

ASSESSMENT OF THE URBAN HEAT ISLAND IN THE CITY OF GALATI

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Abstract

This article evaluates the urban heat island in Galati, Southeastern Romania, for March and April 2023. Daily temperature measurements were taken at 11 points: five points in the city of Galati and six in the periurban and rural areas. The layout of the 11 points covered a north-south transect between Galati and Braila, the neighboring city. Other parameters were also measured, including humidity, pressure, heat index, wind speed, and Dew point. Regarding the measured temperature, it was observed that in April there was a more balanced temperature distribution, with values around the average. March showed greater variability, with more frequent thermal extremes. Strong positive correlations were obtained between temperature and the heat index and between temperature and Dew point. The relative humidity varied inversely with temperature, the coefficient of variation being -0.6. For wind, no consistent relationship was established with the other parameters, possibly because it depends more significantly on several local factors (topography, buildings, etc.). Normality tests (Shapiro–Wilk, Anderson–Darling, and D’Agostino–Pearson) indicated non-normal temperature distributions, justifying the application of non-parametric statistics. Non-parametric statistical methods, such as the Kruskal–Wallis test followed by Dunn’s post-hoc test, were used. For the automatic grouping of locations based on temperature, humidity, etc., the clustering method (K-Means and PCA analysis) was applied. Clustering analysis grouped the stations into distinct thermal zones, with the central areas of Galați forming the warmest cluster. This study revealed a clear north–south and west–east temperature gradient, with the city’s urban center being the thermal core. Water and vegetation determined local temperature drops.

Keywords: Heat island; Non-parametric statistics methods; Microclimate; Galati

Introduction

Heat islands are generally urban areas with much higher temperatures than the surrounding areas. Changes in the microclimate in cities can have direct implications for population health, energy consumption, and quality of life. This phenomenon occurs due to human activities and changes in the natural environment.

The causes of urban heat islands are multiple. Among them, we can mention:

1. Building materials that absorb and retain heat more than natural vegetation.
2. Lack of vegetation that reduces the cooling capacity through evapotranspiration.
3. Air pollution.
4. Energy generated by human activities.

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5. Urban geometry (tall buildings can reduce air circulation) [1]-[5].

The appearance of urban heat islands can have negative effects such as increased energy consumption for cooling, aggravation of health problems (e.g., cardiovascular diseases), favoring of tropospheric ozone formation, increased thermal discomfort, and impact on urban ecosystems [6]-[16].

Recent advances in urban climatology emphasize the combined use of ground-based monitoring, remote sensing, and statistical modeling to quantify the intensity and spatial extent of Urban Heat Islands (UHIs) [2], [12]. While satellite-derived land surface temperature (LST) data are widely used, in situ measurements remain essential for capturing the thermal conditions directly experienced by the population [13].

The cities of Galati and Braila form a metropolitan area in southeastern Romania, located along the Danube River. Despite being an important industrial and transport hub, few studies have analyzed the microclimatic variability and UHI intensity in this region based on continuous surface measurements.

Therefore, the present study aims to:

- (1) Quantify the spatial variability of air temperature and related microclimatic parameters across 11 monitoring points.
- (2) Assess statistical differences between locations using non-parametric tests.
- (3) Identify homogeneous microclimatic groups using K-means and PCA clustering.
- (4) Provide a data-driven evaluation of the Urban Heat Island (UHI) intensity for the Galati–Braila conurbation.

This article evaluates the urban heat island in the city of Galati, using exclusively in situ measurements, between March and April 2023. Without the use of satellite data, the results directly reflect the microclimatic conditions felt by the population and can inform the prioritization of urban green interventions.

Experimental part

Materials

Daily temperature measurements were taken at 11 points: five points in the city of Galati and six in the peri-urban and rural areas (Fig. 1). Table 1 provides the names of the locations (measurement points) along with their corresponding GPS coordinates.



Fig. 1. Experimental area and location of monitoring points

Table 1. Location names and corresponding GPS coordinates

Measurement point	Latitude	Longitude
1. Costache Negri Street	45°24'59.21"N	28° 1'12.30"E
2. Ferry Crossing	45°24'59.91"N	28° 2'0.66"E
3. Courthouse of Galati	45°25'41.94"N	28° 2'11.48"E
4. Danube embankment	45°25'43.29"N	28° 3'13.47"E
5. Winmark shopping complex	45°26'9.12"N	28° 3'21.49"E
6. Bridge over the Siret River	45°24'13.14"N	28° 0'53.65"E
7. Danube Beach Intersection	45°22'44.92"N	28° 1'6.17"E
8. Hydrological station on the dam	45°20'29.53"N	28° 0'23.42"E
9. Wastewater Treatment Plant, Braila	45°18'48.75"N	27°59'2.22"E
10. Braila Exhibition boat	45°18'0.21"N	27°58'55.81"E
11. "Puskin" Secondary School from Braila	45°18'4.12"N	27°58'15.66"E

The layout of the 11 points covered a north-south transect between Galati and Braila. Other parameters were also measured, such as humidity, pressure, heat index, wind speed, and dew point.

To identify significant differences in temperature among measurement points and select the appropriate statistical tests, the normality of the data distribution was first assessed. In the first phase, normality tests were applied, specifically the Shapiro–Wilk, Anderson–Darling, and D’Agostino–Pearson tests. The Shapiro–Wilk test is known to be highly sensitive when the sample size is large ($n > 500$), as even minor deviations from normality may result in $p < 0.05$. The Anderson–Darling test, less affected by large samples, places greater emphasis on the tails of the distribution. The D’Agostino–Pearson test combines information about skewness and kurtosis, providing a more comprehensive assessment of normality. Given the large number of observations in our study, this test was particularly appropriate

All three tests (Shapiro–Wilk, Anderson–Darling, and D’Agostino–Pearson) consistently indicated that the temperature distribution deviates significantly from normality. This result supports the use of non-parametric statistical methods, such as the Kruskal–Wallis test followed by Dunn’s post-hoc test.

Using multiple regression, a model was found that explains 99.6% of the variation in the heat index depending on temperature, humidity, wind speed, and dew point. For the automatic grouping of locations based on temperature, humidity, etc., the clustering method (K-Means) was applied.

Results and discussion

At first glance, from the distribution of temperature values at the 11 measurement points in the Galati–Braila area (Fig. 2), it results in the following: points 1, 2, 7, and 9 have higher temperatures and a large dispersion, suggesting that these areas may represent urban heat islands; points 3, 6, 8, and 11 have lower temperatures, with small means and medians, which may indicate less urbanized areas or areas with greater vegetation influence; and points 4, 5, and 10 have intermediate values, but they also show moderate variability.

The large number of outliers (especially at locations 3, 6, 8, 9, and 10) suggests sudden temperature variations, possibly related to local meteorological conditions or different physical-geographical characteristics. The boxplot highlights significant differences between measurement points. Urban areas tend to have higher temperatures and greater variability, while peripheral areas or areas close to water/vegetation show lower temperatures and a more compact distribution.

Before applying the parametric statistical tests, the normality of the distribution of temperatures recorded in each location was assessed. For this purpose, the Shapiro–Wilk test was used, recognized for its accuracy in detecting deviations from normal distribution, especially in the case of small or medium samples. The results are presented in Table 2 and indicate whether

the analyzed variables respect the normality hypothesis, an essential condition for the subsequent application of the ANOVA and linear regression tests.

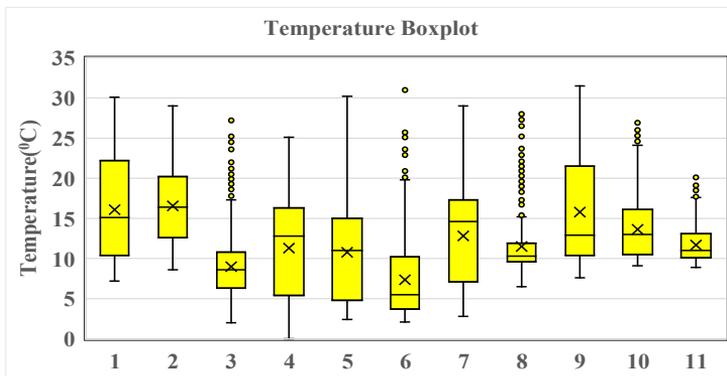


Fig. 2. Distribution of temperature values at the 11 measurement points in the Galati–Braila area. 1-Costa Negri Street, 2-Ferry crossing, 3-Galati Courthouse, 4-Danube embankment, 5-Winmark Shopping Complex, 6-Bridge over the Siret, 7-Danube Beach Intersection, 8-Hydrological station on the dam, 9-Wastewater treatment plant, Braila, 10-Braila Boat, 11-Puskin Secondary School from Braila.

The p-value being much lower than 0.05 (Table 2) in all cases rejects the hypothesis of normality for the data corresponding to the 11 locations.

Table 2. Normality Shapiro-Wilk test

Locations	W	p-value
Point 1	0.929386	2.50E-19
Point 2	0.879862	3.44E-23
Point 3	0.691768	7.69E-36
Point 4	0.835796	4.40E-29
Point 5	0.903967	3.57E-21
Point 6	0.427214	4.03E-33
Point 7	0.610765	7.65E-29
Point 8	0.860583	4.57E-19
Point 9	0.855969	2.68E-21
Point 10	0.970427	3.74E-12
Point 11	0.926282	3.51E-14

To more robustly assess the normality of the temperature data distribution in the 11 analyzed locations, the Anderson–Darling and D’Agostino–Pearson tests, recognized for their high sensitivity in detecting deviations from normality, were additionally applied. These tests complement the analysis performed with the Shapiro–Wilk test, providing an additional check of the validity of the hypotheses for the application of parametric tests. The p-values obtained were compared with the significance threshold $\alpha = 0.05$.

For the Anderson–Darling statistic A^2 , the value 78.31 was obtained. For the significance level α , the critical value is 0.787. Since $A^2 \gg 0.787$, it follows that the data distribution is not normal.

For the D’Agostino–Pearson test, the Statistica value is 361.25 and the p-value is 3.6×10^{-7} . The p-value < 0.05 results in the rejection of the normality hypothesis.

In conclusion, all three tests (Shapiro, Anderson–Darling, D’Agostino) confirm that the temperature distribution is not normal; the ANOVA test cannot be applied. This supports the choice of non-parametric tests such as Kruskal–Wallis and Dunn’s test.

To highlight the relationships between the meteorological variables recorded in the 11 measuring stations, a Spearman correlation matrix was built. This allows us to interpret the relationships between microclimatic factors that define urban heat islands. The value and direction of the correlation coefficients facilitate the interpretation of the interdependence between the variables and support the identification of factors associated with the formation of urban heat islands. Spearman correlations were calculated on all combined data from the other locations, as well as on each location. The major correlations obtained on the combined data are shown in Table 3.

Table 3. Major Spearman correlations

Pair	Rho	p-value	Relationship type	Interpretation
Temperature-Heat Index	0.9	0.001	Very strong positive	Heat Index depends directly on temperature, an almost perfect relationship, statistically significant.
Temperature-Dew Point	0.7	0.02	Moderately-strong positive	Higher temperatures lead to higher dew points – warmer air holds more absolute humidity.
Humidity - Dew Point	0.8	0.005	Strong positive	$\rho = 0.8$ is very large for real daily data. These correlations can be influenced by the physical interdependence of the parameters (not just statistical). Robust physical correlation
Temperature-Humidity	-0.6	0.03	Moderately negative	At high temperatures, relative humidity decreases, typical of urban heat islands.
Pressure - Temperature	-0.5	0.06	Moderately negative	Pressure tends to decrease at high temperatures, but without robust statistical significance.
Wind Speed - Temperature	-0.4	0.08	Weak negative	Stronger wind reduces the effect of perceived heat; insignificant relationship at the total scale.

Parameters related to wind and pressure have a smaller influence, indicating that local variations are dominated by surface factors (buildings, soil, and vegetation) and not by the general air circulation.

To identify the influence of meteorological parameters on the thermal index, a multiple regression analysis was applied. The model used has the general form:

$$\text{Thermal Index} = a_0 + a_1 \cdot T + a_2 \cdot H + b_3 \cdot \text{WS} + b_4 \cdot \text{DP} \quad (1)$$

where T represents the air temperature, H the relative humidity, WS the wind speed, and DP the Dew point.

The most influential factor on thermal comfort is air temperature; wind does not have a consistent relationship with other parameters, it depends more on local factors (topography, buildings, etc.); and temperature and humidity are inversely proportional, a thermodynamic effect typical of spring. Low pressure associated with high temperatures indicates unstable periods (local baric variations due to differently heated surfaces).

In conclusion, the total dataset and those at each location show that temperature variations are significantly correlated with humidity, Dew point and heat index, which confirms the consistency of the measurements. The negative correlations between temperature and humidity suggest typical urban heat island conditions, where the air is drier and warmer.

The coefficients obtained from the analysis (Table 4) show that temperature is the main predictive factor, with a coefficient of 0.957.

Humidity and Dew point had a positive, but smaller, contribution, while wind speed had a slight decreasing effect on the index.

The coefficient of determination $R^2 = 0.99$ indicates that the model explains 99% of the variation in the thermal index, and the p -value < 0.0001 confirms the high statistical significance of the model.

All included predictors contribute significantly to the variation in the thermal index in the urban context analyzed.

Table 4. Coefficients of the multiple regression

$p < 0.0001$ $R^2=0.99$	Coefficient value	Statistical interpretation
a_1 (Temperature)	+0.957	the main factor, a very strong relationship
a_2 (Humidity)	+0.026	small but significant contribution; humid air reduces evaporation and increases the perceived heat.
a_3 (Wind Speed)	-0.005	the wind slightly reduces the heat index due to convection.
a_4 (Dew Point)	+0.053	Dew point increases thermal discomfort: more saturated air in water vapor increases its heat retention capacity.
a_0	-2.195	The intercept value, with no direct physical significance, is just a reference point for the model.

To evaluate the spatial differences in meteorological parameters measured in the 11 observation points in the urban and peri-urban areas of the municipalities of Galati and Braila, the Kruskal–Wallis test was applied, a non-parametric test used to determine whether there are significant differences between independent groups.

Table 5 presents the results of the Kruskal–Wallis test for all 6 parameters (temperature, humidity, pressure, heat index, wind speed, and Dew point) among the 11 locations. The results include, for each parameter, the H statistic value, the p value, and the interpretation of the statistical significance.

The Kruskal–Wallis test clearly highlights that temperatures and humidity vary significantly between the analyzed locations, confirming the existence of distinct microclimates in the Galați–Brăila urban area. The results of the Kruskal–Wallis test indicated the existence of statistically significant differences for several parameters, which justified the application of a post-hoc multiple comparison test to identify pairs of locations between which these differences are significant.

For this purpose, the Dunn test was used, a non-parametric paired comparison method that allows for detailed analysis of the differences between all possible combinations of locations.

Table 5. Kruskal–Wallis test results

Parameter	H Statistic	p-value	Interpretation
Temperature	155.097	0	Significant differences between locations ($p < 0.05$)
Humidity	276.152	0	Significant differences between locations ($p < 0.05$)
Pressure	348.635	0	Significant differences between locations ($p < 0.05$)
Heat Index	154.837	0	Significant differences between locations ($p < 0.05$)
Wind Speed	8.181	0.6112	There are no significant differences between locations ($p \geq 0.05$)
Dew Point	195.19	0	Significant differences between locations ($p < 0.05$)

The significant differences in temperature and heat index between central and peripheral points demonstrate the statistically significant effect of the urban heat island.

The results of the Dunn test (Table 6) with Bonferroni correction ($p < 0.05$) show that:

- Statistically significant differences ($p < 0.05$) are concentrated between dense urban areas and peri-urban or natural areas.

- Central urban locations (e.g., Galati Courthouse, Winmark Shopping Complex, Danube Embankment) showed significantly higher temperatures than the Bridge over the Siret, Hydrological Station, Puskin Secondary School (Brăila), and Wastewater Treatment Plant (Brăila).

- No significant differences were observed between locations with similar thermal profiles (e.g., between "Courthouse" and "Winmark" or between "Bridge Siret" and "Hydrological Station").

The analysis confirms the existence of distinct microclimates:

- In the urban center of Galați, temperatures are higher due to the high density of buildings, asphalt and concrete surfaces, intense traffic, and anthropogenic activities.

- In the peri-urban and riverside areas (Siret, Brăila), temperatures are significantly lower due to the presence of vegetation and water, reduced solar reflection, and more efficient natural ventilation.

Table 6. Significant pairs according to Dunn's test

Pairs of measurement points		p-value	Pairs of measurement points		p-value
Point 1	Point 10	0.002553436	Point 2	Point 6	$4.49 \cdot 10^{-7}$
Point 1	Point 11	$3.18 \cdot 10^{-7}$	Point 2	Point 8	0
Point 1	Point 5	$1.69 \cdot 10^{-9}$	Point 2	Point 9	0.04523376
Point 1	Point 6	0.003250087	Point 3	Point 4	0.000229895
Point 1	Point 7	$3.39 \cdot 10^{-5}$	Point 3	Point 5	0
Point 1	Point 8	0	Point 3	Point 6	$2.01 \cdot 10^{-9}$
Point 1	Point 9	$2.21 \cdot 10^{-5}$	Point 3	Point 8	0
Point 10	Point 4	$6.10 \cdot 10^{-8}$	Point 4	Point 5	0.000103985
Point 10	Point 5	0	Point 4	Point 7	$1.17 \cdot 10^{-10}$
Point 10	Point 6	$2.44 \cdot 10^{-14}$	Point 4	Point 8	0
Point 10	Point 8	0	Point 4	Point 9	$6.02 \cdot 10^{-11}$
Point 11	Point 2	0.000608864	Point 5	Point 7	0
Point 11	Point 3	0.020018139	Point 5	Point 8	0
Point 11	Point 4	$3.16 \cdot 10^{-12}$	Point 5	Point 9	0
Point 11	Point 5	0	Point 6	Point 7	0
Point 11	Point 6	0	Point 6	Point 8	0
Point 11	Point 8	0	Point 6	Point 9	0
Point 2	Point 4	0.011370717	Point 7	Point 8	0
Point 2	Point 5	0	Point 8	Point 9	0

Dunn's post-hoc test revealed statistically significant differences in air temperature between urban and peri-urban areas. The high values in the central area confirm the existence of the urban heat island in Galati, while the lower temperatures in the hydrological and peripheral areas reflect the influence of water bodies and vegetation.

Both Principal Component Analysis (PCA) and K-means clustering were applied to assess the spatial distribution of air temperature measured at 11 monitoring points within the Galati–Braila urban area.

The main objective was to identify homogeneous microclimatic groups, ranging from urban heat zones (urban heat island core) to cooler peri-urban areas, influenced by vegetation and the proximity of water bodies.

The K-means algorithm was applied to the average temperature values recorded at each station. The optimal number of clusters was $K = 3$ (Table 7), corresponding to three microclimate types:

1. Urban hot areas (Cluster 1)
2. Transitional zones (Cluster 2)
3. Cool peri-urban areas (Cluster 3)

The K-means method provides a clear spatial separation between the urban heat and cooler peripheral zones.

The PCA analysis was applied to the full set of six meteorological parameters: Temperature, Humidity, Pressure, Wind Speed, Heat Index, and Dew Point. PC1 is dominated by

temperature and heat index (positively correlated), and PC2 is influenced by humidity and pressure (negatively correlated with temperature). K-means clustering (K = 3) was then applied to the PCA scores (PC1–PC2 space) to identify comparable groups.

Table 7. Comparison between K-means method and PCA analysis

Point ID	Location/ Measurement Point	Mean Temperature	KMeans Cluster	K Means interpretation	PC1	PC2	PCA Cluster	PCA Interpretation
1	Costa Negri Street	20.054	1	Urban hot	-0.69104	-1.700858	1	Urban hot
2	Ferry crossing	20.866	1	Urban hot	-1.74634	-0.466832	1	Urban hot
3	Galati Courthouse	14.729	2	Transitional	2.076711	-0.775291	3	Peri-urban cool
4	Danube embankment	20.543	1	Urban hot	-2.06509	0.1465529	1	Urban hot
5	Winmark Shopping Complex	18.610	1	Urban hot	-1.34011	0.891950	1	Urban hot
6	Bridge over the Siret	11.524	3	Peri-urban cool	2.903305	0.666683	3	Peri-urban cool
7	Danube Beach Intersection	16.015	2	Transitional	1.73016	-1.958167	3	Peri-urban cool
8	Hydrological station on the dam	14.713	2	Transitional	0.497971	1.905895	2	Transitional
9	Wastewater treatment plant, Braila	20.644	1	Urban hot	-1.7328	-0.408427	1	Urban hot
10	Braila Boat Puskin	17.721	1	Urban hot	-0.02261	-0.608201	1	Urban hot
11	Secondary School from Braila	14.328	2	Tranzitie	0.38983	2.306695	2	Tranzition

PCA also confirms the existence of three distinct thermal groups (Table 7) but provides a multivariate perspective showing which variables drive the separation, not only the temperature differences. The variations are explained not only by absolute temperature but also by the combination of temperature, humidity, and pressure.

Both methods confirm a thermal differentiation between the Galati urban core and peripheral or hydrological zones, validating the Urban Heat Island (UHI) effect.

Urban hot zones are identical in both methods. In cluster 1 (urban hot), there are the measurement points: Costa Negri Street, Ferry Crossing, Danube Embankment, Winmark Shopping Complex, Wastewater Treatment Plant (Braila), and Braila Boat.

Galati Courthouse and Danube Beach Intersection appear as transitional in K-means but cool in PCA.

PCA "moved" these two points to the cool group because it also takes into account humidity and pressure, not just temperature.

Conclusions

This research provides quantitative evidence of the Urban Heat Island phenomenon in the Galați–Brăila metropolitan area, based exclusively on ground-level meteorological observations.

Statistically significant temperature differences ($p < 0.05$) were identified between central urban and peri-urban/hydrological zones using the Kruskal–Wallis and Dunn post-hoc tests. Areas with water, green spaces, or peripheral areas functioned as natural barriers to heat accumulation.

The K-means method highlights the spatial distribution of air temperature and clearly delineates the Urban Heat Island core in Galati and Braila.

The PCA-based clustering confirms these patterns but introduces a multivariate understanding showing that humidity and pressure modulate local temperature regimes.

The strong agreement between the two approaches validates the robustness of the results and provides both spatial and causal evidence for the urban heat island phenomenon in the Galati–Braila area.

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