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Assessment of Urbanization-Induced Land-Use Change and Its Impact on Temperature, Evaporation, and Humidity in Central Vietnam

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Abstract: In the present day, the acceleration of urban surface heat impacts resulting from urbanization and industrialization is critical for citizens and municipal governments in developing-country cities. The previous key findings have indicated the association between urban surface heat and the following areas: forests, mixed agricultural land, built-up area, and water bodies. This study was motivated by a lack of knowledge regarding the variation of temperature, evaporation, and humidity in Central Vietnam's major region. The non-parametric Mann–Kendall test, Sen's slope estimator, and Landsat image analysis were employed to determine the trend and statistical significance of the variables across the 42-year study period for Da Nang city and Quang Nam province. Our results show that Da Nang city has a consistent trend with a high correlation between temperature, evaporation, and relative humidity, whereas Quang Nam province showed an inverse relationship between temperature and relative humidity since the beginning of the regional urbanization. The maximum, minimum, and mean temperatures have increased by at least 0.29 °C in Quang Nam province and 0.71 °C in Da Nang city since 2000. Between 1979 and 2021, the frequency of days with temperatures exceeding 35°C has increased by two and seven days during the past decade at the meteorological stations in Da Nang and Tam Ky, respectively. The temperature in Da Nang city varied from 31.80°C to 32.82°C with high temperatures concentrated in urbanized regions with less coverage of small trees, plants, and water bodies. Thus, the results of this study will serve as a scientific basis for decision-makers and regional officials for land-use management and to increase community awareness of sustainable planning, particularly in Da Nang city and Quang Nam province in Central Vietnam.

Keywords: land surface temperature; evaporation; relative humidity; land-use change; urbanization; Mann-Kendall; Sen's slope; Landsat image; Central Vietnam

1. Introduction

Over the last few decades, there was a considerable expansion in global urbanization, which is a worldwide phenomenon. Due to the rapid growth of the economy, it has become more intensive and energetic in developing countries [1]. In 2021, more than 54.5% of the world's population resided in cities, and this number is predicted to rise to 66% before 2050 [2–4]. Moreover, according to the United Nations' projections, about 90% of the world's urbanization will be recorded in developing African and Asian countries by

2050 [2,4]. By 2020, Asian cities would have to accommodate an additional 1.5 billion people, accounting for more than 50% of the world's urban population, doubling in 2045 with about 6 billion people [4]. Thus, the cities' officials should take some actions to prepare for the urbanization expansion, such as providing essential services and increasing the number of infrastructure accommodations to allow citizens' growth [5]. On the other hand, urbanization causes changes in land-use distribution regarding impermeable urban materials and land-surface processes which could promote societal well-being [6] but can also impact the local climate [7]. Furthermore, in terms of hydrologically-related aspects, land cover changes also have a significant effect on hydrological streamflow due to the variations in the physical-based characteristics of the land surface, soil, and vegetation coverage such as in the surface roughness, infiltration capacity, root depth, soil resistivity, leaf area index (LAI), and stomatal conductance [8,9]. In Vietnam, the economic policy reforms from 1987 have resulted in rapid urbanization and social growth. In 1950, roughly 3.2 million people resided in cities, which later grew to 9 million (1975), and then to over 32 million by 2015 [2]. To better reveal the impacts of urbanization in Vietnam in recent years, Quang Nam province and Da Nang city have been selected by this study as major hotspots as strategic geographical and political areas in Central Vietnam. Since 2005, industrialization and modernization in these two regions have accelerated, making the first steps into 21st-century development [10]. Moreover, the population of Da Nang city has increased significantly, doubling in 2020 (1,125,000 people) compared to 2000 (568,000 people) [11]. Quang Nam province has a population of 1,840,000 (2020), which increased significantly from 1389 to 1505 people annually between 2001 and 2020. This province's growth rate then peaked at 0.58% in 2014 before falling to 0.50% in 2020. For deeper insights into these remarkable increases, Quang Nam province and Da Nang city have made good accomplishments in economic development and modernization of the urban infrastructure. However, the remarkable increase in population has resulted in the increase of private vehicles and public transport. A higher concentration of heat emission from autos and air conditioning equipment has been subsequently found, along with the absorption of transmitted heat by buildings and pavement. As a result, they showed a higher demand for energy consumption and increased the local UHI impacts, with higher amounts of heat radiation found in the atmosphere [7].

The earth's mean land surface temperature has risen from 0.6 °C to 0.9 °C, and may possibly climb higher in the future [12–15]. Future climates are more severe due to the significant impacts of increasing land surface temperature. Therefore, managing land surface temperature is important not only predict extreme weather events but also to understand urbanization's impacts on land-use distribution, which relates to urban thermal patterns [16–18]. Key findings from [19] show that the mixture of urbanization and land-use changes in Da Nang city could cause a remarkable increase of UHI, in which the air temperatures in cities can be up to 10°C higher than in neighboring sub-urban regions. Their findings also indicated that between 1970 and 2011, the hot season lasted two to three months longer, and the average heat index overnight across the highest-temperature months (June, July, and August) was found to be increasing over the years, highlighting an urgent need for leaders to manage UHI, particularly in built-up regions.

The storage of urban surface heat, called urban heat islands (UHI), is commonly defined as the higher temperature for built-up areas in neighboring regions [20]. Previous key findings of [21–24] have indicated impacts of UHI on air quality as well as people's health and local temperature, in which it may have a negative effect not only on people but also the environment. The most damaging consequences of urbanization are related to UHI, referring to a metropolitan region with higher air and surface temperatures than the surrounding regions [25]. The two primary forms of UHI, surface UHI and atmospheric UHI, were introduced by [26]. The atmospheric UHI is measured using air temperature, whereas SUHI is measured using land surface temperature [27]. For the correlation between UHI and the urbanization process, many studies [7,18,20,25,28–37] have been conducted, resulting in the same conclusion is that faster urbanization and land-use changes would result in a greater UHI. Additionally, considering climate change impacts due to global warming, UHI-related issues are becoming more severe in magnitude and frequency, especially in livable regions [18]. On the other hand, most of the prior studies were conducted in mid-latitude regions, UHI impacts on major cities in Southeast Asia were not revealed in previous decades until the recent attempts of [7,25,38,39], indicating a gap and the concern over whether urbanization would have more or less impact on the increase of land surface temperature in low-latitude regions. Furthermore, the understanding of urbanization development and its effects on regional temperature during thermal-extreme events is especially critical for coastal regions [40]. This scientific basis is also valuable for streamflow assessment within the context of climate change [41,42]. However, several recent study attempts regarding this topic by [7,25,38,39] for the north mid-latitude area of Vietnam (Hanoi city) could not help in this case, in which the chosen study area is the low-land coastal region, Central Vietnam. Thus, we were motivated to conduct this study, revealing this gap between the chosen period (1979–2021) in order to provide significant scientific basis and support decision-makers and regional officials regarding the preparation for future plans in terms of UHI management.

Evaporation and transpiration occur concurrently, and both processes rely on air temperature and relative humidity [43]. In previous studies, [44] highlighted the correlation and relationship between relative humidity and evaporation. They found that when relative humidity decreased by 50%, evaporation increased by 80% in Lebanon in 2017, using meteorological station datasets. However, other key findings of [45] are contrasted with the study of [44], showing that while the temperature positively correlates with evaporation, it has an inverse relationship to relative humidity. However, we must consider the difference between different regions' weather characteristics. In fact, Iraq has the subtropical aridity of the Arabian desert areas and the subtropical humidity of the Persian Gulf [46], and Lebanon has been defined as a Mediterranean-type region [47]. A recent study in Australia between 1994 and 2016 by [48] indicated consistent results compared to [45] for relative humidity, evaporation, and temperature. It also showed additional explanations regarding these meteorological variables that have been developed from previous studies for temperature and absolute humidity, and [49] for evaporation and relative humidity for all of Australia (inland and coastal regions) [50]. We acknowledge the lack of understanding of the correlation and relationship between these main meteorological variables (air temperature, evaporation, and relative humidity). Thus, this study aims to reveal this gap, which would be helpful to support the region's officials in developing future plans for hazard prevention with extreme events.

In summary, this study will be performed for Da Nang city and Quang Nam province, Central Vietnam between 1979 and 2020 with the aim of: (i) assessing the UHI change due to impacts of urbanization, industrialization, land-use change, and climate change impacts; (ii) revealing the relationship and correlation between temperature (T_{min}, T_{mean}, and T_{max}), evaporation, and humidity; and (iii) indicating the correlation between the UHI change and highly dense urban areas. Thus, key findings of this study would serve as a scientific basis to better understand urban climatology observations and assessments regarding future urban planning initiatives for stakeholders and city authorities.

2. Data and Method

2.1. Study Area

The project region includes the whole Vu Gia Thu Bon (VGTB) River Basin, Central Vietnam, with two main economic hotspots in terms of administrative entities: Quang Nam province and Da Nang city.

Quang Nam province is a leading coastal province of Vietnam, located between 14°57′ to 16°03′ in the North and 107°12′ to 108°44′ in the East. It covers approximately 10,574 square kilometers (Figure 1a). This is a critical economic zone in Central Vietnam because it is bordered to the north by Da Nang city, to the west by Laos, to the southwest by Kon Tum province, and to the east by the East Sea. The province is one of Vietnam's main export and industrial hotspots, well-known for being a tourist attraction with the Hoi An cultural site. The province's terrain is varied, with low land in the center, high mountains in the west, delta and coastal areas in the east [51]. This province has two main river basins, Vu Gia and Thu Bon, located in the center and across the Quang Nam province, forming flood plains and valleys (Figure 1a). The province's climate is tropical, with alternating wet and dry seasons. Around 70 to 75% of the total annual rainfall occurs between September and December [51]. Rainfall is substantially higher in mountainous regions than in low-land areas. On the other hand, while the majority of the province is covered with forests, the forest area has diminished due to agricultural growth, the construction of new dams, and urbanization starting from 2007 onwards [52].

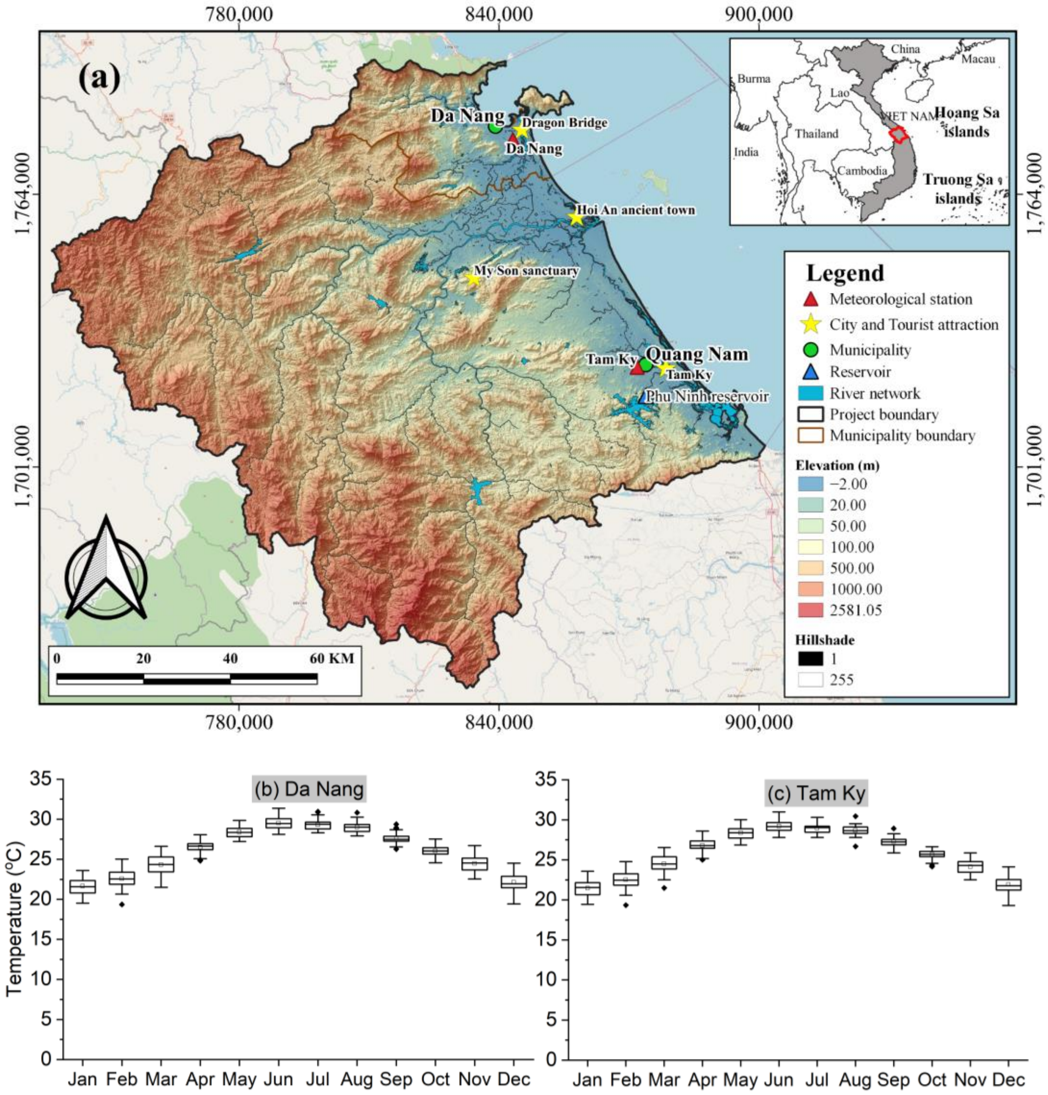

Figure 1. (**a**) Study area of Da Nang city and Quang Nam province; (**b**,**c**) monthly temperature of Da Nang city and Quang Nam province at Da Nang and Tam Ky meteorological stations, respectively.

Da Nang city covers approximately 128,342 square kilometers, including the mainland and the East Sea archipelago (Figure 1a). Da Nang city is a central coastal city of Vietnam located from 15°55′ to 16°14′ in the North and 107°18′ to 108°20′ in the East. Along with Hanoi and Ho Chi Minh City, this is a major tourist destination in Central Vietnam. It is bordered to the north by Hue Province, Quang Nam province to the west and south, and the East Sea to the east. The climate of Da Nang city is tropical monsoon with high temperatures throughout the year. The city's seasons are categorized into two distinct types: the dry season (nine months, January to the end of September) and the wet season (three months, October to December). Additionally, the yearly average temperature is roughly 25 °C, with a maximum temperature of nearly 30°C between June and August and the lowest temperatures averaging from 18°C to 23°C in December, January, and February [53].

2.2. Land-Use

The land-use dataset for this study was extracted from the LUCCi project (Land-use and Climate Change Interactions in Central Vietnam; http://www.lucci-vietnam.info/, accessed on 23 July 2022) with a resolution of 30 m × 30 m. The LUCCi project structure consisted of three main phases: (1) data collection, analysis, and modeling, (2) modeling results integration with strategy development, and (3) implementation and transformation into the study area.

The LUCCi project has been launched through nine different work packages, including the land-use dataset used in this study (http://www.lucci-vietnam.info/database, accessed on 23 July 2022). However, this study focuses on the land-use dataset produced under the LUCCi project's framework and is the critical component of this study used to reveal analysis of the relationship between the UHI, urbanization, evaporation, and relative humidity in the study area. Over the last two decades, rapid urbanization has radically transformed the land-use classes distributed within Da Nang city and Quang Nam province, mainly due to the coverage of urban infrastructures such as highways and buildings over the water bodies and vegetation [7]. Thus, we decided to use the land-use maps from four different years, 2000, 2005, 2010, and 2020 to assess the change of land-use impacts for both Da Nang city and Quang Nam province within the chosen period. The land-use classes retrieved from the LUCCi project's dataset have been simplified to only four main classes: forest, mixed agricultural land, water bodies, and built-up area. Regarding urban expansion, residential areas, industrial areas, roads, and other paved areas were included in the built-up class.

For temperature observation, we used the long-term observed dataset from the Da Nang meteorological station (Figure 1a) and the Tam Ky meteorological station (Quang Nam province) (T_{max}, T_{min}, T_{mean}) (Table 1) within a 42-year period from 1979 to 2021, provided by the Dong Bac Area Hydro-Meteorological Station (http://kttvdb.net/, accessed on 13 July 2022) in Vietnam.

Table 1. Geographical characteristics of the study's weather station locations.

Station Name	Longitude (E)	Latitude (N)	Elevation (m a.s.l.)
Da Nang	108°12′	16°40′	10
Tam Ky	108°28′	15°34′	7

To evaluate the spatial distribution within the studied areas, we used a collection of two Landsat images retrieved from USGS (https://earthexplorer.usgs.gov/, accessed on 13 July 2022) in 2005 and 2017, with the details listed in table 2. To determine the land surface temperature of the study area, the thermal infrared bands in Landsat 5 TM (band 6) and Landsat 8 OLI (band 10) were used with the following stages involved in land surface temperature retrieval [54,55]. Our method is based on the calculation of changing the temperature from the grayscale on the thermal channel of the Landsat satellite image. The process begins by converting Digital Number (DN) to the value of spectral radiation ($L\lambda$) and then converting this radiation value to temperature value [56,57]. This radiation value is then converted to a temperature value:

$$L_{\lambda} = \left(\frac{\text{LMAX} - \text{LMIN}}{\text{QCALMAX} - \text{QCALMIN}}\right) \times (\text{QCAL} - \text{QCALMIN}) + \text{LMIN} \quad (1)$$

where QCAL = Radiated values are calibrated, quantitative properties in integer form with LMINs and LMAXs are spectral radiation values in integer form.

Planck's formula carries out the conversion of spectral radiation to temperature:

$$\mathrm{T} = \frac{\mathrm{K2}}{\ln\left(\frac{\mathrm{K1}}{\mathrm{L_\lambda}} + 1\right)} \tag{2}$$

in which T = Effective temperature on satellites (K); and K1, K2: Correction factor.

Table 2. Landsat image data for spatial analysis of temperature distribution.

Source	Sensor	Cloud Cover (%)	Path/Row	Date	Time Acquired	Cell Size (m)
Landsat 5	TM	12	125/49	20/05/2005	02:59:58	30 × 30
Landsat 8	OLI	2.21	124/49	01/7/2017	03:06:14	30 × 30

2.3. Methodology

To reveal the relationship between urban temperature changes (between 1979 and 2021) and the regional development of Da Nang city and Quang Nam province in the 21-year assessment period, the Mann–Kendall test and Sen's slope estimator were used to assess the relationship between urbanization and urban temperature, evaporation, and relative humidity, resulting in a summary of urbanization change impacts on main meteorological variables in Da Nang city and Quang Nam province. To study the spatial distribution of temperature over years, focusing on densely populated areas, the assessed periods were defined as (1) pre_1999 (1979–1999) and (2) post_1999 (2000–2021).

2.3.1. Trend Analysis Methods

Two typical types of tests (Mann–Kendall test and Sen's slope estimator) have been used to assess the trend in climatologic time series: parametric and non-parametric techniques. Parametric trend tests require both independent and regularly distributed data, whereas non-parametric trend tests require both. In this study, the two approaches would help to reveal the distribution of meteorological variables' patterns and tendencies over the chosen period (1979–2021).

2.3.2. Mann–Kendall Test

In this study, the Mann–Kendall test has been used, explained by [58]:

$$\mathrm{S} = \sum_{\mathrm{a}=1}^{\mathrm{n}-1} \sum_{\mathrm{b}=\mathrm{a}+1}^{\mathrm{n}} \mathrm{sgn}(\mathrm{x_a} - \mathrm{x_b}) \tag{3}$$

In which n is the number of used data points, $\mathrm{x_a}$ and $\mathrm{x_b}$ are the data values in time series a and b (a > b), respectively, and the sign function $\mathrm{sgn}(\mathrm{x_a} - \mathrm{x_b})$ is defined as:

$$\mathrm{sgn}(\mathrm{x_a} - \mathrm{x_b}) = \begin{cases} +1, & \mathrm{if}(\mathrm{x_a} - \mathrm{x_b}) > 0 \\ 0, & \mathrm{if}(\mathrm{x_a} - \mathrm{x_b}) = 0 \\ -1, & \mathrm{if}(\mathrm{x_a} - \mathrm{x_b}) < 0 \end{cases} \tag{4}$$

and the calculated variance Var (S):

$$\mathrm{Var\ (S)} = \frac{c(c-1)(2c+5) - \sum_{c=1}^{d} \mathrm{t_i}(\mathrm{t_i}-1)(2\mathrm{t_i}+5)}{18} \tag{5}$$

C represents the number of data samples, d represents the number of connected groups, and $\mathrm{t_i}$ represents the number of ties of extent i. Furthermore, a tied group is a sample data collection with the same value. The Mann–Kendall test is commonly used to evaluate the significance of trends in hydro-meteorological time series [59–64].

2.3.3. Sen's Slope Estimator

Sen's slope estimator test was introduced by [65] as the non-parametric approach for determining the tendency of a slope within a sample of A pairs of data:

$$Q_i = \frac{x_m - x_n}{m - n} \text{ for } i = 1, 2, 3, \ldots, A \quad (6)$$

in which, x_m and x_n are the data values at times m and n, respectively, with m > n. Initially, if each period has only one datum, then $A = \frac{a(a-1)}{2}$ with a as the number of periods. If there are several observations in one or more periods, then $A < \frac{a(a-1)}{2}$ where a is the total of used observation (Sen, 1968).

The A values of Q_i are sorted from least to greatest, and the Sen's slope test estimator value is calculated:

$$Q_{med} = \begin{cases} Q_{[(A+1)/2]} & , \text{ if A is odd} \\ \frac{Q_{[A/2]} + Q_{[(A+2)/2]}}{2}, & \text{if A is even} \end{cases} \quad (7)$$

The Q_{med} indicator signifies the data trend reflection, and its value indicates the steepness of the trend. To ensure that the median slope is statistically distinct from zero, the confidence interval of Q_{med} for a certain probability would be computed. Nowadays, this indicator is widely used [65–69] due to its capacity for meteorological variable trend predictions and assessments.

3. Results and Discussions

3.1. Land-Use Change in Da Nang City and Quang Nam Province

Figures 2 and 3 indicated that built-up areas have gradually increased in this region, in which it has increased by 0.04% from 2.18% (2000) to 2.22% (2005). However, a remarkable increase has been observed with the built-up area increase of 0.34% in 2010, and it reached its peak at 2.73% at the end of the studied period (2020), corresponding to 68.03 km^2 compared to 2000 (Figures 2 and 3). Other land-use classes, such as forests, showed an upward trend by around 3% by the end of 2020 compared to 2000. On the other hand, mixed agricultural land has decreased over time, with a 4% decrease in its area by the end of 2020 (Figure 3).

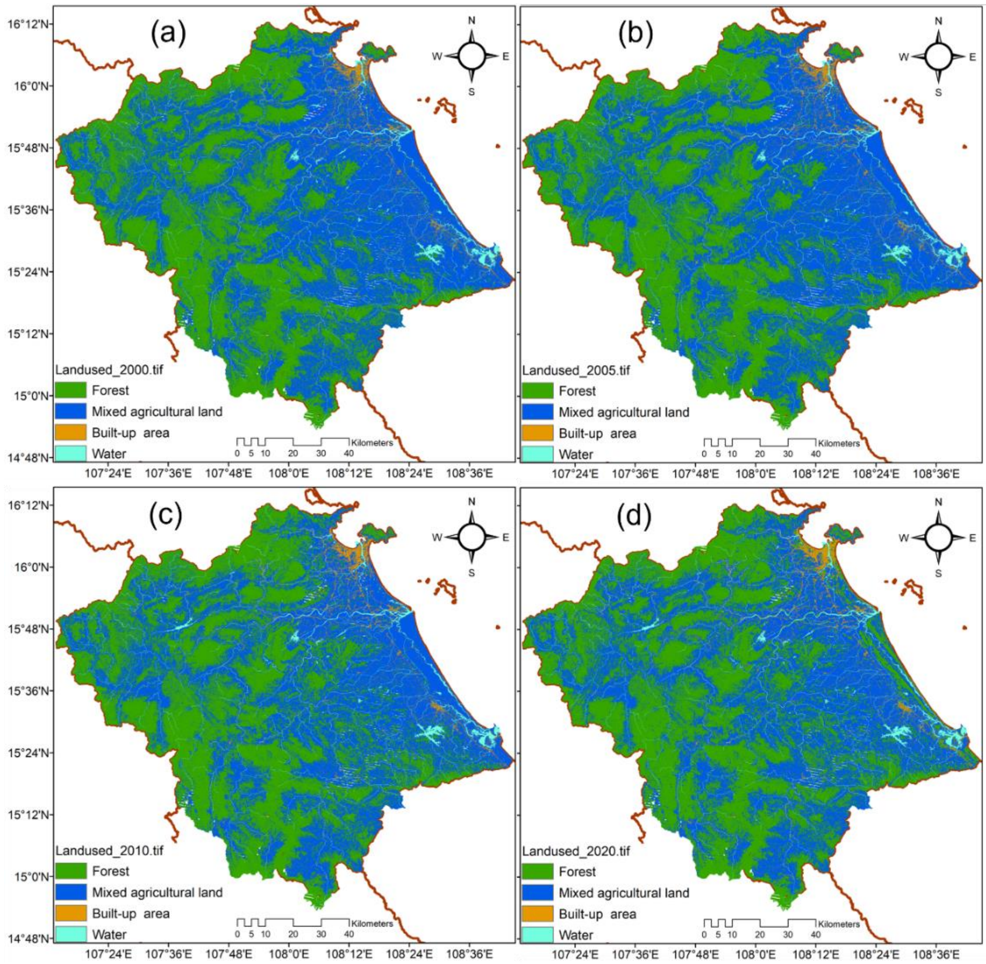

Figure 2. The Land-use maps in (**a**) 2000, (**b**) 2005, (**c**) 2010, and (**d**) 2020 for the study area.

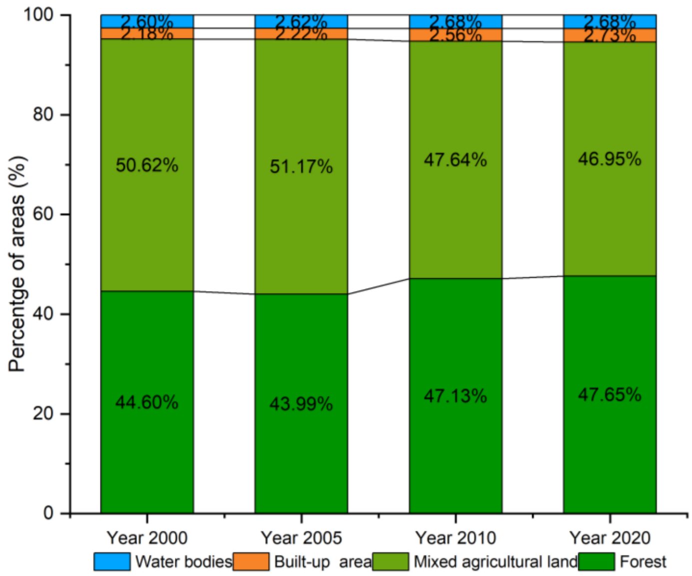

Figure 3. The distribution (%) of different land-use classes in the study area for the studied years in Da Nang city and Quang Nam province.

Figures 4 and 5 depict the distribution of built-up areas in Da Nang over the years (2000, 2005, 2010, and 2020). It indicated that urbanization has primarily occurred in the city's northern outskirts as well as on the other side of the Dragon Bridge (Ngu Hanh Son district) (Figure 1a), which has been identified as the primary area for tourism-related hotspots as the most appealing to tourists (Figures 3 and 4). Furthermore, the area has shown a high ability to attract visitors to the nation, notably in the towns of Quy Nhon–Binh Dinh, Nha Trang–Khanh Hoa, and Da Nang, as reported by [70,71]. In fact, Da Nang city welcomed about 3 million tourists in 2014, with around 25% of tourists visiting from abroad. In 2015, those statistics increased to nearly 4 million, with almost 1 million international visitors [72,73]. Visitation climbed to more than 5 million in 2016, which has risen to 6.6 million (2017), and 7.6 million (2019) (an increase of 17% compared to 2018), including more than 2 million tourists from overseas, a 36.8% increase over 2016 [71,73,74]. The rapid development in tourism visitation rates showed an upward trend as demonstrated by its ranking in the top 10 destinations for holidays in Asia [73,75]. This is shown in Figures 4 and 5, where the increase in built-up areas is visible. It has also indicated a significant increase in the number of hotels, with a total of 478 hotels (2020) as reported by the authorities from the Ministry of Culture, Sports, and Tourism in Da Nang [73].

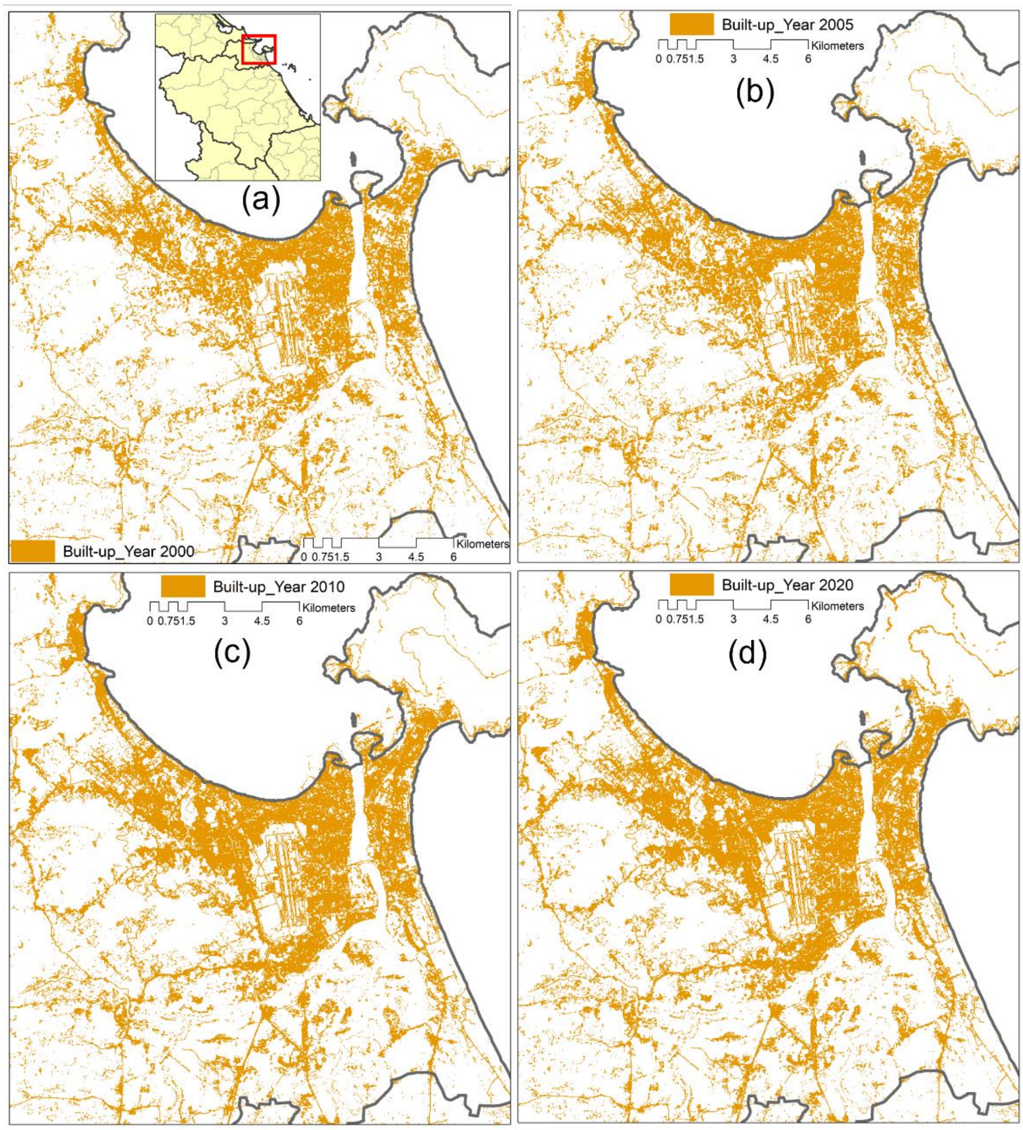

Figure 4. The built-up area distribution in (**a**) 2000, (**b**) 2005, (**c**) 2010, and (**d**) 2020 in Da Nang city.

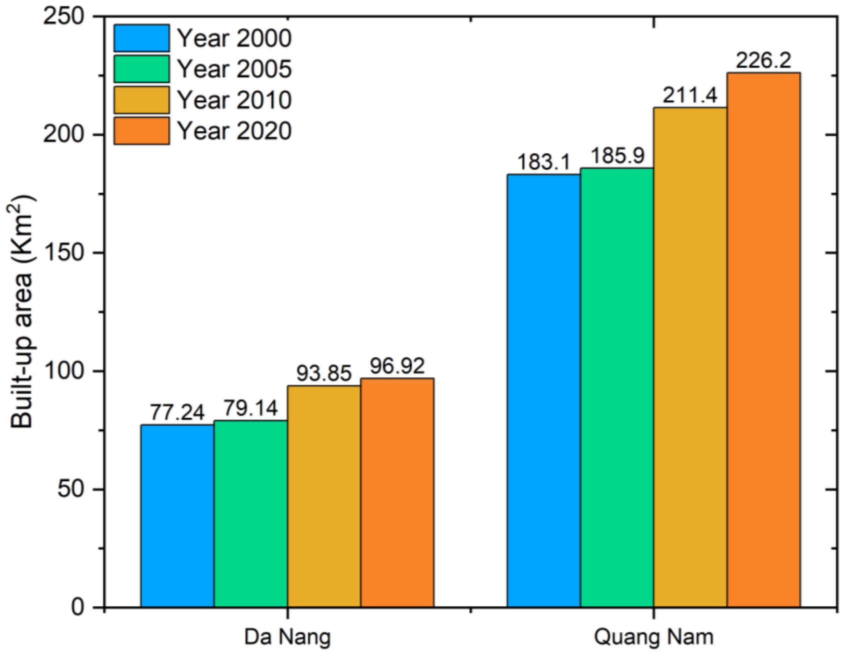

Figure 5. The summary of the built-up area of Da Nang city and Quang Nam province in 2000, 2005, 2010, and 2020.

Figures 5 and 6 show the increase in the total built-up area in Quang Nam province from 2000 to 2020. Between 2005 and 2010, this province experienced a significant change due to an increase in infrastructure, which could be explained by the success of Quang Nam province regarding the development of tourism sector [74]. In fact, due to the UNESCO's designation as World Heritage Sites for the old town of Hoi An (Figure 1a) [76], and the My Son sanctuary (Figure 1a) [77], the Quang Nam Provincial Party Committee chose tourism as a critical industry for their immediate plan in term of the province's economic development strategy [74], consistent with the city official's strategy since 2000. As a consequence, the Provincial People's Committee adopted an adjustment to the master plan for the province's tourist sector in 2015, with a focus on the end of 2020 to encourage tourism in the right direction and contribute to the socio-economic growth of Quang Nam province[74]. Following improvements to the transportation infrastructure connecting tourist locations, private companies invested in the construction of high-class hotels and resorts with sufficient amenities to fulfill the demands of tourists and the local tourism sector, resulting in more than 730 accommodation buildings [74] between 2005 and 2010.

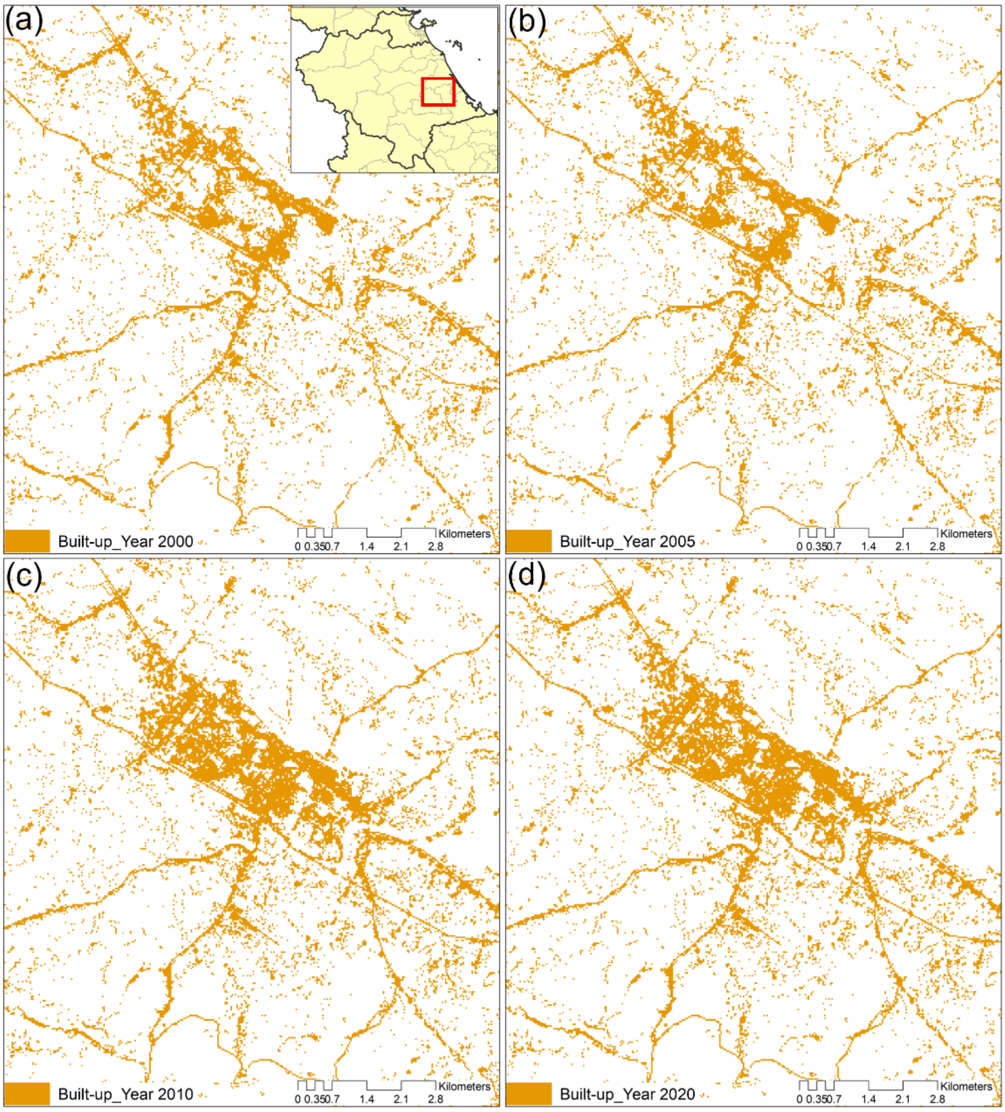

Figure 6. The distribution of built-up area in (**a**) 2000, (**b**) 2005, (**c**) 2010, and (**d**) 2020 in Quang Nam province.

3.2. Trends in the Meteorological Variables

3.2.1. Analysis of Maximum, Minimum, and Mean Temperature

The analysis was conducted using the in-situ temperature data from the Da Nang and Tam Ky meteorological stations between 1979 and 2021 (Figure 1a). We used Mann–Kendall test and Sen's estimator (described in Sections 3.2.2 and 3.2.3, respectively).

The maximum, minimum, and mean temperatures increased in the Da Nang and Tam Ky meteorological stations, especially since 2000 (Figures 7 and 8; Tables 3 and 4). This increase was statistically significant when $p < 0.1$. The increasing trend of the maximum (S = 117), minimum (S = 111), and mean temperatures (S = 129) at Da Nang station has a standard deviation of Var(S) and standard Z values of 1257.667, 1257.667, and 1257.667 for Var(S); and 3.271, 3.10180, and 3.60930 for the standard Z value between 2000 and 2021 (Table 5).

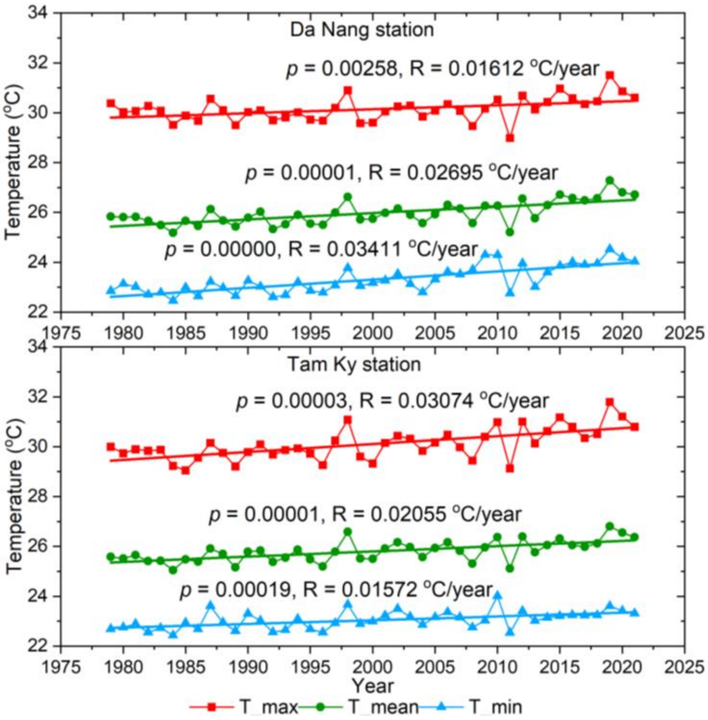

Figure 7. The maximum, minimum, and mean temperature in the Da Nang and Tam Ky meteorological stations from 1979 to 2021. *p*—statistically significant, R—Decreased/increased rates are the slopes of the linear regression.

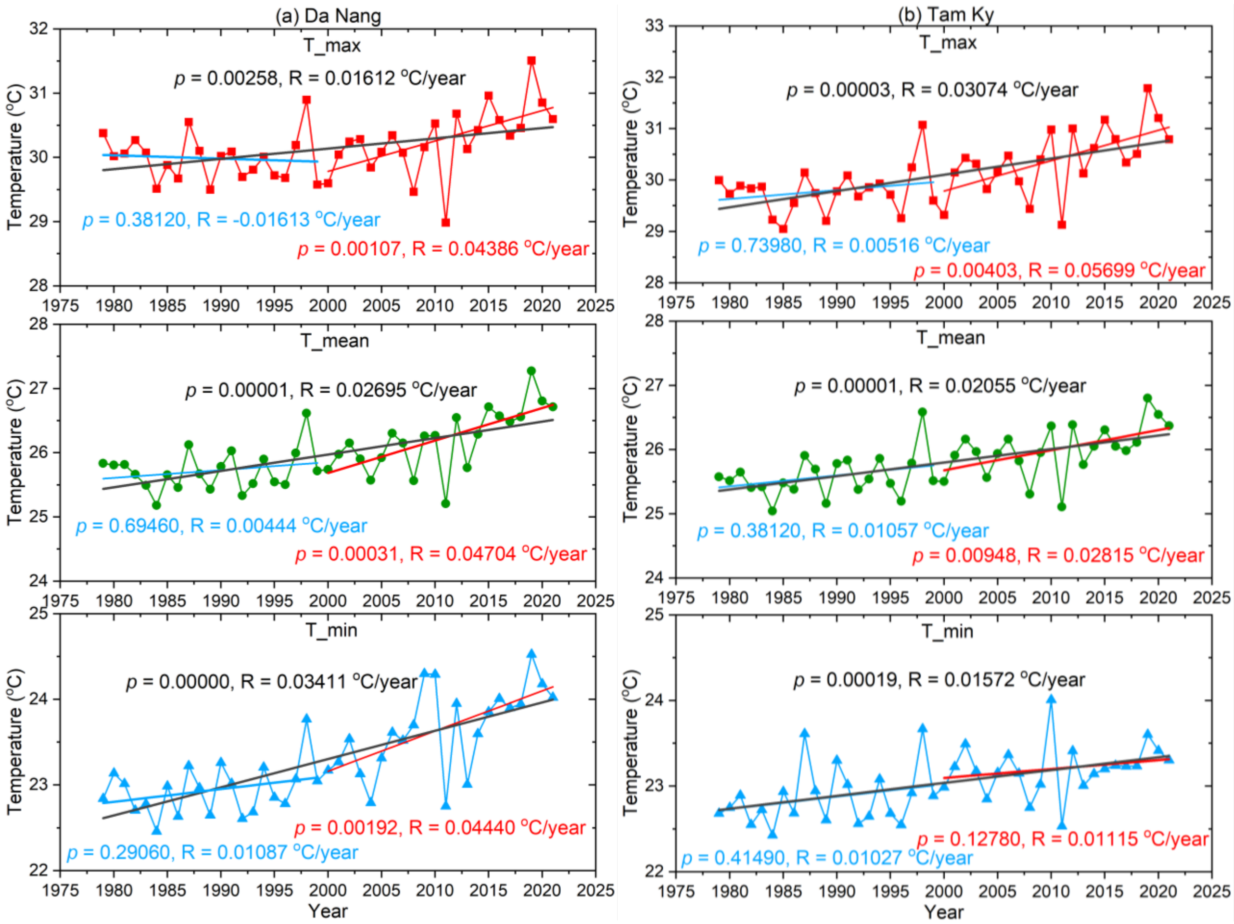

Figure 8. The maximum, mean, and minimum temperature trends in 1979–2021, 1979–1999, and 1999–2021 in (**a**) Da Nang meteorological station for Da Nang city; (**b**) Tam Ky meteorological station for Quang Nam province. *p*—statistically significant, R—Decreased/increased rates are the slopes of the linear regression.

Table 3. Mann–Kendall test trend and Sen's estimator results at the Da Nang meteorological station for Da Nang city.

Da Nang Station	Man-Kendall Test							Sen's slope
	Period	S	Var(S)	z	*p*	tau	Trend	
Minimum temperature	1979–2021	503	9130.333	5.25360	0.00000	0.55703	+	0.03411
	1979–1999	36	1096.667	1.05690	0.29060	0.17143	+	0.01087
	2000–2021	111	1257.667	3.10180	0.00192	0.48052	+	0.04440
Mean temperature	1979–2021	433	9130.333	4.52110	0.00001	0.47951	+	0.02695
	1979–1999	14	1096.667	0.39256	0.69460	0.06667	+	0.00444
	2000–2021	129	1257.667	3.60930	0.00031	0.55844	+	0.04704
Maximum temperature	1979–2021	289	9130.333	3.01400	0.00258	0.32004	+	0.01612
	1979–1999	−30	1096.667	−0.87571	0.38120	−0.14286	−	−0.01613
	2000–2021	117	1257.667	3.27100	0.00107	0.50649	+	0.04386
Relative humidity	1979–2021	−243	9130.333	−2.53260	0.01132	−0.26910	−	−0.04285
	1979–1999	128	1096.667	3.83500	0.00013	0.60952	+	0.11985
	2000–2021	−165	1257.667	−4.62450	0.00000	−0.71429	−	−0.19616
Evaporation	1979–2021	−79	9130.333	−0.81630	0.41430	−0.08749	−	−0.00290
	1979–1999	−140	1096.667	−4.19740	0.00003	−0.66667	−	−0.03643
	2000–2021	−13	1257.667	−0.33838	0.73510	−0.05628	−	−0.00452
Number of high-temperature	1979–2021	238	9106.667	2.48350	0.01301	0.26669	+	0.36667

Table 4. Mann–Kendall test trend and Sen's estimator results at the Tam Ky meteorological station for Quang Nam province.

Tam Ky Station	Man-Kendall Test							Sen's slope
	Period	S	Var(S)	z	*p*	tau	Trend	
Minimum temperature	1979–2021	357	9130.333	3.72570	0.00019	0.39535	+	0.01572
	1979–1999	28	1096.667	0.81532	0.41490	0.13333	+	0.01027
	2000–2021	55	1257.667	1.52270	0.12780	0.23810	+	0.01115
Mean temperature	1979–2021	417	9130.333	4.35360	0.00001	0.46179	+	0.02055
	1979–1999	30	1096.667	0.87571	0.38120	0.14286	+	0.01057
	2000–2021	93	1257.667	2.59420	0.00948	0.40260	+	0.02815
Maximum temperature	1979–2021	403	9130.333	4.20710	0.00003	0.44629	+	0.03074
	1979–1999	12	1096.667	0.33217	0.73980	0.05714	+	0.00516
	2000–2021	103	1257.667	2.87620	0.00403	0.44589	+	0.05699
Relative humidity	1979–2021	441	9130.333	4.60480	0.00000	0.48837	+	0.10533
	1979–1999	136	1096.667	4.07660	0.00005	0.64762	+	0.17944
	2000–2021	1.1	1257.667	0.28198	0.77800	0.04762	+	0.01304
Evaporation	1979–2021	−517	9130.333	−5.40020	0.00000	−0.57254	−	−0.04268
	1979–1999	−166	1096.667	−4.98250	0.00000	−0.79048	−	−0.09101
	2000–2021	−39	1257.667	−1.07150	0.28390	−0.16883	−	−0.01239
Number of high-temperature	1979–2021	457	9114.333	4.77640	0.00000	0.51006	+	0.95652

Table 5. The average temperature for different periods in Da Nang and Tam Ky meteorological stations.

Station	**Maximum Temperature (°C)**			**Mean Temperature (°C)**			**Minimum Temperature (°C)**		
	1979–2021	**1979–1999**	**2000–2021**	**1979–2021**	**1979–1999**	**2000–2021**	**1979–2021**	**1979–1999**	**2000–2021**
Da Nang	30.14	29.99	30.28	25.97	25.72	26.22	23.30	22.94	23.65
Tam Ky	30.11	29.79	30.41	25.80	25.58	26.01	23.04	22.86	23.21
Temperature increase compared to the 2000–2021 period (°C)									
Da Nang	0.14	0.29		0.25	0.50		0.35	0.71	
Tam Ky	0.30	0.62		0.21	0.43		0.17	0.35	

For Tam Ky station, the increasing trend of maximum (S = 103), minimum (S = 55), and mean temperatures (S = 93) have standard a deviation of Var(S) and standard Z values of 1257,667, 1257.667, 1257.667 and 2.87620, 1.52270, 2.59420, respectively, for the period of (2000–2021) (Table 6).

Table 6. The maximum, minimum, and mean temperatures in different study periods for the Da Nang meteorological station.

Season	**Max Temperature (°C)**			**Mean Temperature (°C)**			**Min Temperature (°C)**		
	1979–2021	**1979–1999**	**2000–2021**	**1979–2021**	**1979–1999**	**2000–2021**	**1979–2021**	**1979–1999**	**2000–2021**
Spring	28.66	28.74	28.59	24.49	24.32	24.66	22.10	21.82	22.37
Summer	34.13	33.88	34.37	29.07	28.75	29.37	25.77	25.32	26.21
Autumn	31.83	31.64	32.01	27.56	27.35	27.76	24.68	24.37	24.97
Winter	25.89	25.66	26.11	22.73	22.41	23.03	20.63	20.21	21.03
Temperature difference compared to the 2000–2021 period (°C) (−) indicates lower, (+) indicate higher									
Spring	+0.07	+0.15		−0.17	−0.34		−0.27	−0.55	
Summer	−0.24	−0.49		−0.30	−0.62		−0.44	−0.89	
Autumn	−0.18	−0.37		−0.20	−0.41		−0.29	−0.60	
Winter	−0.22	−0.45		−0.30	−0.62		−0.40	−0.82	

On the other hand, the maximum, minimum, and mean temperatures between 2000 and 2021 (post_1999) increased faster compared to the pre_1999 period (Figure 8a, Table 3). Additionally, the maximum, minimum, and mean temperatures at the Tam Ky meteorological station were 29.99 °C, 22.94 °C, and 25.72 °C between 1979 and 1999, and they increased in the post_1999 period by 0.29 °C, 0.71 °C, and 0.50 °C, respectively (Figure 8b, Table 4). An upward trend with $p < 0.1$ was also observed with the number of high temperatures at both meteorological stations.

The Da Nang meteorological station showed an increasing trend with higher mean and minimum temperature increases in the pre_1999 period compared to the post_1999 period. The mean and minimum temperature were 0.50 °C and 0.71 °C, respectively, between 1979 and 1999 for Da Nang city. The Tam Ky meteorological station showed a higher increase, but the maximum temperature was 0.62 °C compared to 0.29 °C at the Da Nang meteorological station (Figures 7 and 8, Table 5). Over the chosen period (1979–2021), the Da Nang station showed higher sensitivity in the minimum temperature, while the Tam Ky station showed a higher increase in the maximum temperature (Figure 7). The minimum temperature recorded at the Da Nang meteorological station showed a remarkable upward trend compared to that of Tam Ky station (Figure 8). Thus, it indicated the expansion of the total built-up area in these regions due to the development of tourism mentioned in Section 3.1, resulting in an increased UHI similar to the key findings of [78] for their study in Shanghai, China; [30] in Chicago, United States; or [25] in Hanoi, Vietnam. However, a higher increase rate (calculated as the slope of linear regression) has been found in the post_1999 period between 2000 and 2021 in Da Nang city for the maximum, minimum, and mean temperature. For Quang Nam province, a higher increase rate was only found for the maximum temperature (T_{max}) (Figure 8, Tables 3–5).

Between 1979 and 2021, the number of higher-than-35 °C days showed an increasing trend, especially for Quang Nam province (Figure 9). The number of hot days has increased by 2 and 7 days within 10 years for both the Da Nang and Tam Ky meteorological stations, respectively. In general, the post_1999 showed a higher accumulation of hot days than the pre_1999. Since 2000, the number of hot days was greater than in the pre_1999 period (1979–1999) for Da Nang city. Furthermore, Quang Nam province showed a stable increase for the entire examined period (1979–2021) with a higher increasing speed (*p* values) (Figure 9). The highest temperature recorded in 2021 is 40.2°C in Da Nang city while it was 41°C (a higher 0.8°C increase) at the Tam Ky meteorological stations (Figure 9).

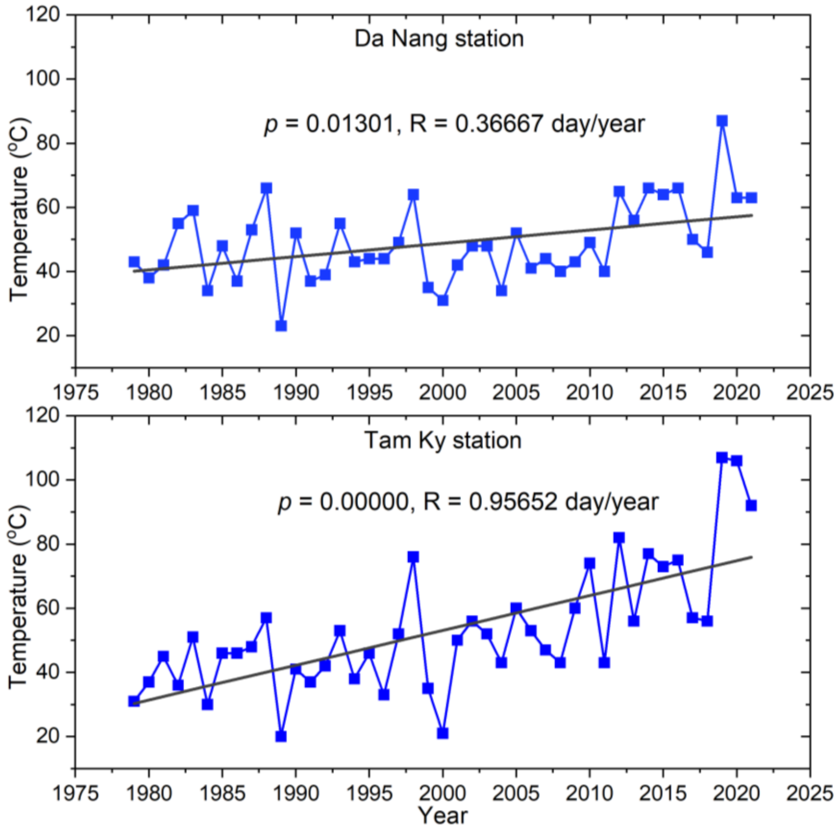

Figure 9. The number of high-temperature days (≥35 °C) at the Da Nang and Tam Ky meteorological stations. *p*—statistically significant, R—Decreased/increased rates are the slopes of the linear regression.

The maximum, minimum, and mean temperatures between 1979 and 2021 increased over yearly seasons for both the Da Nang and Tam Ky meteorological stations, ranging from 0.05°C to 0.96°C. The pre_1999 period (1979–1999) showed a higher increase compared to the entire period (1979–2021) (Tables 6 and 7). A consistent trend has been found in both the Da Nang and Tam Ky meteorological stations, with the highest increase occurring during the summer season. Da Nang city showed a higher increase (0.89°C) in terms of minimum temperature compared to the 2000–2021 period (Table 6). Quang Nam province also indicated a 0.37°C increase in the minimum temperature for the same period (Table 7). During the summer period, they showed the least change, which was 0.15°C and 0.38°C (maximum temperature), 0.34°C and 0.27°C (mean temperature), and 0.55°C and 0.1°C (minimum temperature) for Da Nang city and Quang Nam province, respectively (Tables 6 and 7).

Table 7. The maximum, minimum, and mean temperatures in different study periods for the Tam Ky meteorological station.

Season	**Max Temperature (°C)**			**Mean Temperature (°C)**			**Min Temperature (°C)**		
	1979–2021	**1979–1999**	**2000–2021**	**1979–2021**	**1979–1999**	**2000–2021**	**1979–2021**	**1979–1999**	**2000–2021**
Spring	29.11	28.91	29.29	24.62	24.48	24.75	21.92	21.87	21.97
Summer	34.23	33.73	34.69	28.85	28.53	29.15	25.32	25.13	25.50
Autumn	31.59	31.28	31.87	27.22	27.07	27.35	24.37	24.24	24.49
Winter	25.47	25.16	25.76	22.49	22.21	22.75	20.54	20.22	20.82
Temperature difference compared to 2000–2021 period (°C) (−) indicates lower, (+) indicate higher									
Spring	−0.18	−0.38		−0.13	−0.27		−0.05	−0.10	
Summer	−0.46	−0.96		−0.30	−0.62		−0.18	−0.37	
Autumn	−0.28	−0.59		−0.13	−0.28		−0.12	−0.25	
Winter	−0.29	−0.60		−0.26	−0.54		−0.28	−0.60	

3.2.2. Correlation between Maximum, Minimum, and Mean Temperature and Built-Up Area

To reveal the impacts of urbanization on the UHI change in Da Nang city and Quang Nam province, the in-situ temperature data from the Da Nang meteorological station and the Tam Ky meteorological station has been used (Figures 7 and 10), showing the maximum temperature (T_{max}), minimum temperature (T_{min}), and mean temperature (T_{mean}) between 1979 and 2021.

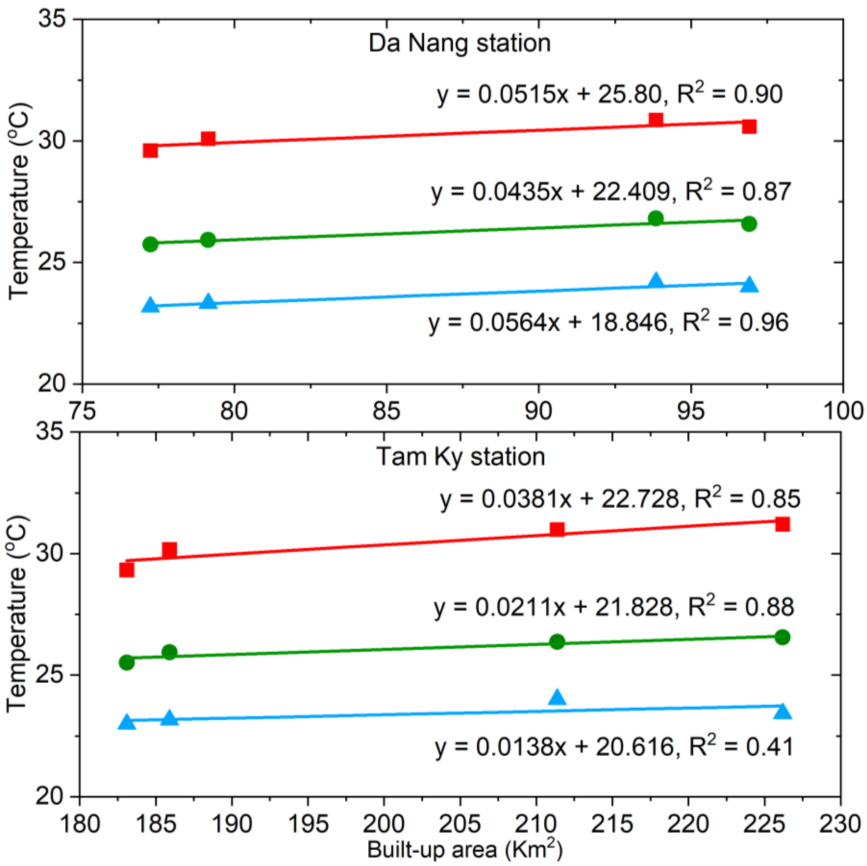

Figure 10. The correlation between the UHI and built-up area in 2000, 2005, 2010, and 2020 at the Da Nang and Tam Ky meteorological stations for Da Nang city and Quang Nam province, respectively.

Figure 10 shows a strong correlation between the UHI and built-up area in the Da Nang city. For mean temperature, a higher built-up area (km^2) shows a higher temperature record (°C), indicating a strong relationship and positive correlation between them, followed by minimum and maximum temperatures. It then confirmed the previous main key findings regarding the effects of increasing urbanization to UHI [7,25,29,30,32,78]. However, our results indicated a lower correlation between UHI and the built-up area for the maximum, minimum, and mean temperatures in Quang Nam province with the built-up area of around 215 km^2 shows a lower minimum temperature.

3.2.3. Correlation between Temperature, Relative Humidity, and Evaporation

We initially assumed that the temperature change in both Da Nang city and Quang Nam province would have an inverse relationship with relative humidity and a positive relationship with evaporation based on previous key findings of [45] for Baghdad city, Iraq, or [48], [79], and [49] for all of Australia. However, the results from the Da Nang and Tam Ky meteorological stations have indicated an interesting result for evaporation, which is supposed to show an increasing trend due to the increase in temperature over the examined period (1979–2021) (Figure 11, Tables 4 and 5). In fact, Da Nang city confirmed the consistent trend compared to previous key findings. However, Quang Nam province revealed an inconsistent trend compared to Da Nang city, in which temperature has increased over years whereas relative humidity has decreased in the same period, especially after 2000, which has been marked as the beginning of the province's urbanization due to the development of the tourism sector. Interestingly, instead of having a decreasing trend, which is consistent with key findings of [48], [79], and [80], Quang Nam province showed an increasing trend over the studied periods (Figure 11, Table 5), with the main reason being the high ratio of urbanization development. We also recognized that Quang Nam province has a very high and un-controlled urbanization development since 2017, showing a high rate of concrete replacement over natural areas. In fact, this resulted in a remarkable decrease of free space for evaporation-related processes, affecting the total amount of water vapor in the air (Figure 11b). This finding is reasonable when compared to other case studies in Australia, in which their urbanization has been managed systematically to restrict the rapid and un-controlled increase of the concrete coverage [48,80]. Moreover, due to the complex terrain, the distribution of the Phu Ninh reservoir (Figure 1a), and the Tam Ky meteorological station location over the Quang Nam province, both relative humidity and evaporation in the Tam Ky meteorological station would be affected.

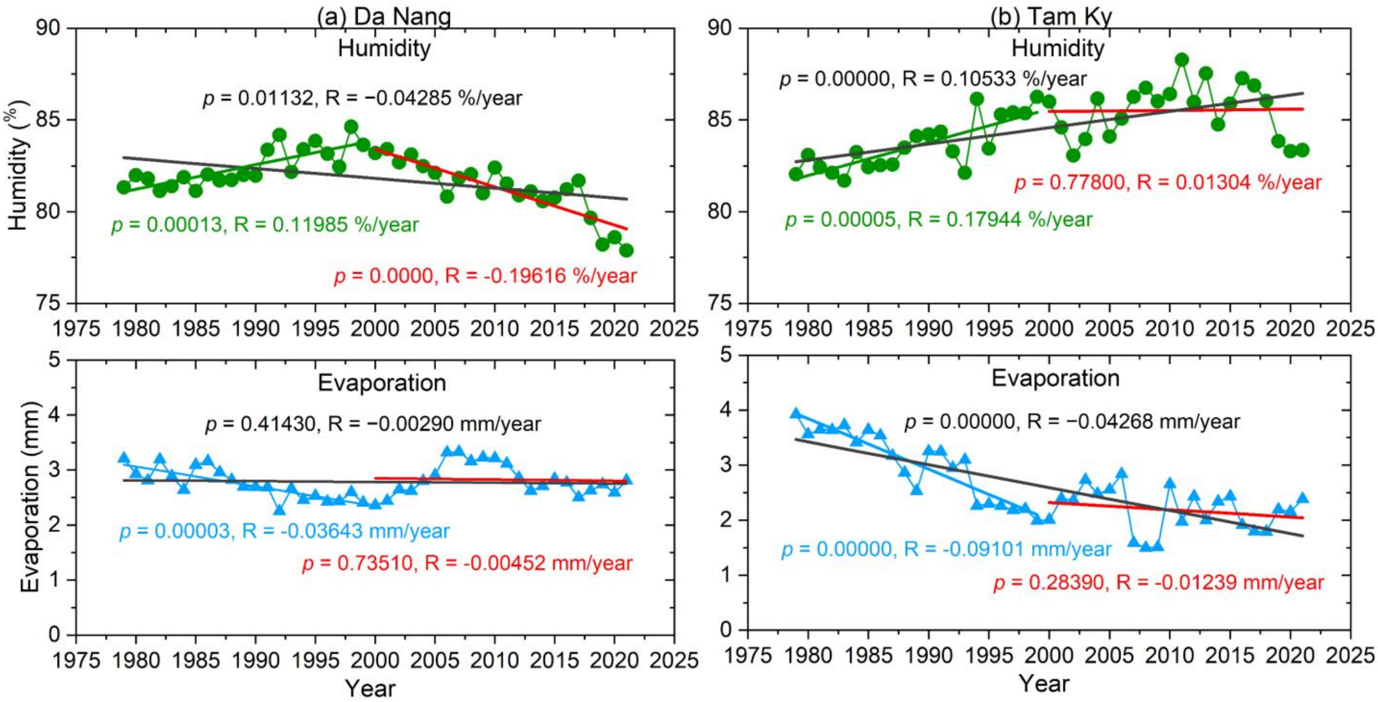

Figure 11. Humidity and evaporation trends in 1979–2021, 1979–1999, and 1999–2021 in (**a**) Da Nang meteorological station for Da Nang city; (**b**) Tam Ky meteorological station for Quang Nam province. *p*—statistically significant, R—Decreased/increased rates are the slopes of the linear regression.

On the other hand, Da Nang city and Quang Nam province showed a consistent trend in relative humidity and evaporation in the period of 2017– 2021. Indeed, these years witnessed extreme heat, especially during summer (highest in June and July, lower in August). Therefore, due to the significant increase in temperature, Da Nang city and Quang Nam province both show noticeable increases in evaporation and steady decreases in relative humidity (Figure 11a,b).

3.3. Spatial Distribution of Temperature

The analysis of the chosen Landsat images indicated that the mean temperature in Da Nang has varied significantly over the last 12 years (2005 to 2017).

Figure 12 shows the regional temperature distribution across the highly populated area between 2005 and 2017. It indicated that the temperature in Da Nang city varies from 31.80°C to 32.82°C over the 12-year chosen period. The high temperatures were predominantly concentrated in urbanized regions with less coverage of trees, plants, and water bodies, consistent with key findings from [18] for the land surface temperature patterns in 2003, 2007, and 2015 (Hanoi inner city) or [25]'s key findings on the increased UHI from 10.98% (1999) to 31% (2016) for the same study area. It again confirmed the consistency of the increase of UHI reported by [10] and highlighted by the [2–4] with the rapid acceleration of industrialization and modernization Vietnamese cities and the key findings of [7] regarding the change of green or water cover into urban land cover (built-up) contributing the most to the temperature increase.

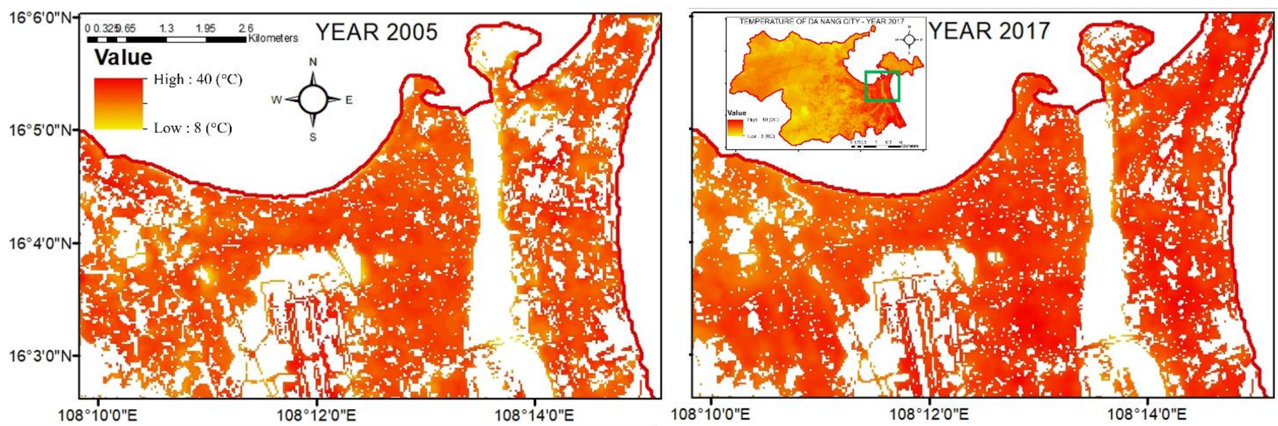

Figure 12. The spatial temperature distribution of Da Nang city and Quang Nam province in 2005 and 2017.

Figure 13 depicts the regional distribution of temperature from the northern to the southern side of the study region. The overall trend of temperature change over the studied periods shows consistency with more fluctuations over the chosen years (Figure 12). However, temperature fluctuates substantially across years, particularly in urban areas, rivers, and forests, with temperature differences between urban and forest areas in 2005 and 2017 being 4.84°C and 6.37°C, respectively (Figure 13). Furthermore, the surface temperature in 2005 was lower compared to 2017, with higher temperature records observed closer to densely inhabited areas (Figures 12 and 13). Moreover, the average temperature in 2005 was around 26.83°C whereas the temperature difference between urban and forest regions was 7.15°C. This difference in temperature has increased significantly in regions with high water coverage (Figure 13) between 2005 and 2017. Additionally, the surface temperatures in 2005 and 2017 were comparable to the mean temperature, which were at 26.83°C and 26.45°C, respectively. The temperature was higher in urban areas as well as between different regions, which could indicate the increase of the built-up area.

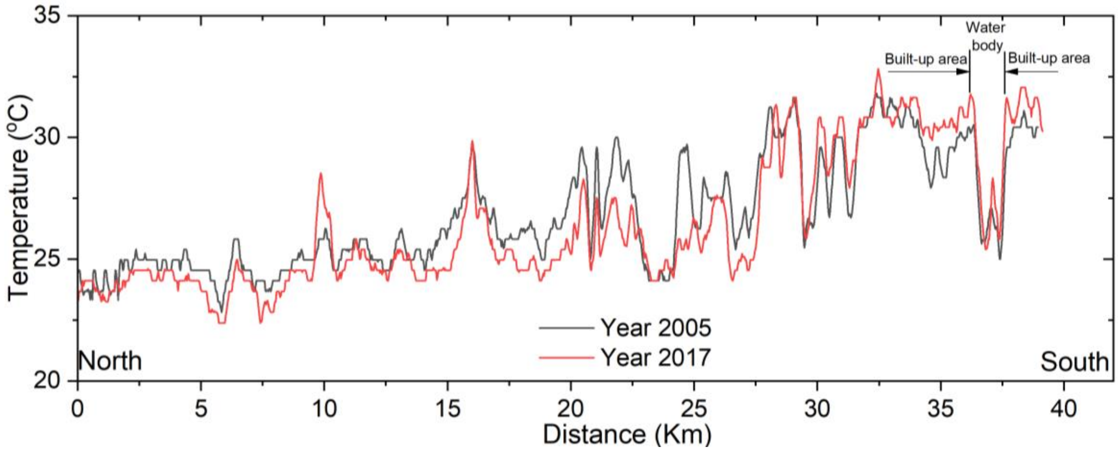

Figure 13. The geographical temperature distribution in the study area from north to south in 2005 and 2017.

3.4. Limitation of the Study

For the nature of this journal, we acknowledge that our study area is one of the main constraints. Only two main meteorological stations in Da Nang city and Quang Nam province in Central Vietnam were used to present for the Central Vietnam due to a significant lack of in-situ datasets. Furthermore, we did not consider waste heat in industrial factories, and we would like to identify waste heat priority zones for specific locations where the ratio of waste heat emitted from industrial processes, vehicular traffic, or air conditioning exceeds the proportion of surface-emitted heat in future studies. Moreover, we also did not consider the type of industry or the features of the industrial location. For urban planning, we need to concentrate more on waste heat sources and wind patterns and how these affect temperature, evaporation, and relative humidity, along with their correlation and relationship.

4. Conclusions

This study has indicated and revealed important key findings which serve as the scientific basis to reveal the land-use change impact on the land surface temperature, evaporation, and relative humidity using Mann–Kendall test and Sen's slope estimator. This study used the in-situ datasets from the Tam Ky meteorological station (Quang Nam province) and the Da Nang meteorological station (Da Nang city) for pre_1999 (1979–1999) and post_1999 (2000–2021). The summary of key findings has been summarized to address study's objectives: (i) the assessment the UHI change due to the impacts of urbanization, industrialization, land-use change, and climate change (ii) the relationship and correlation between temperature (T_{min}, T_{mean}, and T_{max}), evaporation, humidity, and (iii the UHI change in high density urban area.

(1) The rapid increase in urbanization resulting from the tourism sector's development has increased the built-up area by 0.04% from 2.18% (2000) to 2.22% (2005) before increasing 0.34% in 2010 and peaking at 2.73% (2020). Our study showed that temperature has increased in this region with maximum, minimum, and mean temperatures of 29.99°C, 22.94°C, and 25.72°C found between 1979 and 1999, and increased since 2000 by 0.29°C, 0.71°C, and 0.50°C, respectively, in Quang Nam province. Moreover, Da Nang city showed a higher sensitivity in the minimum temperature compared to the Tam Ky station, in which the minimum temperature has increased 0.71°C between 2000 and 2021, compared to the previous period (1979–1999). Thus, these results indicated a strong correlation between the UHI impacts and the increase in built-up area.

(2) Between 1979 and 2021, the frequency of days with temperatures exceeding 35°C has increased, particularly in Quang Nam province. In fact, the number of hot days has increased by two and seven days during the past decade at the meteorological stations in Da Nang and Tam Ky, respectively. The period between 2000 and 2021 also showed a more significant accumulation of hot days than the preceding period (1979–1999). Since 2000, Da Nang city has experienced an increase in the frequency of hot days compared to the previous period (1979–1999).

(3) The results from the Da Nang and Tam Ky meteorological stations indicated interesting results for evaporation, in which main meteorological variables confirmed a consistent trend compared to previous key findings for temperature, evaporation, and relative humidity, whereas Quang Nam province revealed an inconsistent result with the opposite trend in relative humidity, particularly after 2000, marked as the beginning of the province's urbanization. Nevertheless, they show a consistent trend in relative humidity and evaporation between 2017 and 2021, in which Da Nang city and Quang Nam province experience noticeable increases in evaporation and steady decreases in relative humidity as the result of the summer temperature increase (highest in June and July, lowest in August).

(4) The temperature in Da Nang city varied from 31.80°C to 32.82°C over the chosen period, with high temperatures predominantly concentrated in urbanized regions with less coverage of small trees, plants, and water bodies. This finding is consistent with previous studies' findings, indicating that change of green or water coverage into urban land cover (built-up) would contribute the most to the increase of surface temperature.

In general, UHI has a significant impact on temperature, evaporation, and humidity in general. In fact, these have shown an upward tendency in recent years, particularly since the beginning of urbanization and industrialization. Thus, findings of this study would serve as a scientific basis for officials and stakeholders to better prepare future plans regarding the mitigation of hazards, particularly in the context of climate change.

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