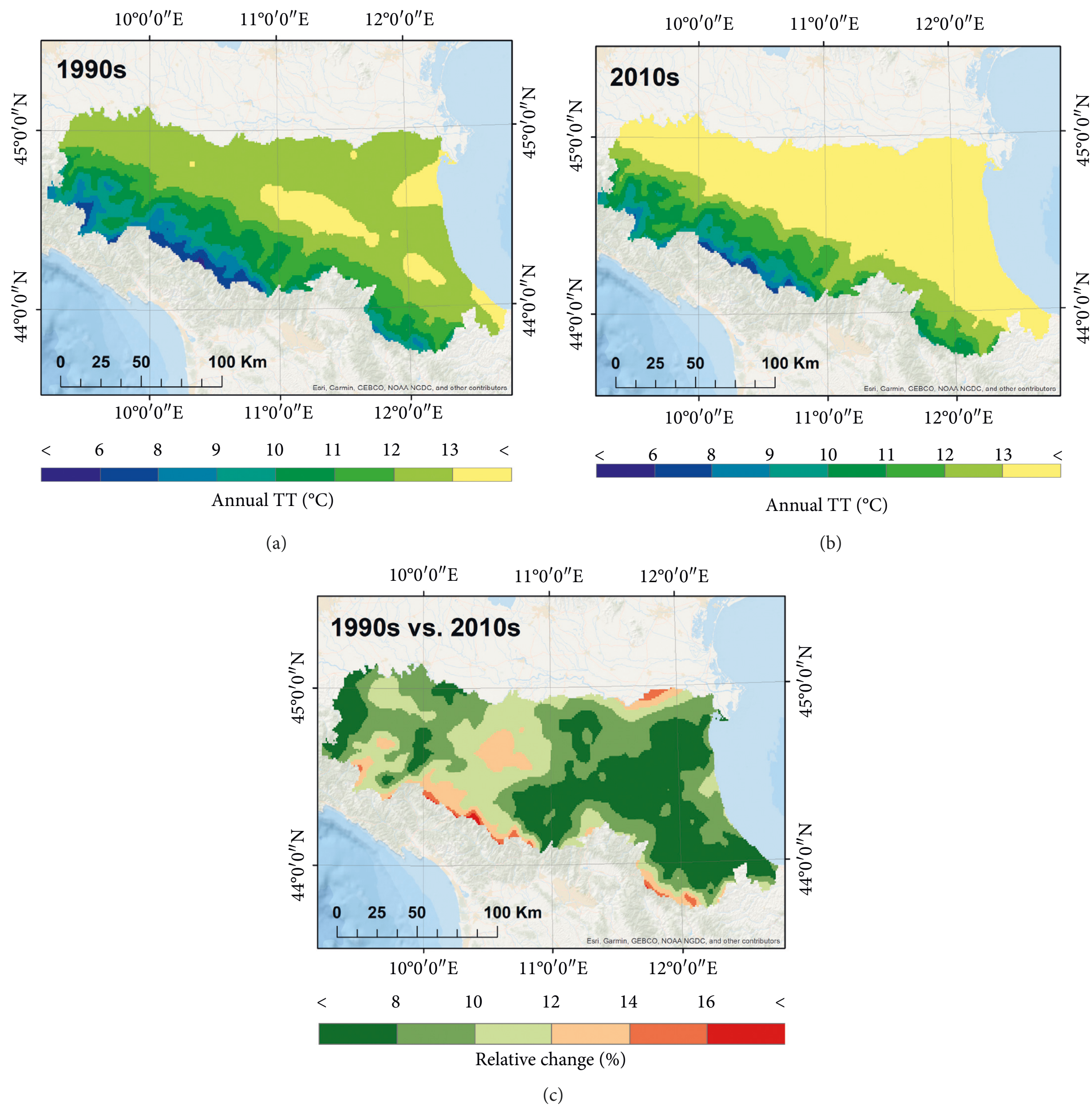


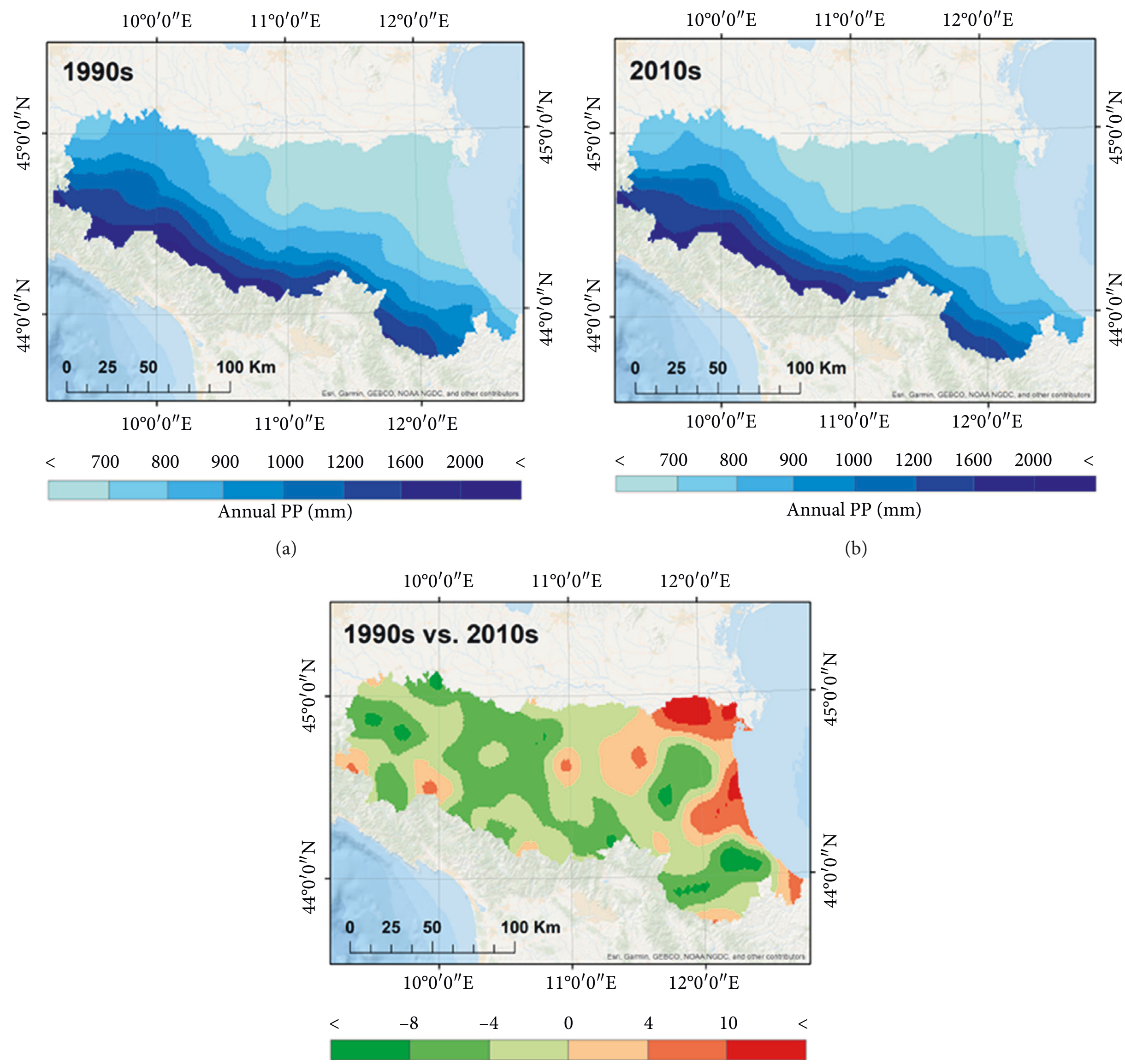
Figure 2: Spatial distribution of mean annual TT. (a) The average of mean annual air TT between 1961 and 1990. (b) The average of mean annual air TT between 1991 and 2015. (c) The relative changes in mean annual TT as a difference between the two time-periods. Background image source: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

periods. In both cases, TT is related directly to the relief altitudes and ranges between 5.4°C and 14°C (1990s) and from 6.4°C to 15.1°C (2010s). An increase of the mean annual TT is detected in the overall region (Figure 2(c)). The increment is more intense in the northern, southern, and central parts of the area (Po Plain; increases up to 1.6°C) and in the south-eastern sector (around 1.0°C). As correctly pointed out by Antolini et al. [5], the presence of isolated structures such as that located in the central part of the region (Figure 2(c)) is linked to an intense urbanization that lasted over the period 2010s. In this case, a quota of the increase of the mean annual temperature between the two selected periods is due to land use change rather than climate change.

Monthly analysis indicates also the increase of TT values, especially in the summer period. Thus, the months of June, July, and August represent the warmest and driest months during the year, when the mean monthly TT values exceed 20°C (Supplementary material 3). Shifted over south part of the higher values of monthly TT was observed at spatial scale during the 2010s (Supplementary material 4).

Figures 5(a) and 5(b) describe the spatial distribution of mean annual PP. The latter closely reflects the topography. The normal period (1990s) shows values that vary from 583 mm to 2222 mm, while during the recent decades (2010s), the PP indicates values between 617 mm and 2086 mm.

Unlike TT, marked discrepancies are noticed in the mountainous sector of the area; by moving on to the period



(a) (b) (c)

Figure 3: Spatial distribution of mean annual PP. (a) The average of mean annual PP between 1961 and 1990. (b) The average of mean annual PP between 1991 and 2015. (c) The relative changes in mean annual PP as a difference between the two time-periods. Background image source: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

2010s, decrements up to 10% are evidenced in the southwestern border of the area (Figure 3(c)). On the contrary, positive changes occur in the eastern and northeastern parts of the region, with maximum increase of mean annual PP by 16%.

4.2. Spatial Analysis of ET0, AET0, and WA. Spatial distributions of mean annual ET0s are reported in Figure 4. In the period 1990s, the annual ET0 ranges between 532 mm and 663 mm (Figure 4(a)). The period 2010s shows a slight increase in ET0, which varies from 542 mm to 668 mm (Figure 4(b)). In both periods, ET0 closely follows the mean annual TT distribution. The relative change between the two periods shows an overall increment of the annual ET0 that is mainly concentrated in the southern part of the region by about 5% (Figure 4(c)). The monthly ET0 indicates values over 120 mm during July in both periods, while the lower values were depicted during winter months (Supplementary material 5 and 6).

Spatial distributions of mean annual AET0 are reported in Figures 5(a) and 5(b). AET0 vary from 428 mm to 565 mm (1990s) and from 444 mm to 572 mm (2010s). The higher values (equivalent to about 500 mm) characterize the southern, south-eastern, and western sectors of the region. The mountain sector of the Emilia-Romagna region experiences an overall increase in AET0, which is in the order of 6% (Figure 5(c)).

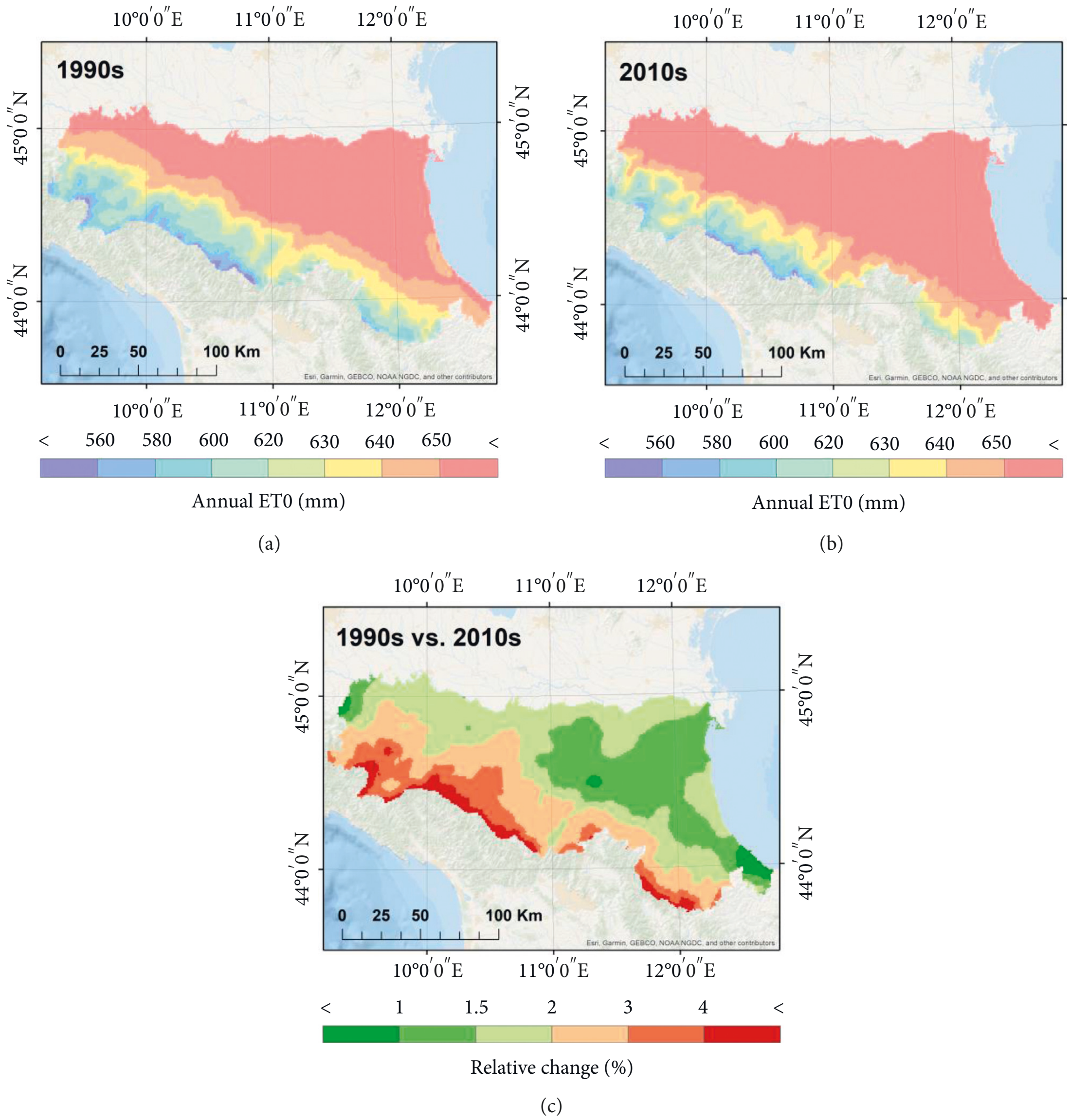


Figure 4: Spatial distribution of mean annual ET0. (a) The average of mean annual ET0 between 1961 and 1990. (b) The average of mean annual ET0 between 1991 and 2015. (c) The relative changes in mean annual ET0 as a difference between the two time-periods. Background image source: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

Figures 6(a) and 6(b) illustrate the spatial distribution of WA. A decrease in the value of WA is evidenced in the major part of the Emilia-Romagna region, with exception of the northeastern part. The WA varied during the 1990s from 155 mm to 1514 mm, while during the 2010s, the WA varied from 173 mm to 1542 mm. Also the western sector of the region is remarkably affected by changes of WA, with a reduction by 15% (hilly areas) and 20% (Po plain). Increases in this parameter only involve the Po delta and are about 20%.

4.3. Annual Trends of Climate Variables: Maximum/Minimum TT and PP. By considering the annual trends of minimum and maximum TT, a general increase in temperature along the Emilia-Romagna region is further confirmed (see Figures 7 and 8 and Tables 2 and 3). The trend indicates increases by +0.49°C/decade of minimum TT and by +0.69°C/decade of maximum TT at Reggio Emilia station. The trend of annual minimum temperature of Bedonia, Conselice Nord, and Vigoleno is not statistically significant as p value exceeds the threshold (Tables 2 and 3).

The trends of annual PP for the 6 meteorological stations indicate a slight increase over 1961–2015 for Verghereto and Abetone stations (Figures 9(a) and 9(f)). On the contrary, Bedonia, Reggio Emilia, Vigoleno, and Conselice Nord show negative trends (Figures 9(b)–9(e)). By considering the Kendall-Mann test (Table 4), the only trend of Bedonia station (about −175 mm) is close to significant (p value 0.1).

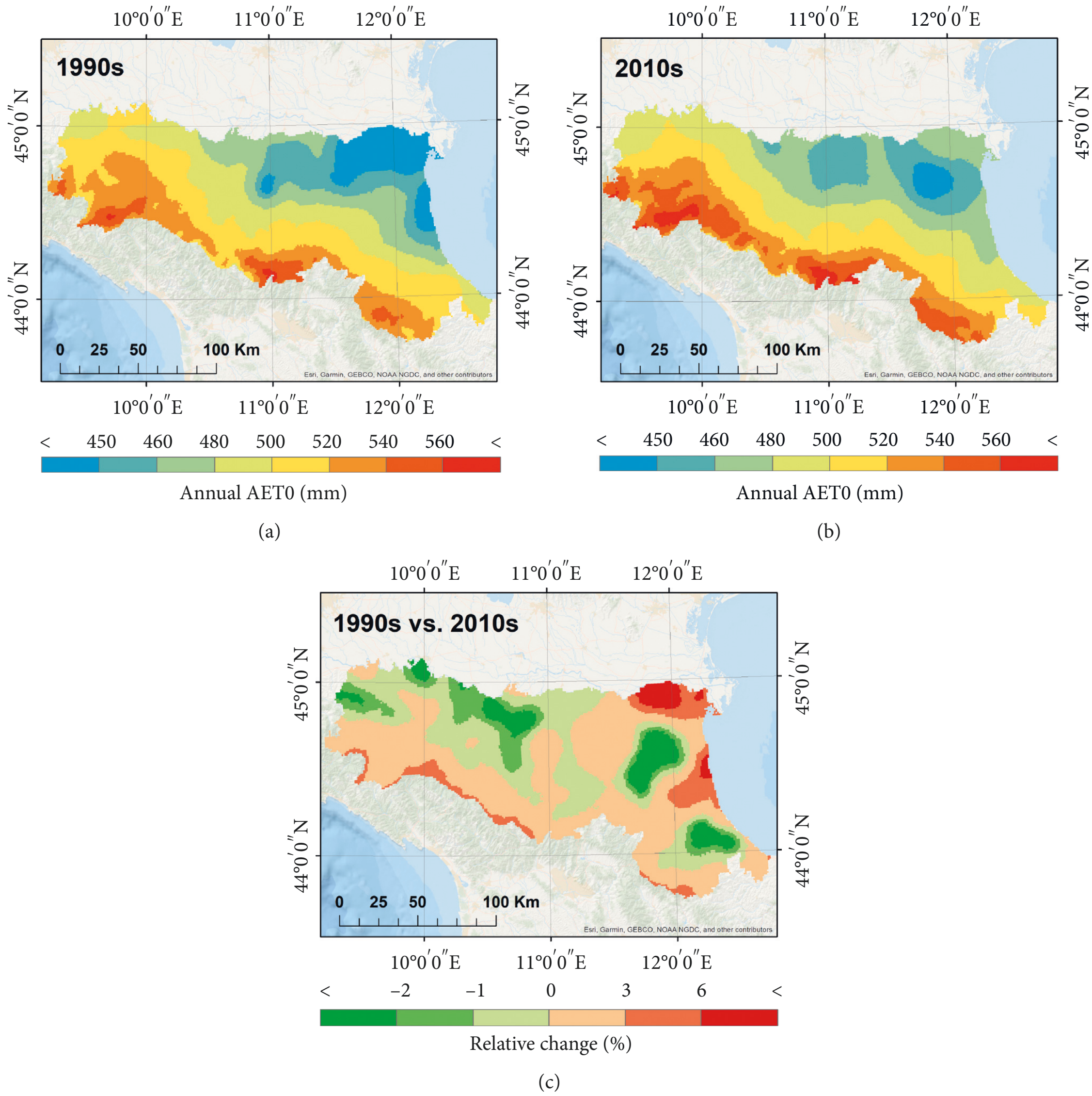


Figure 5: Spatial distribution of mean annual AET0. (a) The average of mean annual AET0 between 1961 and 1990. (b) The average of mean annual AET0 between 1991 and 2015. (c) The relative changes in mean annual AET0 as a difference between the two time-periods. Background image source: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

5. Discussion

The results highlight a temperature increase across the whole area that does not induce a remarkable increment in the average yearly actual evapotranspiration AET0 by passing from the 1990s (1961–1990) to the 2010s (1991–2015). On the contrary, a consistent reduction in water availability is observed at spatial scale for most part pf the territory. This reduction is more intense in the central, southern, and western sectors of the Emilia-Romagna region and is related to a consistent precipitation decrease that occurred along the main watershed divide of the northern Apennines. The decrease is unevenly distributed during the year and takes place mainly in winter and in the beginning of spring seasons (from December to March). This behaviour (i.e., a marked reduction in water availability induced by a decrease in precipitations in winter and spring) involves also the lowlands located in the western part of the region.

These results lead to a number of implications regarding the water management in the Emilia-Romagna. Firstly, we anticipated in the Introduction and Study Area sections that water management of the whole Emilia-Romagna is strongly linked to the average yearly annual precipitation occurring in the Apennines. Here, the water supply for human purposes is ensured by hundreds of low-yield springs whose flow rates depend strictly on the inter- and intra-annual precipitation recharge pattern. This means that a reduction in mean annual precipitation and changes in their distribution are not mitigated by these shallow aquifers. At the same time, a reduction in precipitations is also reflected on the river flow rates, which have been constantly decreasing in the last decades [35]. This fact leads to further problems in

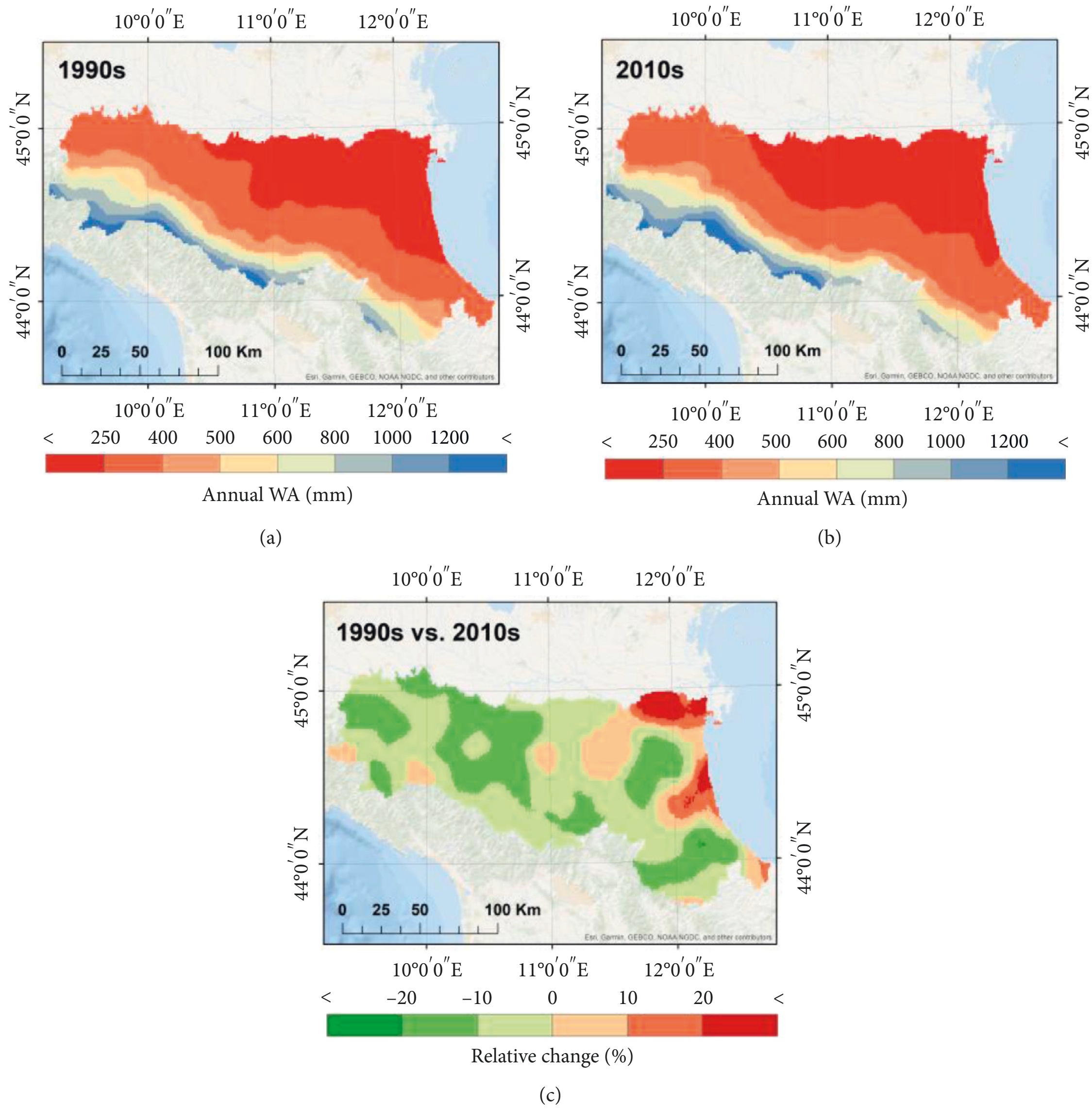


Figure 6: Spatial distribution of mean annual WA. (a) The average of mean annual WA between 1961 and 1990. (b) The average of mean annual WA between 1991 and 2015. (c) The relative changes in mean annual WA as a difference between the two time-periods. Background image source: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors.

the management of the river diversions in the lowlands and has caused a reduction in agricultural activities with significant economic losses starting from 2000 [36]. To avoid the zeroing of several cultivations and to ensure water provision for farms, an increment in groundwater pumping from the aquifers of the Po Plain has been necessary. It is worth noting that these aquifers are already displaying clear signs of water deficiency due to severe overexploitation [12, 13, 37]. Being fed by water losses from the stream beds, changes in the mean monthly water availability over the mountainous catchment areas further impacts these porous aquifers. In particular, the decrease in river discharges detected in the last decades in the Emilia-Romagna region has caused a deficit in recharging of the aforementioned aquifers as a consequence of reduced water losses through the stream beds [15].

A number of actions are under consideration in order to reduce the uncertainties in water supply during the summer and autumn seasons. In the mountainous sector of the region, stakeholders in charge of water management are going to increase the size of water tanks. Especially during the low-flow period, this will ensure that the water needs are ensured. At the foothills of the Apennines, the construction of artificial reservoirs is a resource as they will permit further water storage during the winter and spring months. This water will be released through the river diversions to feed the agricultural activities allowing for a reduction in the withdrawals from the porous aquifer.

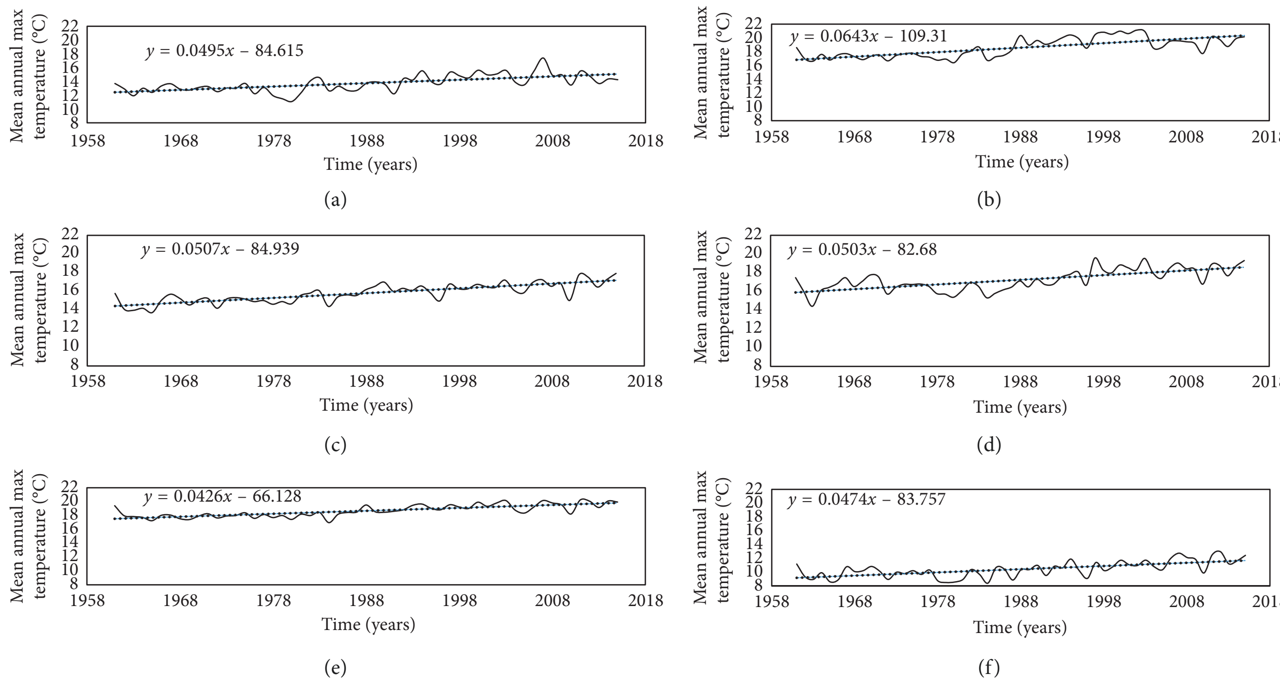


Figure 7: Temporal variation and trend line of annual maximum TT for six meteorological stations during the period 1961–2015. (a) Verghereto, (b) Reggio Emilia, (c) Bedonia, (d) Vigoleno, (e) Conselice, and (f) Abetone. For the locations of the weather stations, refer to Figure 1.

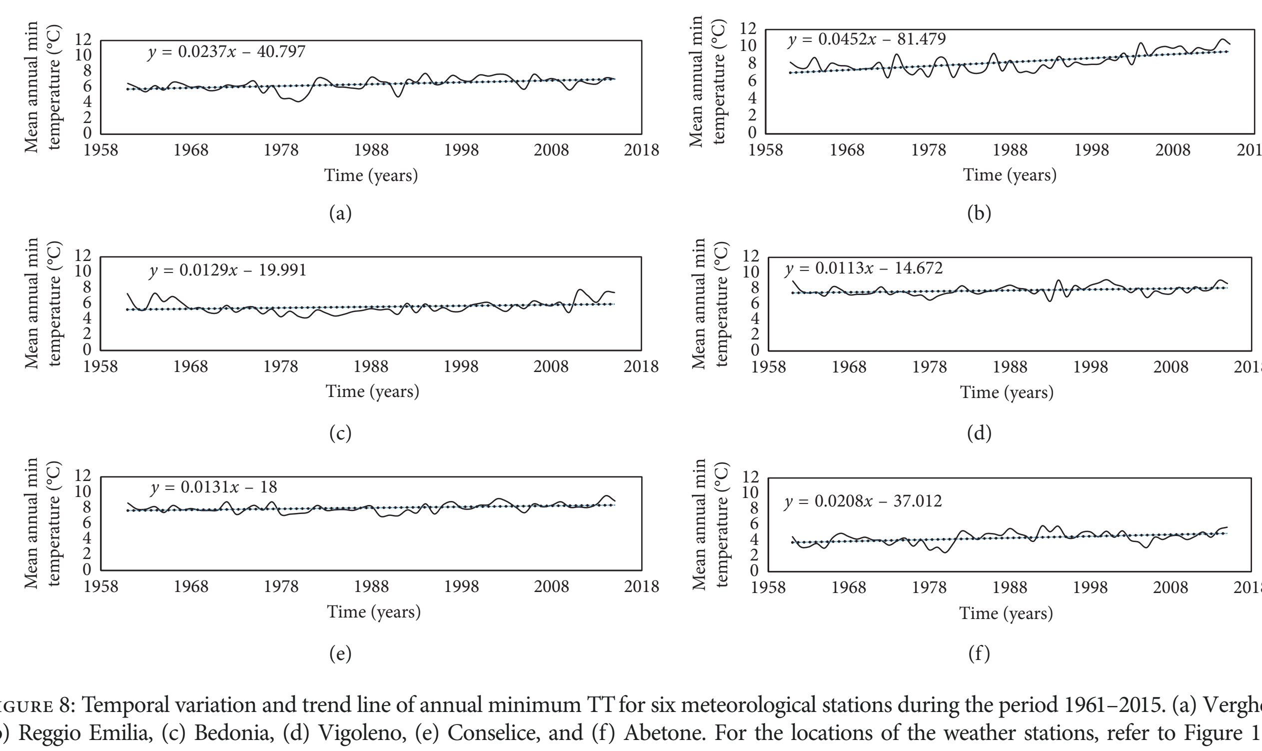


Figure 8: Temporal variation and trend line of annual minimum TT for six meteorological stations during the period 1961–2015. (a) Verghereto, (b) Reggio Emilia, (c) Bedonia, (d) Vigoleno, (e) Conselice, and (f) Abetone. For the locations of the weather stations, refer to Figure 1.

In addition, stakeholders and local administration are currently investing resources to estimate the effectiveness of aquifer recharge by means of the numerous existing quarries located near rivers [38]. Here, channels connect the rivers with quarry lakes. The initial results seem to be promising as this approach allows for remarkable quotas of runoff to be conveyed to the groundwater.

Table 2: The Mann-Kendall trend test statistic applied for annual maximum temperature observations.

Test/Station	Verghereto	Bedonia	Conselice Nord	Reggio Emilia	Vigoleno	Abetone
Kendall's tau	0.45	0.61	0.61	0.51	0.49	0.46
S	663.00	911.00	899.00	751.00	723.00	687.00
Var(S)	18975.00	18975.00	18975.00	18975.00	18975.00	18975.00
p value (two-tailed)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Alpha	0.05	0.05	0.05	0.05	0.05	0.05

Table 3: The Mann-Kendall trend test statistic applied for annual minimum temperature observations.

Test/Station	Verghereto	Bedonia	Conselice Nord	Reggio Emilia	Vigoleno	Abetone
Kendall's tau	0.33	0.19	0.24	0.44	0.22	0.27
S	489.00	277.00	359.00	649.00	323.00	403.00
Var(S)	18975.00	18975.00	18975.00	18975.00	18975.00	18975.00
p value (two-tailed)	0.00	0.05	0.01	<0.0001	0.02	0.00
Alpha	0.05	0.05	0.05	0.05	0.05	0.05

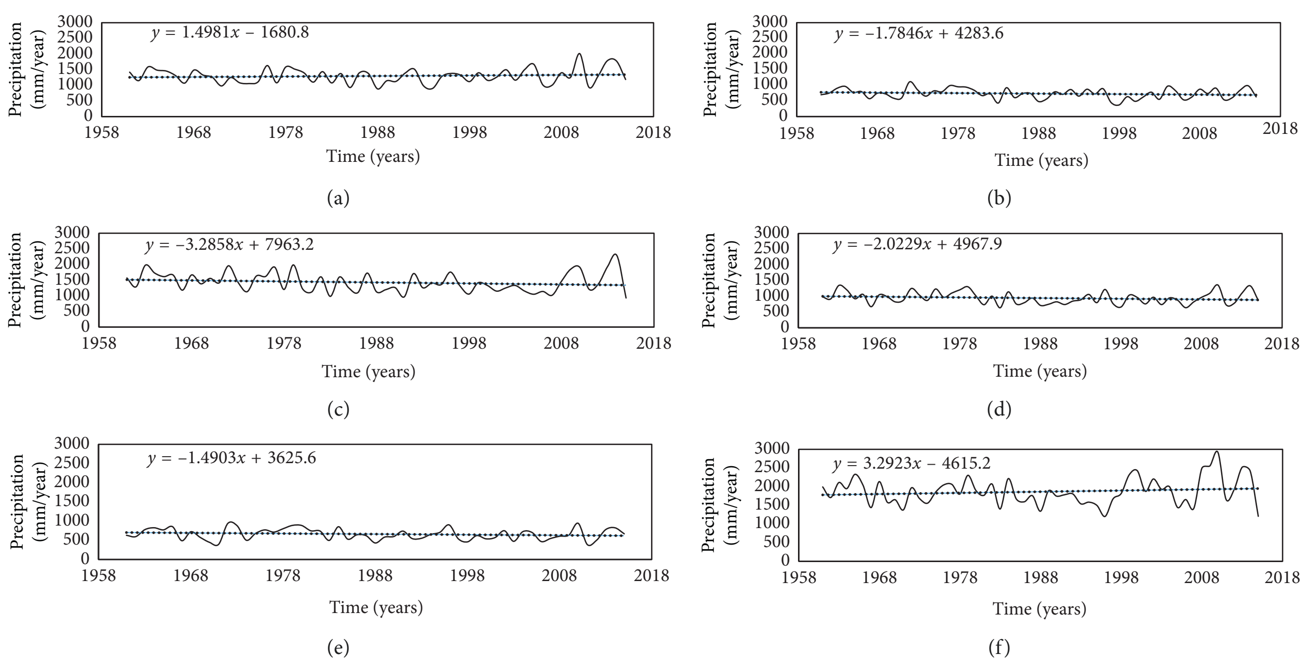


Figure 9: Temporal variation and trend line of annual PP for six meteorological stations during the period 1961–2015. (a) Verghereto, (b) Reggio Emilia, (c) Bedonia, (d) Vigoleno, (e) Conselice, and (f) Abetone. For the locations of the weather stations, refer to Figure 1.

Table 4: The Mann-Kendall trend test statistic applied for annual precipitation observations.

Test/Station	Verghereto	Bedonia	Conselice Nord	Reggio Emilia	Vigoleno	Abetone
Kendall's tau	0.02	−0.15	−0.11	−0.10	−0.12	0.04
S	33.00	−225.00	−167.00	−153.00	−181.00	61.00
Var(S)	18975.00	18975.00	18975.00	18975.00	18975.00	18975.00
p value (two-tailed)	0.82	0.10	0.23	0.27	0.19	0.66
Alpha	0.05	0.05	0.05	0.05	0.05	0.05

6. Conclusions

The spatial distribution of water availability in the Emilia-Romagna region is analysed over two time-periods (i.e., 1961–1990 and 1991–2015). The climate dataset from 1024 homogeneous and controlled weather stations uniformly distributed over the territory allows ET0 and AET0 to be computed. The Mann-Kendall test is applied for the trend analysis of annual maximum/minimum temperature and precipitation recorded at 6 stations. The trend analysis indicates an increment in the maximum and minimum temperatures for the period 1961–2015. On the contrary, the rainfall trends show a decrement. With exception of Bedonia, decrement of annul precipitation over same period is not statistically significant. If we exclude the Po delta, estimates indicate an overall decrease in water availability in the whole region, a territory that is well known for its sensitivity to climate variation. This reduction is more marked along the main watershed divide of the Apennines and reflects a consistent decrease in precipitations, which mainly occurs in the winter and spring months. As a consequence, water management has become complicated in the last decades with more frequent drought periods and an increasing number in problems regarding the water supply for drinking and agricultural purposes.

We believe that our results could be of use for the stakeholders in charge of water management to mitigate the effect of climate change.

Data Availability

Data of water availability obtained in this paper are included within the supplementary information file along with precipitation and maximum and minimum temperature datasets.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

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Supplementary Materials

Supplementary material 1: study area with meteorological station locations and codes as used in the table "Supplementary material 2" for reference. Supplementary material 2: code and name of each meteorological station used in this study. Supplementary material 3: mean monthly temperature in the Emilia-Romagna region over 1961–1990. Supplementary material 4: mean monthly temperature in the Emilia-Romagna region over 1991–2015. Supplementary material 5: mean monthly ET0 in the Emilia-Romagna region over 1961–1990. Supplementary material 6: mean monthly ET0 in the Emilia-Romagna region over 1991–2015. (*Supplementary Materials*)

References

[1] M. M. Nistor and M. Mîndrescu, "Climate change effect on groundwater resources in Emilia-Romagna region: an improved assessment through NISTOR-CEGW method," *Quaternary International*, 2017, In press.

[2] V. Pavan, R. Tomozeiu, C. Cacciamani, and M. Di Lorenzo, "Daily precipitation observations over Emilia-Romagna: mean values and extremes," *International Journal of Climatology*, vol. 28, no. 15, pp. 2065–2079, 2008.

[3] D. Pavanelli and A. Capra, "Climate change and human impacts on hydroclimatic variability in the Reno river catchment, Northern Italy," *CLEAN-Soil Air Water*, vol. 42, no. 5, pp. 1–11, 2014.

[4] F. Tomei, G. Antolini, R. Tomozeiu, V. Pavan, G. Villani, and V. Marletto, "Analysis of precipitation in Emilia-Romagna (Italy) and impacts of climate change scenarios," in *Proceedings of Statistics in Hydrology Working Group (STAHY-WG) International Workshop*, pp. 23–25, Taormina, Italy, May 2010.

[5] G. Antolini, L. Auteri, V. Pavan, F. Tomei, F. Tomozeiu, and V. Marletto, "A daily high-resolution gridded climatic data set for Emilia-Romagna, Italy, during 1961-2010," *International Journal of Climatology*, vol. 36, no. 4, 2016.

[6] R. Tomozeiu, M. Lazzeri, and C. Cacciamani, "Precipitation fluctuations during the winter season from 1960 to 1995 over Emilia-Romagna, Italy," *Theoretical and Applied Climatology*, vol. 72, no. 3-4, pp. 221–229, 2002.

[7] R. Tomozeiu, V. Pavan, C. Cacciamani, and M. Amici, "Observed temperature changes in Emilia-Romagna: mean values and extremes," *Climate Research*, vol. 31, no. 2/3, pp. 217–225, 2006.

[8] A. Corsini, F. Cervi, and F. Ronchetti, "Weight of evidence and artificial neural networks for potential groundwater spring mapping: an application to the Mt. Modino area (Northern Apennines, Italy)," *Geomorphology*, vol. 111, no. 1-2, pp. 79–87, 2009.

[9] A. Gargini, M. De Nardo, L. Piccinini, S. Segadelli, and V. Vincenzi, "Spring discharge and groundwater flow systems in sedimentary and ophiolitic hard rock aquifers: experiences from Northern Apennines (Italy)," in *Fractured Rock Hydrogeology*, J. M. Sharp, Ed., CRC Press Book, Netherlands, pp. 129–145, 2014.

[10] F. Cervi, G. Blöschl, A. Corsini, L. Borgatti, and A. Montanari, "Perennial springs provide information to predict low flows in mountain basins," *Hydrological Sciences Journal*, vol. 62, no. 15, pp. 1–13, 2017.

[11] B. Gumiero, N. Surian, B. Maiolini, B. Boz, M. Rinaldi, and F. Moroni, "The Italian rivers," in *Rivers of Europe*, K. Tockner, C. T. Robinson, and U. Uehlinger, Eds., pp. 467–495, Academic Press, Amsterdam, Netherlands, 2009.

[12] M. Farina, M. Marcaccio, and A. Zavatti, *Esperienze e prospettive nel monitoraggio delle acque sotterranee. Il contributo dell'Emilia-Romagna*, Pitagora Editrice, Bologna, Italy, 2014.

[13] G. Martinelli, A. Chahoud, A. Dadomo, and A. Fava, "Isotopic features of Emilia-Romagna region (North Italy) groundwaters: environmental and climatological implications," *Journal of Hydrology*, vol. 519, pp. 1928–1938, 2014.

[14] J. C. Davis, *Statistics and Data Analysis in Geology*, John Wiley and Sons, New York, NY, USA, 2001.

[15] G. Di Dio, "Modelling groundwater-stream water interactions in the Taro river hydrogeological basin (western Emilia-Romagna region, northern Italy)," *Italian Journal of Engineering Geology and Environment*, vol. 12, no. 1, pp. 23–39, 2012.

[16] F. Cervi, F. Petronici, A. Castellarin, M. Marcaccio, A. Bertolini, and L. Borgatti, "Climate-change potential effects on the hydrological regime of freshwater springs in the Italian Northern Apennines," *Science of the Total Environment*, vol. 622-623, pp. 337–348, 2017.

[17] G. Antolini et al., *Atlante Climatico dell'Emilia-Romagna 1961-2015*, Casma Tipolito, Bologna, Italy, 2017.

[18] F. Cervi, A. Corsini, M. Doveri, M. Mussi, and A. Tazioli, "Characterizing the recharge of fractured aquifers: a case study in a Flysch rock mass of the Northern Apennines (Italy)," *Engineering Geology for Society and Territory*, vol. 3, pp. 563–567, 2015.

[19] ARPAE-EMR, "Regional agency for environmental protection in Emilia-Romagna Region:Analisi climatica giornaliera 1961-2015," November 2018, https://www.arpae.it/dettaglio_documento.asp?id=6147&idlivello=1528.

[20] M. Dall'Amico and M. Hornsteiner, "A simple method for estimating daily and monthly mean temperatures from daily minima and maxima," *International Journal of Climatology*, vol. 26, no. 13, pp. 1929–1936, 2006.

[21] S. Cheval, M. V. Birsan, and A. Dumitrescu, "Climate variability in the Carpathian mountains region over 1961–2010," *Global and Planetary Change*, vol. 118, pp. 85–96, 2014.

[22] M. M. Nistor, A. F. Gualtieri, S. Cheval, S. T. Dezsi, and V. E. Boţan, "Climate change effects on crop evapotranspiration in the Carpathian region from 1961 to 2010," *Meteorological Applications*, vol. 23, no. 3, pp. 462–469, 2016.

[23] A. Deniz, H. Toros, and S. Incecik, "Spatial variations of climate indices in Turkey," *International Journal of climatology*, vol. 31, no. 3, pp. 394–403, 2011.

[24] R. G. Allen, L. S. Pereira, D. Raes, and M. Smith, *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage Paper 56, Rome*, 1998.

[25] C. W. Thornthwaite, "An approach toward a rational classification of climate," *Geographical Review*, vol. 38, no. 1, pp. 55–94, 1948.

[26] L. Zhao, J. Xia, C. Xu, Z. Wang, L. Sobkowiak, and C. Long, "Evapotranspiration estimation methods in hydrological models," *Journal of Geographical Sciences*, vol. 23, no. 2, pp. 359–369, 2013.

[27] B. Čenčur Curk, S. Cheval, P. Vrhovnik et al., CC-WARE Mitigating Vulnerability of Water Resources under Climate Change. WP3: Vulnerability of Water Resources in SEE, Report Version 5, 2014, http://www.ccware.eu/output-documentation/output-wp3.html.

[28] S. Cheval, A. Dumitrescu, and M. V. Barsan, "Variability of the aridity in the South-Eastern Europe over 1961–2050," *Catena*, vol. 151, pp. 74–86, 2017.

[29] M. I. Budyko, *Climate and Life*, Academic Press, New York, NY, USA, 1974.

[30] A. M. J. Gerrits, H. H. G. Savenije, E. J. M. Veling, and L. Pfister, "Analytical derivation of the Budyko curve based on rainfall characteristics and a simple evaporation model," *Water Resources Research*, vol. 45, no. 4, 2009.

[31] ESRI, *Using ArcGIS Geostatistical Analyst*, Esri Press, Redlands, CA, USA, 2003.

[32] M. G. Kendall, *Rank Correlation Methods*, Charles Griffin, London, UK, 4th edition, 1975.

[33] R. O. Gilbert, *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, NY, USA, 1987.

[34] K. H. Hamed, "Trend detection in hydrologic data: the Mann–Kendall trend test under the scaling hypothesis," *Journal of Hydrology*, vol. 349, no. 3-4, pp. 350–363, 2008.

[35] P. Billi and M. Fazzini, "Global change and river flow in Italy," *Global and Planetary Change*, vol. 155, pp. 234–246, 2017.

[36] P. Pagliara and C. Cacciamani, "2016-2017, Un lungo periodo di siccità eccezionale," *Ecoscienza*, vol. 4, pp. 56–58, 2017.

[37] P. Teatini, M. Ferronato, G. Gambolati, and M. Gonella, "Groundwater pumping and land subsidence in the Emilia-Romagna coastland, Italy: modeling the past occurrence and the future trend," *Water Resources Research*, vol. 42, no. 1, 2006.

[38] P. Severi, L. Bonzi, and V. Ferrari, "Managed aquifer recharge in the Marecchia alluvial fan (Rimini, Italy): trial and early results," *European Geologist Journal*, vol. 5, 2016.