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Received: 15/06/2026

Revised: 17/08/2026

Accepted: 29/09/2026

Published: 10/10/2026

Editor:

Dr Alexandros Bartzokas-Tsiompras

DOI: 10.48088/ejg.o.eft.17.1.358.378

ISSN: 1792-1341

E-ISSN: 2410-7433



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Research Article

Declared Unauthorised Construction in Greece: An Indicator-Based Spatial Analysis

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Abstract: Unauthorised construction has been a persistent feature of spatial development in Greece, yet its geographical variation cannot be adequately captured by counts of recorded cases or total unauthorised building area alone. This study examines the officially recorded and legally regularised component of the phenomenon using administrative data from the Technical Chamber of Greece, comprising approximately 1.2 million declarations and more than 4.1 million violation records. A four-indicator framework is applied to distinguish complementary dimensions of unauthorised construction: relative severity, average scale, spatial intensity, and degree of integration into the building stock. Three indicators are calculated for 1,036 municipal units nationwide. The Unauthorised Share Ratio is examined separately for Athens and Thessaloniki using more detailed building-level data. The analysis combines descriptive and non-parametric statistics with Global Moran's I and local correlation analysis. National correlations between severity, average scale, and spatial intensity are weak, indicating that these dimensions capture distinct characteristics of recorded unauthorised construction. All three indicators exhibit significant positive spatial autocorrelation, strongest for violation density ($I = 0.546$), while local correlations reveal marked geographical variation in both the strength and direction of their relationships. The analysis of Athens and Thessaloniki further identifies substantial intra-urban variation in the share of unauthorised area within the building stock. These findings demonstrate that recorded unauthorised construction does not follow a single spatial pattern and that its spatial structure is obscured when analysis relies solely on conventional aggregate measures. The proposed framework provides a transferable approach for examining the spatial differentiation of unauthorised development in other planning contexts where comparable administrative data are available.

Keywords: Unauthorised construction; spatial analysis; indicators; spatial autocorrelation; GIS; Greece

Highlights:

- Develops four indicators of unauthorised construction across Greece.
- Severity, scale, and density show weak national but varying local associations.
- USR reveals strong intra-urban variation in Athens and Thessaloniki.

1. Introduction

Unauthorised construction has been a persistent feature of urban and residential development in Greece, substantially shaping the built environment, the implementation of spatial planning, and planning control mechanisms (Filippidis, 1990; Marmaras, 2002; Potsiou, 2014; Wassenhoven & Asprogerakas, 2026). Within Southern Europe, and particularly in Greece, it has been associated with fragmented urban expansion, development outside statutory plans, small-scale landownership, and long-standing patterns of institutional tolerance or ex post management of planning violations

(Allen et al., 2004; Leontidou, 1990; Polyzos & Minetos, 2009; Tsenkova, 2012; Wassenhoven et al., 2010). The Greek case is not confined to informal urbanisation associated with housing deprivation or social exclusion, but also encompasses property strategies, second-home development, tourism and investment pressures, and successive processes of ex post institutional management.

Greece is of broader comparative interest because it combines a long history of built development preceding or extending beyond organised statutory planning with repeated procedures for declaration, regularisation, and temporary or permanent exemption from demolition. These processes have generated an extensive administrative record of declared planning violations, enabling systematic investigation of a phenomenon that, despite its importance for spatial development and land governance, was long documented through fragmented, locally restricted, or non-comparable sources.

The empirical basis of this study does not represent the total stock of unauthorised construction in Greece. It includes only cases that were declared, entered formal regularisation procedures, and were recorded in the Unauthorised Building Declarations System of the Technical Chamber of Greece. Undeclared and unrecorded violations are excluded. The results therefore describe the spatial structure of the officially declared and regularised component covered by the available database up to 28 March 2022 and should not be interpreted as a complete inventory of unauthorised construction. This distinction is essential for interpreting both absolute values and the indicators developed below.

Unauthorised construction is often approached as a deviation from planning legislation or an outcome of inadequate administrative control. However, this perspective alone cannot explain its spatial extent, geographical variation, and long-term persistence. International research suggests that informality may also be shaped by how regulations are implemented, uneven enforcement capacities, and ex post processes of institutional recognition (Marx & Kelling, 2019; Roy, 2005; Watson, 2009). Analysis therefore requires not only counting recorded cases but also examining their composition, scale, and spatial organisation.

Common quantitative approaches rely on numbers of declarations, buildings, or violations, total unauthorised area, revenues from regularisation procedures, or geospatial detection techniques. Although these measures are useful for estimating the extent and geographical distribution of the phenomenon, they do not fully capture the heterogeneity of planning violations. Areas with similar numbers of records may differ substantially in legal severity, average unauthorised area, spatial density, and the share of unauthorised area in the building stock. The same total unauthorised area may result from numerous small violations or a limited number of large interventions. No single variable can adequately represent these differences.

To address this analytical gap, the study develops four complementary indicators. The Violation Severity Index (VSI) captures the composition of recorded unauthorised area according to the statutory classification of violations; the Average Illegal Footprint per Violation (AIFV) measures the average scale of recorded interventions; the Violation Density Index (VDI) measures the number of violations relative to the geographical area of each spatial unit; and the Unauthorised Share Ratio (USR) expresses the share of recorded unauthorised area in total built floor area. The indicators are retained separately because a composite measure could obscure meaningful differences between severity, average scale, spatial intensity, and relative share in the building stock.

The VSI, AIFV, and VDI are applied to 1,036 municipal units, providing a comparable national assessment of the first three dimensions. The USR is examined separately for the Municipalities of Athens and Thessaloniki using more detailed cadastral and building-level data. The research thus combines national analysis of the geographical differentiation of recorded violations with a complementary intra-urban assessment of their relative share in the building stock. The two spatial levels are kept analytically distinct, as they have different conceptual and empirical foundations.

Cartographic analysis is complemented by descriptive, correlational, and spatial statistical methods. The study examines relationships among the VSI, AIFV, and VDI, combinations of high and low values, global spatial autocorrelation, and geographical variation in local correlations, allowing spatial patterns to be assessed beyond the visual impressions conveyed by thematic maps.

Against this background, the study addresses three research questions:

- How do the severity, average unauthorised area, and density of recorded violations vary spatially across the municipal units of Greece?
- To what extent are these three dimensions related, and how do relationships between the corresponding indicators vary geographically?

- What distinct spatial patterns emerge from combinations of high and low indicator values, and how does the share of recorded unauthorised area in the building stock vary within the Municipalities of Athens and Thessaloniki?

The study makes three main contributions. First, it uses the full set of eligible records in the available national administrative database, avoiding additional sampling error within the recorded population, although undeclared cases remain a limitation. Second, it distinguishes severity, average scale, density, and share in the building stock, treating them as separate dimensions. Third, it incorporates spatial dependence and local variation in relationships among the indicators, enabling the identification of areas that depart from the overall national pattern.

Finally, geographical associations observed in metropolitan, peri-urban, coastal, island, and tourism-oriented areas are considered in relation to broader processes of urban expansion and pressures on land development. Because these relationships are not tested through a causal or explanatory model, they are treated as contextual and interpretive links grounded in the spatial distribution of the indicators, the spatial analyses, and the existing literature, without implying established causal mechanisms.

2. Literature Review

Unauthorised construction falls within the broader field of informal development but does not encompass all its forms. Terms such as informal development, informal or irregular settlements, unauthorised construction, and illegal construction describe built development occurring outside or in deviation from prevailing regulatory frameworks (Fernandes, 2011; Roy, 2005; Tsenkova, 2012). These forms may include construction without permits, deviations from approved permits, unauthorised changes of use, unapproved land subdivisions, and development preceding formal planning. Although they overlap, they differ in socioeconomic drivers, property regimes, institutional treatment, and prospects for subsequent formal recognition.

Unauthorised construction cannot be explained solely by absent or ineffective state regulation. Roy (2005) emphasises that boundaries between legal and illegal space are shaped through regulation, exception, and recognition, while Watson (2009) highlights mismatches between formal planning systems and actual urban development. Informality may therefore also emerge through the implementation of rules, particularly where unauthorised development becomes spatially consolidated and is subsequently legalised, regularised, or institutionally incorporated (Potsiou, 2014; Zeković et al., 2020).

Its forms and underlying processes vary substantially across geographical and institutional contexts. In many developing countries, informal housing is closely associated with poverty, limited access to serviced land, and exclusion from formal housing markets. In Southern Europe, unauthorised development has also been linked to self-provided housing, fragmented urban expansion, second homes, and the gradual incorporation of initially unregulated areas into the urban fabric (Allen et al., 2004; Leontidou, 1990; Tsenkova, 2012). Interpretation therefore depends on the social, property, and regulatory context.

In Greece, unauthorised construction developed in close association with small-scale landownership, household housing and property strategies, development outside statutory plans, and delayed expansion of organised urban planning (Karadimitriou & Pagonis, 2019; Leontidou, 1990; Maloutas, 2008; Polyzos & Minetos, 2013). Successive processes of legalisation, exemption from demolition, and regularisation linked initial violation, functional consolidation, and subsequent administrative recognition. The Greek case is therefore characterised by the coexistence of formal planning, regulatory deviations, and ex post institutional procedures, without implying a common origin for all unauthorised construction.

A distinction is consequently required between the actual stock of unauthorised construction and the component that has entered formal administrative procedures. Administrative records provide information on legal category, use, area, construction period, regularisation procedure, and spatial location, but they do not capture the phenomenon in its entirety. Undeclared cases remain unobserved. Geographical differences in the capacity or willingness to declare violations may influence recorded patterns.

Unauthorised construction is also associated with urban sprawl, peri-urban transformation, and land-use change beyond the continuous urban fabric (Polyzos & Minetos, 2009; Polyzos et al., 2013). Dispersed development may involve spatial discontinuity, variable densities, road-network dependence, and mixed urban and rural land uses (Allen, 2003; European Environment Agency [EEA], 2006). Where planning does not respond promptly to development pressures,

construction may precede formal spatial organisation and generate subsequent infrastructure and planning needs (Allen, 2003; Potsiou, 2014). Such processes may occur along settlement fringes, outside statutory plans, or near major transport corridors (Polyzos & Minetos, 2009; Polyzos et al., 2013).

Their spatial expression is nevertheless heterogeneous. Metropolitan fringes may combine housing, productive activities, and land-use change, whereas coastal and island areas may be more closely associated with second homes, tourism, seasonal use, and high-value land. Mountainous and remote areas may display lower densities, although isolated large interventions remain possible. Total counts or total unauthorised area alone cannot adequately represent these differences, because similar absolute values may result from numerous small violations or relatively few large interventions.

Empirical identification also presents difficulties because unauthorised development cannot always be distinguished reliably from legally authorised construction. Relevant sources include administrative databases, cadastral and building-permit records, census data, remote sensing, aerial photographs, unmanned aerial vehicle data, and field surveys. Remote-sensing and automated techniques have improved detection of construction and built-environment change (He et al., 2019; Osennyya et al., 2023; Son & Kim, 2025) but cannot necessarily establish legal status or distinguish among absence of a permit, deviation from an approved permit, and unauthorised change of use.

Common quantitative approaches rely on numbers of declarations, violation records, or buildings and on total unauthorised area, but these measures are not analytically equivalent. A declaration may contain multiple violations, and a building may contain different forms of non-compliance. Absolute values are also sensitive to spatial-unit size. Large units may contain many violations without exhibiting high density. In contrast, smaller urban units may contain fewer records but substantially higher values per km². Similar unauthorised areas may likewise differ in construction period, legal category, use, and severity.

Indicators can address some of these limitations by linking available variables to specific analytical dimensions and enabling comparison across spatial units. They are widely used in analyses of spatial development, sustainability, built-environment quality, planning effectiveness, and factors associated with informal development (Akrofi et al., 2019; Shahraki, 2017; Somiah et al., 2015; Zeković et al., 2020). Their application to unauthorised construction remains fragmented, however, with many studies emphasising either its extent and frequency or its associated drivers. Indicator construction also requires explicit correspondence among the theoretical dimension, data structure, and mathematical procedure, since results depend on variable selection, weighting, spatial units, and classification.

Thematic mapping alone does not constitute spatial analysis. Maps identify concentrations and potential geographical patterns but remain sensitive to classification, symbology, and spatial units. Spatial statistics complement them by testing whether similar values occur in neighbouring areas more frequently than expected under spatial randomness. Recent research in Thessaloniki illustrates the value of combining urban-form indicators with global and local spatial autocorrelation measures to identify spatially coherent patterns (Vartholomaios, 2025).

Global Moran's *I* provides an overall measure of spatial autocorrelation, although results depend on neighbourhood definition and the spatial weights matrix. Similarly, national correlation coefficients summarise overall relationships but not their spatial stability. Weak national associations may coexist with strong positive relationships in some areas and negative relationships elsewhere, which local coefficients can reveal (Anselin, 1995; Fotheringham, 2009; Fotheringham et al., 2000; O'Sullivan & Unwin, 2010). Spatial analysis nevertheless remains affected by the Modifiable Areal Unit Problem (MAUP), because polygon-based indicators depend on unit boundaries, size, shape, and internal heterogeneity. Municipal units provide consistent national coverage and the finest common administrative level to which the available records could be assigned, but they are not geographically neutral. The more detailed USR analysis within the Municipalities of Athens and Thessaloniki therefore provides a complementary view of intra-urban differentiation, although scale effects remain.

Unauthorised construction is examined through four complementary dimensions. The first is violation severity, recognising that forms of non-compliance differ in legal, constructional, and spatial significance. The second is the average scale of unauthorised intervention, distinguishing areas characterised by numerous small interventions from those with fewer but larger cases. The third is spatial intensity, measured relative to the area of each spatial unit and therefore distinguished from absolute counts. The fourth is the share of recorded unauthorised area in the building stock, since similar unauthorised areas may have different significance depending on the extent of the existing built fabric.

These dimensions are examined separately and are not combined into a composite index, which would require additional assumptions about their relative weighting and could obscure meaningful differences. Their parallel analysis allows distinct profiles to emerge, such as high density with lower severity, high severity with low density, or high average area with low density. These profiles are descriptive and should not be interpreted as evidence of specific causal mechanisms. The indicators are constructed from the available administrative and geospatial data and are not derived from a single pre-existing model. Their combined use addresses the limited integrated examination of legal composition, average scale, spatial intensity, and the relative share of recorded unauthorised area in the building stock.

3. Materials and Methods

The study is based on a quantitative and geospatial analysis of the officially declared and regularised component of unauthorised construction in Greece. It combines administrative and geospatial data, four complementary indicators, descriptive and non-parametric statistics, spatial autocorrelation, local correlations, and thematic mapping to capture different dimensions of the recorded phenomenon at the national level and, for the share of unauthorised area in the building stock, within Greece's two largest municipalities.

The primary data source is the "Unauthorised Building Declarations System" of the Technical Chamber of Greece (TCG), developed through successive procedures for the declaration and regularisation of unauthorised constructions and changes of use, particularly under Laws 4178/2013 and 4495/2017 (Greece, 2013, 2017). These laws established procedures for the declaration, classification, and regularisation of unauthorised constructions and changes of use, thereby generating the administrative records used in this study. The available database comprises approximately 1.2 million declarations and more than 4.1 million planning-violation records and includes records available up to 28 March 2022.

A declaration represents the overall administrative case, whereas a single declaration may contain multiple violation records referring to different violations, areas, or categories. Record counts should therefore not be equated with either the number of declarations or the number of buildings. Inclusion in the TCG database does not result from a systematic field inventory of all unauthorised construction by public authorities. Under the statutory regularisation procedure, the application is made by the property owner or another legally entitled applicant, and an authorised engineer enters the relevant information and supporting documentation into the electronic system. The database therefore records cases that have entered the formal declaration and regularisation procedure; it does not represent all unauthorised construction existing in the country.

Although certain administrative processes, including property transactions, require documentation of the legal status of a property, this does not ensure universal identification of unauthorised construction. Cases that have not entered the declaration procedure remain outside the database. Consequently, the available data do not allow the extent of this undercoverage to be quantified.

The data were provided by the Technical Chamber of Greece following formal requests submitted specifically for the purposes of this research and were made available for exclusive use within the framework of the present study. The date, 28 March 2022, reflects the administrative database available for the study and was not selected by the authors as an analytical endpoint. As the system continued to be updated thereafter, the results represent a temporal snapshot of the administrative record and should not be interpreted as reflecting the current state of the phenomenon. Accordingly, the database should be interpreted as the administrative population of cases recorded through the declaration and regularisation system; it does not constitute an inventory of the total actual stock of unauthorised construction in Greece. Using all eligible records improves the representativeness of the recorded population by reducing sampling error. However, undeclared or unrecorded cases remain outside the dataset. Additional data included administrative boundaries from the Hellenic Statistical Authority (ELSTAT, n.d.) and cadastral and building data from the Hellenic Cadastre (n.d.) for the Municipalities of Athens and Thessaloniki.

The VSI, AIFV, and VDI were calculated at the municipal-unit level because the administrative records could be consistently assigned to a common nationwide spatial unit, not because municipal units were assumed to be geographically neutral. The original geodatabase contained 1,037 spatial units; Mount Athos, recorded as a distinct self-governed territorial entity, was excluded, resulting in a final national dataset of 1,036 municipal units.

The USR was applied separately to the Municipalities of Athens and Thessaloniki, where more detailed building and cadastral data were available. This complementary urban-level analysis is analytically distinct from the national municipal-unit analysis, since the same indicators are not calculated across successive spatial levels.

Table 1. Data sources, units of observation, and use in the analysis

Source	Content	Unit of observation	Spatial coverage	Use
Technical Chamber of Greece (n.d.)	Declarations, violation records, categories, and unauthorised areas	Declaration / violation record	Greece	VSI, AIFV, VDI, Figure 1, USR numerator
Hellenic Statistical Authority (ELSTAT, n.d.)	Administrative boundaries	Municipal unit	Greece	Spatial matching, area calculation
Hellenic Cadastre (n.d.)	Building and cadastral data	Building / parcel	Municipalities of Athens and Thessaloniki	Total building area, USR

Geospatial processing was conducted in a GIS environment using the Greek Geodetic Reference System 1987, GGRS87/Greek Grid (EPSG:2100), for area, distance, and neighbourhood analyses. Its metric projection enabled calculation of municipal-unit areas and conversion to km² for the VDI.

Before indicator construction, spatial-unit codes, violation categories, recorded areas, zero and missing values, and correspondence among aggregated tables were checked. The original source contained 4,114,521 records, of which 52,515 were assigned to category 0 and five had no recorded category. Because these records could not be assigned to one of the five severity levels, they were excluded only from the corrected VSI calculation, which was therefore based on 4,062,001 records in categories 1–5.

The data audit also showed that, in the original VSI calculation, category 0 remained in the denominator but received zero weight in the numerator. This systematically lowered the index values. The VSI was therefore recalculated using only categories 1–5 in both the numerator and denominator.

Records with zero unauthorised area were retained when otherwise valid. For count-based indicators, such records remain part of the administrative database; in the AIFV, for example, they contribute zero to the numerator but one observation to the denominator.

The VSI is based on the five statutory violation categories defined by the applicable Greek legislation (Greece, 2017), differentiated according to the period and nature of the recorded unauthorised construction. These categories are part of the statutory classification and were not created for the purposes of this study.

Table 2. Statutory violation categories and analytical VSI weights

Statutory Violation Category	Temporal Criterion	Description	Analytical VSI weight
1	Before 1975	Unauthorised constructions in residential buildings	1
2	Before 1983	Unauthorised constructions	2
3	—	Minor building violations	3
4	Before 28 July 2011	Unauthorised constructions and changes of use involving moderate exceedances	4
5	Before 28 July 2011	Unauthorised constructions and changes of use involving greater exceedances	5

The statutory category number and the analytical VSI weight represent conceptually distinct elements. Categories 1–5 retain the numerical designation established in the legislation, whereas the baseline weights 1–5 constitute an analytical ordinal weighting scheme applied in this study.

The weighting scheme does not imply equal legal, constructional, environmental, or spatial distances between successive statutory categories. The VSI should therefore be interpreted as an index of relative severity based on the statutory classification of violations; it does not directly measure their planning, environmental, or morphological impact. Its robustness was assessed using alternative non-linear weighting scenarios.

The four indicators capture distinct dimensions of the recorded phenomenon and were therefore retained as separate measures. Their formulation, units, spatial application, and analytical dimensions are summarised in Table 3.

Table 3. Indicators used in the analysis

Indicator	Formula	Unit	Spatial application	Dimension
VSI	$VSI_j = \frac{\sum_{i=1}^5 w_i A_{ij}}{\sum_{i=1}^5 A_{ij}}$	1–5	Municipal unit	Severity
AIFV	$AIFV_j = \frac{U_j}{N_j}$	m ² /record	Municipal unit	Average scale
VDI	$VDI_j = \frac{N_j}{S_j}$	records/km ²	Municipal unit	Spatial intensity
USR	$USR_b = \frac{U_b}{B_b}$	0–1	Building record	Share in building stock

The Violation Severity Index (VSI) captures the composition of recorded unauthorised area by severity category. For each municipal unit *j*, it is calculated as:

$$VSI_j = \frac{\sum_{i=1}^5 w_i A_{ij}}{\sum_{i=1}^5 A_{ij}}$$

where *A_{ij}* is the recorded area of category *i* in municipal unit *j*, and *w_i* is the corresponding weight 1–5. The dimensionless index ranges theoretically from 1 to 5, with higher values indicating a greater contribution of higher-severity categories to total recorded unauthorised area. Because weighting is area-based, the VSI measures neither violation frequency nor density.

Sensitivity to the linear 1–5 weighting scheme was assessed using alternative non-linear weights calculated as:

$$w_i(p) = 1 + 4 \left(\frac{i^p - 1}{5^p - 1} \right)$$

for *i* = 1,..., 5. The scenarios *p* = 0.5, 0.75, 1, 1.5, and 2 were examined, with *p* = 1 reproducing the original linear 1–5 scale.

For each alternative VSI, agreement with the baseline index was assessed using Spearman and Kendall rank correlations, absolute rank changes, retention within the same Low–Intermediate–High class, and preservation of the upper and lower quartiles. This allowed assessment of whether alternative weighting schemes materially altered the relative ranking of municipal units.

The Average Illegal Footprint per Violation (AIFV) measures the mean recorded unauthorised area per violation record:

$$AIFV_j = \frac{U_j}{N_j}$$

where U_j is the total recorded unauthorised area in municipal unit j and N_j the corresponding number of violation records. Expressed in m^2 per record, higher AIFV values indicate larger average recorded interventions, whereas lower values reflect smaller, more fragmented interventions. The AIFV measures neither the total number nor the spatial density of violations.

The Violation Density Index (VDI) measures the number of recorded violation records relative to the geographical area of each municipal unit:

$$VDI_j = \frac{N_j}{S_j}$$

where N_j is the number of records and S_j the area of municipal unit j in km^2 . Expressed as records/ km^2 , the VDI normalises record counts by geographical area. It is neither a population- nor building-stock-density measure and does not capture violation severity or average size.

The Unauthorised Share Ratio (USR) measures the share of recorded unauthorised area in the total area of the corresponding building record:

$$USR_b = \frac{U_b}{B_b}$$

where U_b is the recorded unauthorised area and B_b the total building area associated with record b . The ratio theoretically ranges from 0 to 1. The USR was applied to the Municipalities of Athens and Thessaloniki using combined TCG and Hellenic Cadastre (n.d.) data.

For mapping, building-level USR values were aggregated into regular 350-m hexagonal cells. For each cell c , the arithmetic mean of the building-level ratios was calculated as:

$$USR_{\bar{c}} = \frac{1}{n_c} \sum_{b=1}^{n_c} USR_b$$

This calculation differs from the ratio of aggregated sums, $\Sigma U_b / \Sigma B_b$: under the arithmetic-mean approach, each building record contributes equally, whereas the ratio-of-sums approach gives greater weight to larger buildings. The number of building records per cell was also retained to assess the stability of the mean values.

For the VSI, AIFV, and VDI, descriptive statistics included minimum, maximum, mean, median, standard deviation, first and third quartiles, interquartile range, and skewness. These statistics characterised the distributions and informed cartographic classification.

Relationships among the three national indicators were examined using Spearman's ρ and Kendall's τ_b . These non-parametric measures were selected because the AIFV and VDI distributions are strongly skewed and contain extreme values, and because these measures do not require an assumption of linear association. Spearman's coefficient is calculated as the correlation between ranked values:

$$\rho_s = \text{Corr}[R(X), R(Y)]$$

whereas Kendall's τ_b is calculated from concordant and discordant pairs:

$$\tau_b = \frac{C - D}{\sqrt{(C + D + T_x)(C + D + T_y)}}$$

where C and D are the numbers of concordant and discordant pairs, respectively, and T_x and T_y denote ties.

Before correlation analysis, the three indicators were matched by unique municipal-unit identifier, ensuring that VSI, AIFV, and VDI values referred to the same spatial unit.

To identify combined profiles, the three indicators were classified according to national quartile thresholds: values at or below the first quartile (Q_1) were classified as Low, values at or above the third quartile (Q_3) as High, and all remaining values as Intermediate.

$$\text{Low: } x_j \leq Q_1$$

$$\text{High: } x_j \geq Q_3$$

$$\text{Intermediate: } Q_1 < x_j < Q_3$$

The classifications were combined for the VSI–VDI, VSI–AIFV, and AIFV–VDI pairs to produce High–High, High–Low, Low–High, Low–Low, and Intermediate profiles. These form a descriptive typology and should not be interpreted as LISA clusters or other statistically significant spatial clusters.

Global spatial autocorrelation of the VSI, AIFV, and VDI was assessed using Moran's I (Moran, 1950):

$$I = \frac{n}{S_0} \frac{\sum_i \sum_j w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2}$$

where w_{ij} denotes the spatial weights and S_0 their sum. The primary matrix used Queen contiguity; the 55 mainly island or otherwise disconnected municipal units with no Queen neighbour were each linked to their nearest neighbour. The weights were row-standardised.

Statistical significance was assessed using 9,999 random permutations, with the pseudo-p value calculated as:

$$p = \frac{b + 1}{R + 1}$$

where b is the number of permutations yielding a value equal to or more extreme than the observed statistic and $R = 9,999$. Robustness was assessed using kNN4 and kNN8 spatial weights matrices, alternative VSI weighting schemes, and log-transformed $\ln(1+x)$ values for the AIFV and VDI.

Because an overall correlation coefficient cannot capture the spatial stability of relationships, local Spearman correlations were calculated for all three indicator pairs. For each municipal unit, a neighbourhood of the 20 nearest spatial units was constructed, symmetrised, and expanded to include the focal unit. Symmetrisation resulted in local sample sizes of 21–39 observations.

For each spatial unit (i):

$$\rho_i = \rho_s(X_{N_i}, Y_{N_i})$$

where N_i denotes the local neighbourhood of spatial unit i .

Because 1,036 local tests were conducted for each indicator pair, p values were adjusted using the Benjamini–Hochberg False Discovery Rate (FDR) procedure (Benjamini & Hochberg, 1995). Relationships were classified as significantly positive when $q < 0.05$ and $\rho_i > 0$, significantly negative when $q < 0.05$ and $\rho_i < 0$, and non-significant when $q \geq 0.05$. Sensitivity to neighbourhood size was assessed for $k = 15$, $k = 20$, and $k = 25$, with $k = 20$ retained as the primary specification.

For national cartographic representation, geolocated violation records were aggregated in ArcGIS Pro using the Aggregate Points tool into regular 10-km hexagonal cells. Each cell value represents the number of recorded violation records it contains:

$$\text{COUNT}_c = \text{number of violation records in cell } c$$

Accordingly, Figure 1 is not a point map, and each hexagon represents neither a single declaration nor a building. Because record counts were strongly right-skewed, the following transformation was applied:

$$y_c = \ln(1 + \text{COUNT}_c)$$

The transformed counts were classified into five Natural Breaks–Jenks classes (Jenks, 1967), with class boundaries back-transformed so that the legend reports actual violation-record counts per hexagonal cell.

National indicators were classified according to their distributional characteristics, with different classification methods applied where appropriate. Given its limited skewness, the VSI was classified by standard-deviation intervals around the mean, with boundaries defined as:

$$\bar{x} - 1.5s, \bar{x} - 0.5s, \bar{x} + 0.5s, \bar{x} + 1.5s$$

For the strongly right-skewed AIFV and VDI distributions, the following transformation was applied:

$$y = \ln(1 + x)$$

The transformed AIFV and VDI values were classified into five Natural Breaks–Jenks classes (Jenks, 1967), with boundaries back-transformed so that the legends report m² per record and records/km², respectively.

Categorical symbology was used for combined-profile and local-correlation maps. The USR maps for the Municipalities of Athens and Thessaloniki use identical manual class boundaries—0.00–0.02, >0.02–0.03, >0.03–0.04, >0.04–0.06, and >0.06–1.00—and the same colour scale, enabling direct comparison.

The results are subject to several methodological limitations. The database covers only the declared and regularised component of unauthorised construction and includes records available up to 28 March 2022; the distribution of undeclared cases remains unknown. The use of municipal units is also subject to the Modifiable Areal Unit Problem (MAUP), as units vary in size, shape, and internal heterogeneity. They were selected for consistent national coverage and spatial assignment of administrative records, not because they eliminate aggregation effects. Finally, relationships among the indicators and with broader processes such as peri-urban development, tourism, or land-development pressures should not be interpreted causally, since no explanatory model incorporating these variables was applied. Such relationships are therefore discussed in relation to the existing literature, with no causal conclusions drawn.

The USR is additionally limited by the accuracy of spatial matching between administrative and cadastral records and the availability of total building-area data. It is therefore restricted to the Municipalities of Athens and Thessaloniki and should not be generalised to their wider metropolitan areas or to Greece as a whole.

4. Results

4.1 Spatial distribution of recorded violations

The national distribution of officially recorded violations shows pronounced geographical heterogeneity. Aggregation into 10-km hexagonal cells reveals predominantly low-to-intermediate concentrations, with higher densities concentrated in the Attica basin, Thessaloniki and parts of Central Macedonia, and selected coastal and island areas; mountainous and remote mainland areas generally show lower concentrations. This representation captures record distribution only, not violation severity or average area.

Among 1,987 non-empty cells, 164 (8.25%) contain 1–20 records, 455 (22.90%) contain 21–140, 735 (36.99%) contain 141–585, 527 (26.52%) contain 586–3,794, and 106 (5.33%) contain 3,795–192,010 records. The 141–585 class is the largest (36.99%), while the highest class comprises only 5.33% of cells but contains the extreme values.

4.2 National indicator patterns

Because record counts alone do not capture how the phenomenon varies across spatial units, the national analysis was extended using the VSI, AIFV, and VDI, whose descriptive statistics reveal distinct distributional characteristics.

Table 4. Descriptive statistics of the national indicators

Indicator	N	Min	Max	Mean	Median	SD	Q1	Q3	Skewness
VSI	1,036	1.564	4.967	3.625	3.663	0.575	3.257	4.069	–0.430
AIFV (m ² /record)	1,036	21.929	837.870	76.037	63.370	50.898	50.627	83.409	5.714
VDI (records/km ²)	1,036	0.169	9,132.084	141.529	8.856	591.501	3.678	29.136	9.341

The corrected VSI ranges from 1.564 to 4.967, with a mean of 3.625, median of 3.663, standard deviation of 0.575, and limited negative skewness (–0.430), indicating a more balanced distribution than the AIFV and VDI. Q1 and Q3 are 3.257 and 4.069, respectively.

Despite its lower dispersion, the VSI remains spatially heterogeneous. Of the 1,036 municipal units, 383 (36.97%) fall within 3.34–3.91 and 303 (29.25%) within 3.91–4.49, together accounting for about two-thirds of the total. At the extremes, 82 units (7.92%) fall within 1.56–2.76 and 44 (4.25%) exceed 4.49. High and low values therefore reflect localised geographical differences, with no single regional pattern emerging.

The consistency assessment showed that the previous VSI values were reproduced almost exactly when category 0 area remained in the denominator without contributing to the weighted numerator. Excluding category 0 from both parts of the formula increased the mean from 3.586 to 3.625 and the median from 3.611 to 3.663, but the rankings remained largely unchanged. The original and corrected VSI were strongly correlated (Spearman $\rho = 0.9908$; Kendall $\tau_b = 0.9443$); 95.37% of municipal units remained in the same Low–Intermediate–High class, and 96.14% of those originally in the upper quartile remained there.

Sensitivity analysis further confirmed VSI stability. For $p = 0.5$, Spearman $\rho = 0.9983$, Kendall $\tau_b = 0.9655$, and 97.10% of units remained in the same class; for $p = 2$, the corresponding values were 0.9942, 0.9357, and 96.33%. For $p = 0.75$ and $p = 1.5$, Spearman correlations also exceeded 0.998. Detailed sensitivity results are reported in Appendix Table A1.

The AIFV ranges from 21.93 to 837.87 m² per record, with a mean of 76.04 m², median of 63.37 m², and strong positive skewness (5.714), reflecting a small number of municipal units with exceptionally high average values. Q1 and Q3 are 50.63 and 83.41 m² per record.

High AIFV values show no coherent geographical pattern. The two largest classes, 48.13–68.52 and 68.52–104.99 m², contain 415 (40.06%) and 277 (26.74%) municipal units, respectively. Only 22 (2.12%) exceed 199.56 m² per record. Their distribution across mainland and island Greece indicates a comparatively fragmented spatial pattern.

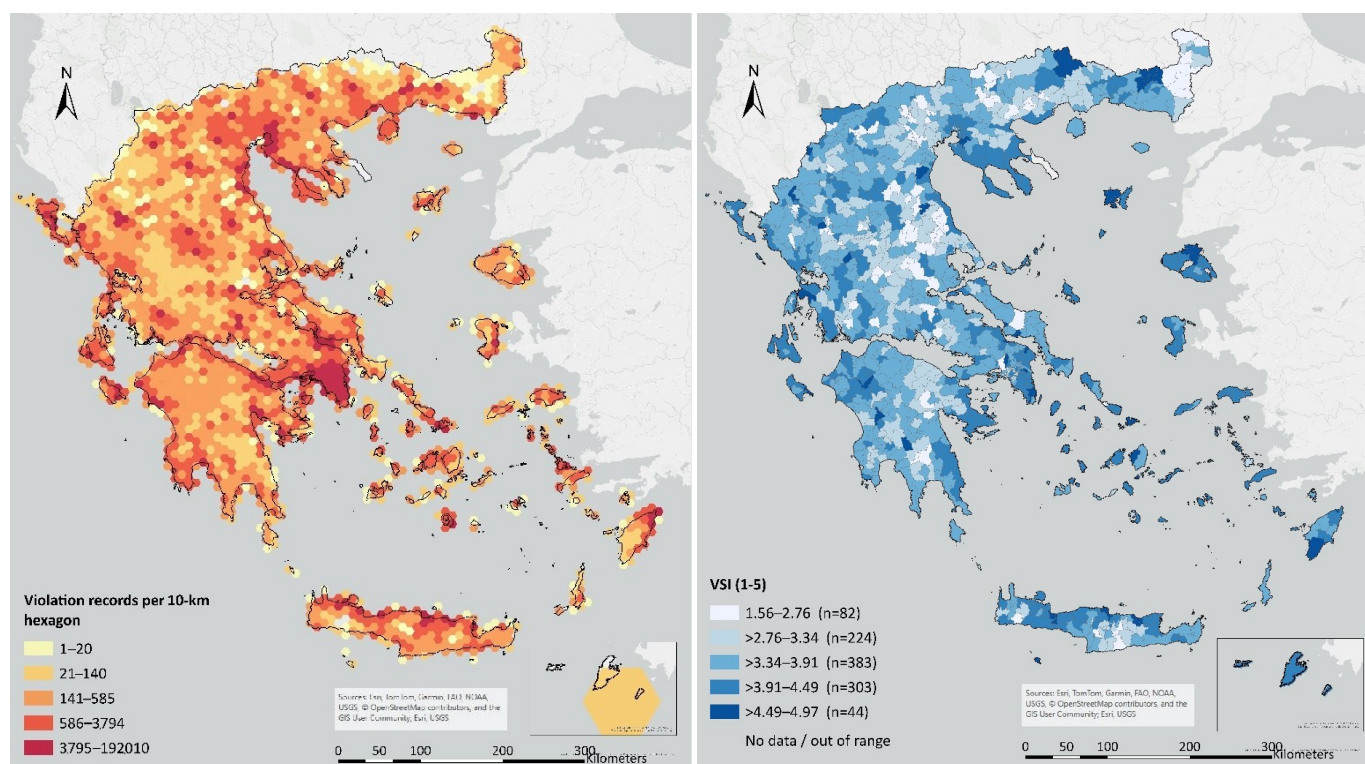


Figure 1 (Left). Spatial distribution of violation records in Greece aggregated into 10-km hexagonal cells. *Note: Only non-empty cells are shown. Five Natural Breaks–Jenks classes were derived from $\log_{10}$ -transformed counts and reported as original violation-record counts. Data: Technical Chamber of Greece.* **Figure 2 (Right).** Corrected Violation Severity Index (VSI) by municipal unit. *Classification: Five standard-deviation classes. Data: Technical Chamber of Greece and Hellenic Statistical Authority (n.d.).*

The VDI shows the greatest dispersion among the three national indicators, ranging from 0.169 to 9,132.084 records/km². Its median (8.856) is far below the mean (141.529), while high positive skewness (9.341) and Q3 of 29.136 records/km² indicate that extreme values are confined to relatively few municipal units.

Of the 1,036 municipal units, 288 (27.80%) fall within 0.17–4.13 records/km² and 371 (35.81%) within 4.13–14.99. At the upper end, 100 units (9.65%) fall within 67.49–428.93 records/km² and 75 (7.24%) exceed 428.93. Unlike the AIFV, high VDI values show clearer geographical concentration.

The three indicators therefore capture distinct dimensions: the VSI shows relatively limited dispersion, the AIFV strong positive skewness with spatially dispersed high values, and the VDI the greatest dispersion and clearer spatial concentration. This supports their parallel use as distinct, non-interchangeable measures.

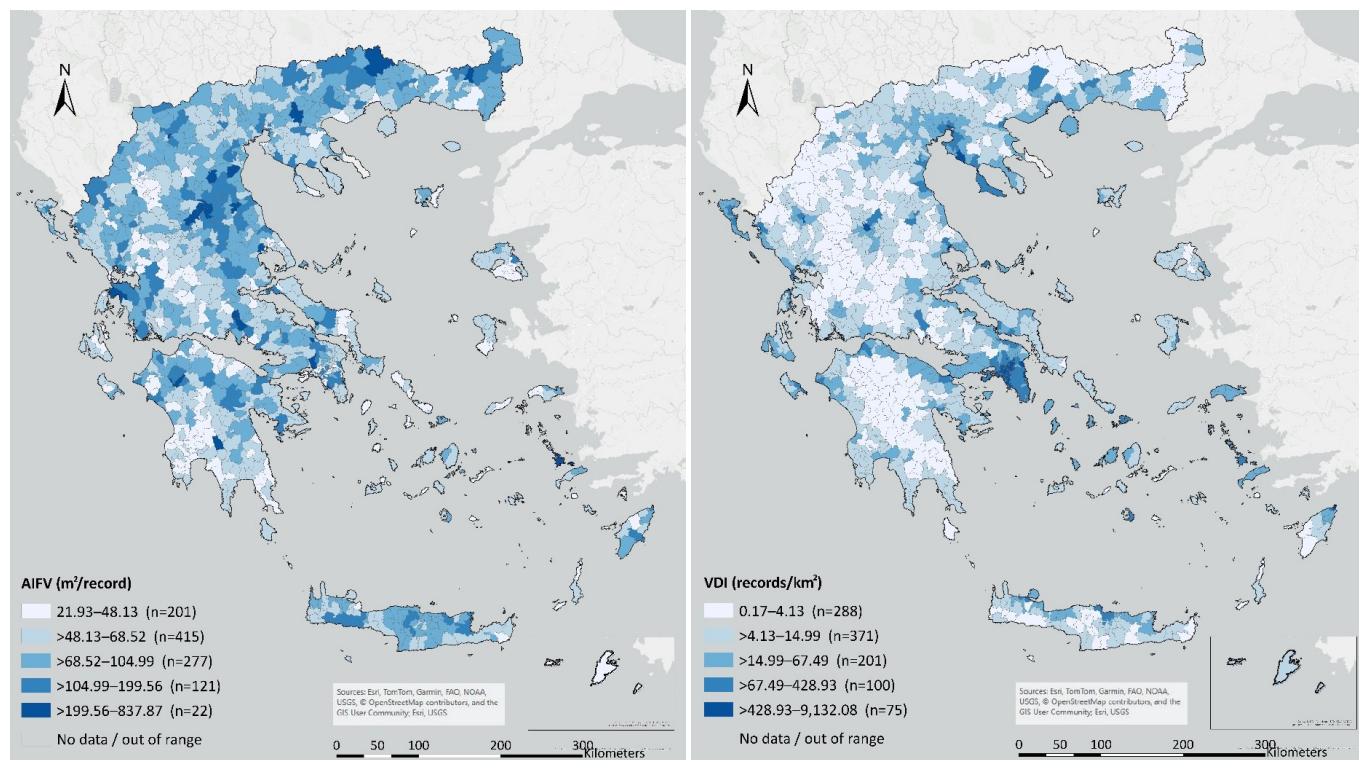


Figure 3 (Left). Average Illegal Footprint per Violation (AIFV) by municipal unit. Classification: Five Natural Breaks–Jenks classes derived from log1p-transformed values and reported as back-transformed m² per record. *Data: Technical Chamber of Greece and Hellenic Statistical Authority (n.d.).* **Figure 4 (Right).** Violation Density Index (VDI) by municipal unit. Classification: Five Natural Breaks–Jenks classes derived from log1p-transformed values and reported as back-transformed records/km². *Data: Technical Chamber of Greece and Hellenic Statistical Authority (n.d.).*

4.3 Relationships and combined indicator profiles

Non-parametric correlations confirm this distinction. VSI–AIFV shows a weak positive association (Spearman’s $\rho = 0.1388$, $p < 0.001$). VSI–VDI shows the strongest positive association, though it remains weak ($\rho = 0.2277$, $p < 0.001$). AIFV–VDI shows a weak negative association ($\rho = -0.0920$, $p = 0.0031$). Kendall’s τ_b coefficients show the same directions and similarly weak associations.

Table 5. Non-parametric correlations between VSI, AIFV, and VDI

Pair	Spearman’s ρ	p	Kendall’s τ_b	p
VSI–AIFV	0.1388	<0.001	0.0925	<0.001
VSI–VDI	0.2277	<0.001	0.1569	<0.001
AIFV–VDI	–0.0920	0.0031	–0.0662	0.0014

Weak national correlations indicate that severity, average area, and density do not necessarily coincide. This is further illustrated by the high–low combinations. The complete counts for all indicator-pair profiles are reported in Appendix Table A2.

Using national quartiles, Low and High thresholds were ≤ 3.257 and ≥ 4.069 for VSI, ≤ 50.627 and ≥ 83.409 m²/record for AIFV, and ≤ 3.678 and ≥ 29.136 records/km² for VDI; intermediate values fell between Q1 and Q3.

For VSI–VDI, 110 municipal units (10.62%) are High–High, 46 (4.44%) High–Low, 40 (3.86%) Low–High, and 86 (8.30%) Low–Low, while 754 (72.78%) include at least one Intermediate value. The High–Low and Low–High profiles confirm that severity and density do not necessarily coincide.

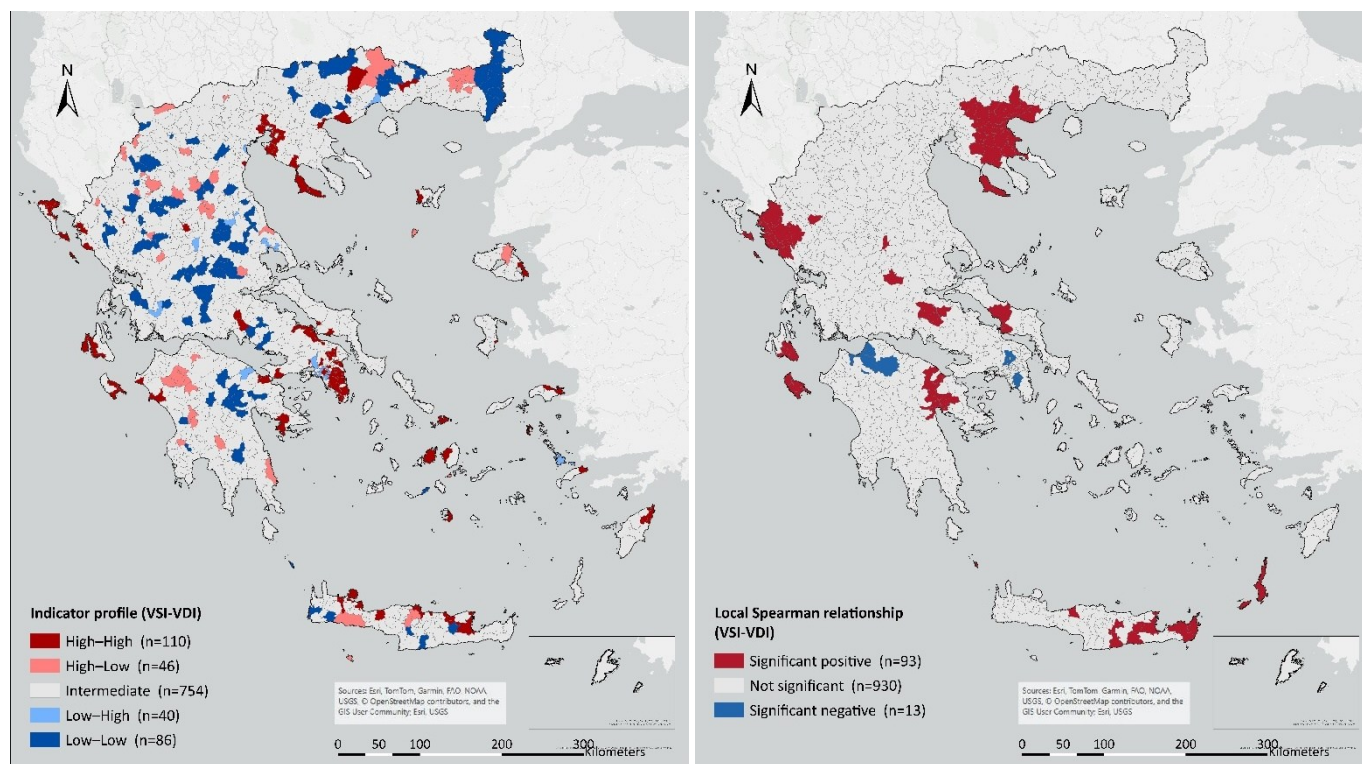


Figure 5. Spatial relationships between VSI and VDI by municipal unit: (a, left) high–low profiles based on national quartile thresholds and (b, right) significant local Spearman relationships after Benjamini–Hochberg FDR correction ($q < 0.05$). Data: Technical Chamber of Greece and Hellenic Statistical Authority (n.d.).

For VSI–AIFV, 113 municipal units (10.91%) are High–High, 34 (3.28%) High–Low, 61 (5.89%) Low–High, and 59 (5.69%) Low–Low, and 769 (74.23%) are Intermediate. The discordant profiles confirm that average scale does not necessarily increase with relative severity.

For AIFV–VDI, 68 municipal units (6.56%) are High–High, 82 (7.92%) High–Low, 74 (7.14%) Low–High, 65 (6.27%) Low–Low, and 747 (72.10%) Intermediate. The discordant profiles outnumber High–High cases, reinforcing the distinction between average unauthorised area and spatial density.

The extreme profiles show no single geographical pattern, occurring across mainland and island Greece and varying among indicator pairs. AIFV–VDI particularly illustrates the spatial decoupling reflected in its weak negative national correlation.

4.4 Spatial autocorrelation and local relationships

Global Moran’s I indicates significant positive spatial autocorrelation for all indicators, but with differing strength. Using Queen contiguity with nearest-neighbour links for the 55 isolated units, Moran’s I is 0.3838 for VSI, 0.1540 for AIFV, and 0.5463 for VDI, with pseudo- $p = 0.0001$ in all cases based on 9,999 permutations.

The VDI shows the strongest global spatial autocorrelation, consistent with its clearer geographical concentration in Figure 4. The VSI exhibits moderate positive autocorrelation, whereas the AIFV has the lowest Moran’s I , consistent with its more fragmented pattern.

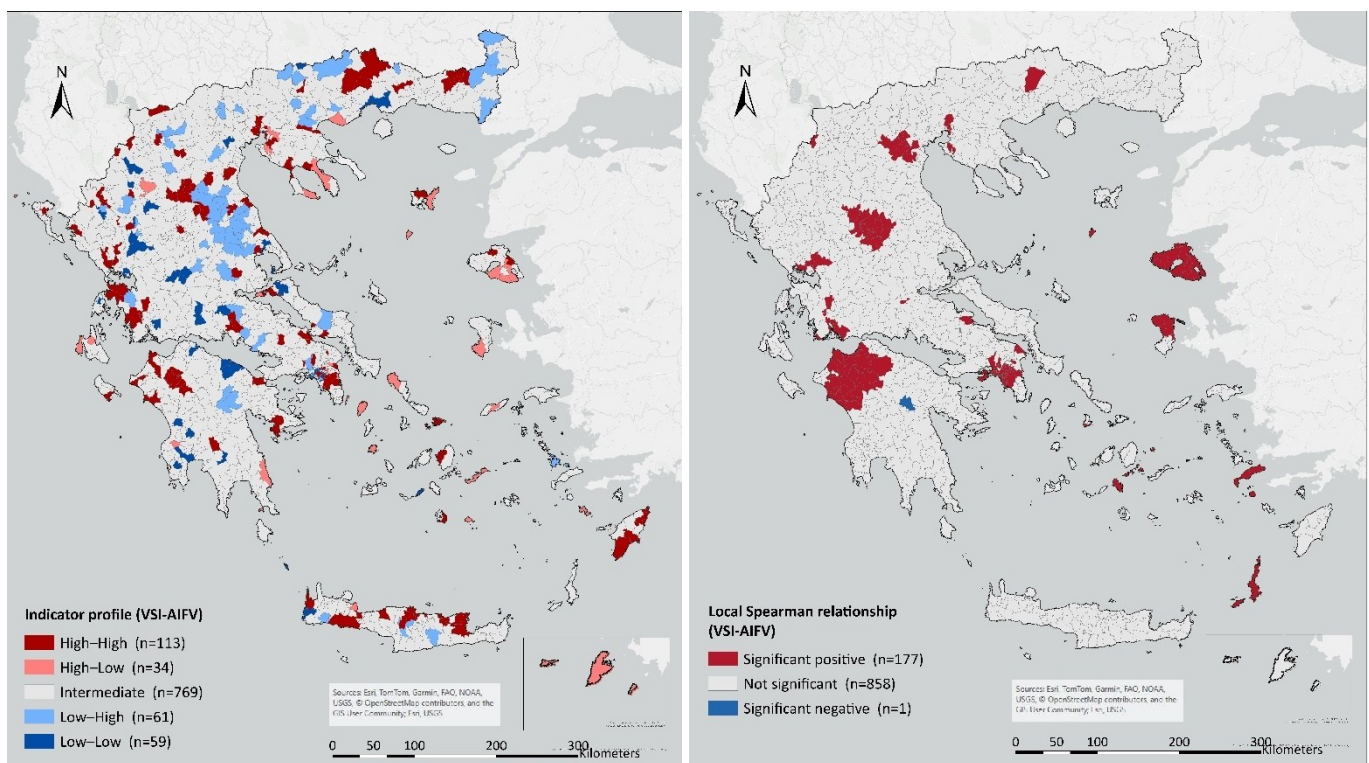


Figure 6. Spatial relationships between VSI and AIFV by municipal unit: (a, left) high-low profiles based on national quartile thresholds and (b, right) significant local Spearman relationships after Benjamini-Hochberg FDR correction ($q < 0.05$). Data: Technical Chamber of Greece and Hellenic Statistical Authority (n.d.).

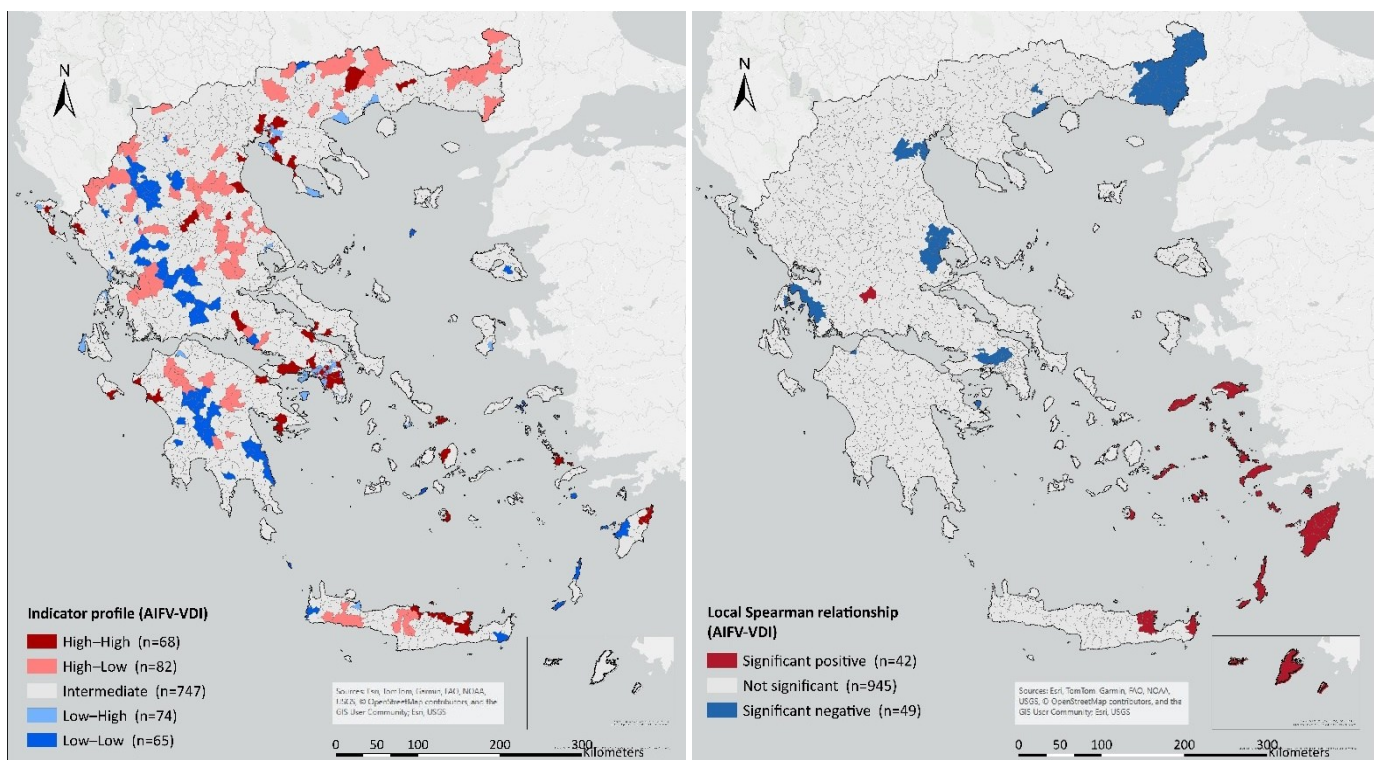


Figure 7. Spatial relationships between AIFV and VDI by municipal unit: (a, left) high-low profiles based on national quartile thresholds and (b, right) significant local Spearman relationships after Benjamini-Hochberg FDR correction ($q < 0.05$). Data: Technical Chamber of Greece and Hellenic Statistical Authority (n.d.).

Results remain stable under alternative spatial weights. With kNN4, Moran's I is 0.3665 for VSI, 0.1623 for AIFV, and 0.4799 for VDI; with kNN8, the corresponding values are 0.3166, 0.1197, and 0.4080. All are significant at pseudo- $p = 0.0001$. Alternative VSI weights also produce similar Moran's I values: $I = 0.3859$ for $p = 0.5$ and $I = 0.3764$ for $p = 2$. After log1p transformation, positive autocorrelation persists and increases for AIFV ($I = 0.2403$) and VDI ($I = 0.7541$), with pseudo- $p = 0.0001$, indicating that the observed spatial structure is not driven solely by extreme values.

Table 6. Global Moran's I for the national indicators

Indicator	Moran's I	Expected I	Permutation z	pseudo-p
VSI	0.3838	-0.0010	17.177	0.0001
AIFV	0.1540	-0.0010	7.246	0.0001
VDI	0.5463	-0.0010	26.098	0.0001

Note: Spatial weights: Row-standardised Queen contiguity with nearest-neighbour links for 55 isolated units; 9,999 permutations.

Local Spearman correlations nevertheless reveal substantial geographical variation. For VSI–VDI, local p ranges from -0.741 to 0.812. After FDR correction, 106 municipal units remain significant, including 93 positive and 13 negative relationships. The highest positive local correlations are observed in Stageira–Akanthos ($p = 0.812$), Arnaia ($p = 0.796$), Rentina ($p = 0.786$), and Madytos ($p = 0.769$).

For VSI–AIFV, local p ranges from -0.548 to 0.829, with 178 significant units: 177 positive and one negative. This contrasts with the weak national association and indicates stronger local covariation in specific neighbourhoods.

AIFV–VDI is the most heterogeneous, with local p ranging from -0.743 to 0.776. Of 91 significant units, 42 show positive and 49 negative relationships, indicating geographical variation in both magnitude and direction.

Table 7. Summary of local Spearman correlations ($k = 20$, FDR-corrected)

Pair	Min local	Max local	Significant	Positive	Negative
VSI–VDI	-0.741	0.812	106	93	13
VSI–AIFV	-0.548	0.829	178	177	1
AIFV–VDI	-0.743	0.776	91	42	49

Note: Significance based on Benjamini–Hochberg FDR-adjusted $q < 0.05$. For the main $k = 20$ specification, symmetrisation of the k -nearest-neighbour structure and inclusion of the focal municipal unit resulted in effective local sample sizes ranging from 21 to 39 observations (median = 24) for all three indicator pairs.

The maps highlight clear differences among indicator pairs. VSI–AIFV is dominated by significant positive relationships, VSI–VDI by mainly positive relationships with fewer negative cases, whereas AIFV–VDI shows nearly equal positive and negative frequencies. National coefficients therefore mask substantial spatial variation.

Sensitivity tests for $k = 15$, 20, and 25 show that, although the number of significant units varies, the broader spatial pattern remains stable. For VSI–VDI, correlations between local p surfaces are 0.912 for $k = 15$ versus $k = 20$, and 0.946 for $k = 20$ versus $k = 25$. For VSI–AIFV, the corresponding values are 0.883 and 0.918; for AIFV–VDI, they are 0.906 and 0.929.

4.5 Unauthorised Share Ratio in Athens and Thessaloniki

The USR measures the share of recorded unauthorised area in total building area. Aggregation into 350-m hexagons produced 350 non-empty cells in Athens and 178 in Thessaloniki. Both distributions are positively skewed, with greater dispersion in Athens.

Table 8. Descriptive statistics of mean USR by 350-m hexagonal cell

City	N cells	Min	Q1	Median	Mean	Q3	Max	SD	Skewness
Athens	350	0.0002	0.0283	0.0369	0.0628	0.0579	1.0000	0.0934	6.375
Thessaloniki	178	0.0005	0.0192	0.0291	0.0421	0.0487	0.3547	0.0439	3.614

Note: Cell values represent the arithmetic mean of building-level USR values.

In Athens, mean and median USR per cell are 0.0628 and 0.0369, compared with 0.0421 and 0.0291 in Thessaloniki. Athens also shows stronger positive skewness (6.375 vs. 3.614) and a higher maximum (1.000 vs. 0.355).

Using common class thresholds, 5.43% of Athens cells and 29.21% of Thessaloniki cells fall within 0.00–0.02, while 24.00% and 17.98%, respectively, exceed 0.06. Lower USR values are therefore more prevalent in Thessaloniki.

Both maps show marked intra-urban differentiation, with adjacent cells often belonging to contrasting classes over short distances; heterogeneity is greater in Athens. Cell values are arithmetic means of building-level USR values, not ratios of total unauthorised to total building area within each cell.

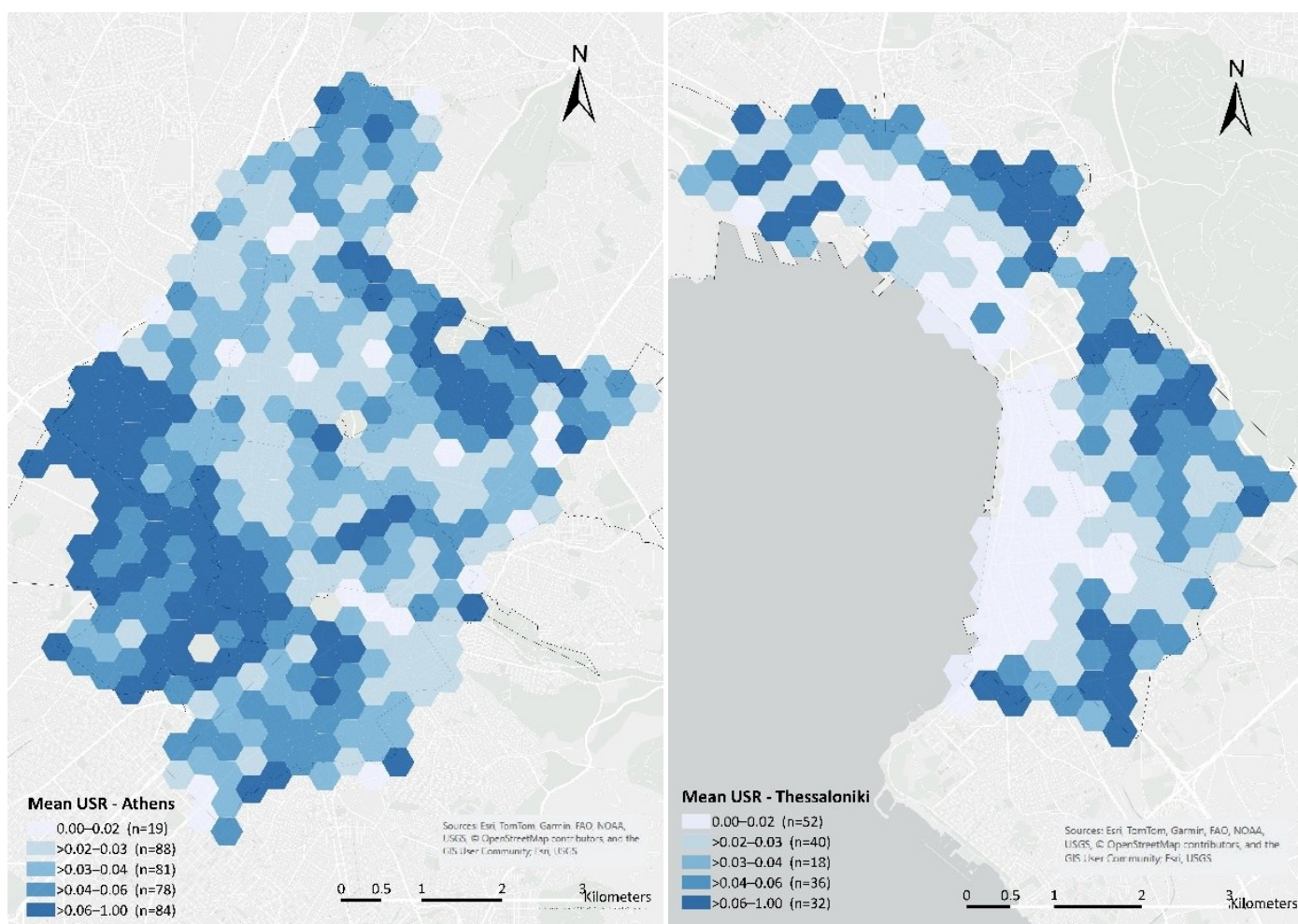


Figure 8. Mean Unauthorised Share Ratio (USR) by 350-m hexagonal cell in (a, left) Athens and (b, right) Thessaloniki. Note: Identical class limits and colour scales are used for both municipalities. Cell values are arithmetic means of building-level USR values. Data: Technical Chamber of Greece and Hellenic Cadastre (n.d.).

Overall, the examined dimensions do not follow a single spatial pattern. Severity shows lower dispersion but clear spatial organisation, average recorded area is more skewed and fragmented, and density exhibits the greatest dispersion and strongest spatial autocorrelation. Weak national correlations and frequent discordant profiles confirm that severity, average scale, and density are distinct measures.

Local correlations further reveal spatial variation obscured by national coefficients: VSI–AIFV is overwhelmingly positive, whereas AIFV–VDI includes similar numbers of significant positive and negative relationships. The USR likewise reveals substantial intra-urban differentiation in the share of recorded unauthorised area within the building stock of Athens and Thessaloniki.

5. Discussion

The results show that the officially recorded and regularised component of unauthorised construction in Greece does not follow a single spatial pattern. Relative severity, average recorded area, and spatial density display different distributions and degrees of spatial organisation, while weak national correlations for VSI–AIFV ($p = 0.139$), VSI–VDI ($p = 0.228$), and AIFV–VDI ($p = -0.092$) confirm that none of the three indicators can substitute for the others. This distinction is important because unauthorised construction is often represented through total counts or total unauthorised area, which capture overall extent but not the composition, average scale, or spatial intensity of recorded violations. International research has examined unauthorised development in relation to socioeconomic, demographic, institutional, and planning factors (Akrofi et al., 2019; Somiah et al., 2015; Zeković et al., 2020). However, severity, average scale, and spatial density are not always distinguished within the same analytical framework. The present results support treating these dimensions in parallel as distinct measures.

Spatial autocorrelation reinforces this differentiation. The VSI shows moderate positive autocorrelation ($I = 0.38$), the AIFV the weakest spatial organisation ($I = 0.15$), and the VDI the strongest ($I = 0.55$). These patterns persist under alternative neighbourhood definitions, indicating that they are not dependent on a single spatial weights matrix. The VDI therefore forms more spatially coherent geographical concentrations than average unauthorised area per record, consistent with the value of combining thematic mapping with global and local spatial statistics (Vartholomaios, 2025).

Interpretation of the VDI requires distinguishing spatial density from absolute counts. High VDI values indicate many recorded violations relative to geographical area, not necessarily the largest total number of violations or unauthorised area. This is especially evident in small urban units: Sykies exceeds 9,132 records/km², while the municipal unit of Thessaloniki exceeds 8,300 records/km². Yet High–High VSI–VDI profiles are not confined to dense urban areas, also occurring in units such as Drama, Xanthi, Thermi, Mikra, Oreokastro, and Kassandra. Overall, 110 municipal units have both indicators at or above Q3, showing that high relative severity and high density coexist across different spatial contexts.

The discordant profiles are equally informative. Kechros and Organi combine very high VSI values with VDI below 0.3 records/km², whereas Neapoli and Ampelokipoi combine comparatively low VSI values with very high density. For AIFV–VDI, the discordance is stronger: 82 municipal units are High–Low and 74 Low–High, compared with 68 High–High. High average unauthorised area and high spatial density are therefore not alternative expressions of the same characteristic. Some areas may contain relatively large but sparse violations. Others may contain many records with smaller average area.

These results are consistent with the broader literature on unauthorised development in Greece and Southern Europe, where the phenomenon has been linked to small-scale landownership, self-provided housing, fragmented urban expansion, development outside statutory plans, second homes, and ex post institutional management (Allen et al., 2004; Leontidou, 1990; Polyzos & Minetos, 2009; Tsenkova, 2012; Wassenhoven et al., 2010). Some high record counts and VDI values also overlap with metropolitan, peri-urban, coastal, and island areas. However, the study does not include explanatory variables for urban sprawl, tourism intensity, land values, second-home development, or land-use change. These correspondences should therefore be treated as contextual associations and hypotheses for further investigation, with no causal mechanism considered established.

Local correlations further show how national coefficients can conceal geographically differentiated relationships. For VSI–AIFV, 178 municipal units remain significant after FDR correction, 177 of them positive, despite the weak national correlation. VSI–VDI also shows predominantly positive significant local relationships. AIFV–VDI is more heterogeneous, with 42 significant positive and 49 significant negative local correlations. Significant negative relationships occur in parts of eastern and northeastern Greece, including Alexandroupoli, Traianoupoli, Feres, Didymoteicho, and

Tychero. These local patterns do not establish causality, but they identify areas where the national relationship is insufficient to describe local covariation. The contrast between weak national coefficients and stronger or directionally different local relationships also highlights the need to examine spatially varying associations directly, as a single country-wide coefficient may conceal important local variation.

The USR adds a different dimension by measuring the share of recorded unauthorised area in the corresponding building area. Clear intra-urban differentiation is evident in both Athens and Thessaloniki. Athens has a higher mean USR per hexagonal cell (0.0628 versus 0.0421), higher median (0.0369 versus 0.0291), and greater dispersion. The lowest common class contains 29.21% of Thessaloniki cells but only 5.43% of Athens cells. These differences do not imply a larger total actual stock of unauthorised construction in Athens. The USR is calculated only for records that could be matched between the administrative and building datasets. Values assigned to each cell are based on the arithmetic mean of building-level ratios, so each building contributes equally to the resulting value. The indicator is intended to capture fine-grained intra-urban variation in the relative presence of recorded unauthorised area within the building stock. It should therefore not be used to compare Athens and Thessaloniki in terms of the absolute amount of unauthorised construction.

The findings also have an institutional dimension. Unauthorised construction in Greece cannot be understood solely as an absence of regulation, since its long-term persistence has coexisted with uneven enforcement, institutional tolerance, and repeated ex post procedures of declaration and regularisation. These processes did not constitute a single or direct cause of unauthorised construction, but they shaped the institutional environment within which non-compliant development was managed, tolerated, and subsequently brought into formal administrative procedures. Successive regularisation frameworks therefore influenced both the institutional treatment of unauthorised construction and the composition of the administrative record analysed in this study. The present analysis does not establish a causal relationship between specific institutional policies and the observed spatial patterns. It shows that the empirical representation of these patterns is shaped by the procedures through which violations were declared, classified, and regularised.

The VSI sensitivity analysis strengthens confidence in the findings on relative severity. Although the 1–5 scale is an analytical weighting scheme and does not represent an objectively equidistant legal scale, alternative non-linear weights produce Spearman correlations of 0.9942–0.9996 with the baseline index and retain more than 96% of municipal units in the same class. Correcting the treatment of category 0 was therefore methodologically necessary but did not materially alter the relative geographical structure of the VSI.

From a planning perspective, the high–low profiles provide a differentiated diagnostic and should not be interpreted as a normative classification. High VDI with low VSI raises different questions from high VSI with low VDI, while high AIFV with low VDI represents a different configuration from dense concentrations of smaller violations. The typology can therefore help prioritise further investigation, but it should not be translated automatically into specific policy interventions.

Several limitations remain. The database includes only cases declared and entered into formal regularisation procedures up to 28 March 2022, the distribution of undeclared cases is unknown, and observed differences may partly reflect geographical variation in participation in declaration procedures. The national analysis is also subject to the Modifiable Areal Unit Problem (MAUP), because municipal units differ in area, morphology, density, and internal heterogeneity. Although the VDI limits the direct influence of unit area through normalisation per km², it does not eliminate the effects of administrative boundaries. Robustness tests using alternative spatial weights and neighbourhood sizes show that the principal spatial findings are not dependent on a single definition of proximity, but they do not eliminate aggregation effects or the MAUP.

Because all three indicators exhibit significant positive spatial autocorrelation, the independence assumption underlying the significance tests of the national Spearman correlations may be affected; therefore, their p-values should be interpreted with caution, and the coefficients are used primarily as descriptive measures of global association.

Overall, combining VSI, AIFV, VDI, and USR with high–low profiles, spatial autocorrelation, and local correlations provides a more differentiated account than mapping declared cases alone. The contribution lies in treating relative severity, average scale, spatial density, and share in the building stock as distinct analytical dimensions, with each retained as a separate measure. Their spatial patterns sometimes coincide but often diverge, providing an empirical basis for future explanatory research on the socioeconomic, institutional, property-related, tourism-related, and planning factors associated with unauthorised construction.

6. Conclusions

This study examined the spatial differentiation of the officially recorded and regularised component of unauthorised construction in Greece through four complementary indicators: the Violation Severity Index (VSI), Average Illegal Footprint per Violation (AIFV), Violation Density Index (VDI), and Unauthorised Share Ratio (USR). The VSI, AIFV, and VDI were applied to 1,036 municipal units nationwide, and the USR provided a complementary intra-urban analysis for the Municipalities of Athens and Thessaloniki.

The main finding is that relative severity, average recorded area, and spatial density constitute distinct dimensions of the recorded phenomenon. Their weak national associations and the presence of discordant high–low profiles show that high values in one dimension do not necessarily coincide with high values in another. Spatial analysis further demonstrates that these dimensions differ in their degree of geographical organisation, and local relationships reveal patterns that are not captured by national coefficients alone.

The USR extends this perspective by showing substantial intra-urban differentiation in the relative share of recorded unauthorised area within the building stock of Athens and Thessaloniki. Its contribution is therefore complementary to the national indicators rather than directly comparable with them across spatial scales.

Methodologically, the study shows the value of combining complementary indicators with spatial autocorrelation, local correlations, and profile analysis. This approach extends the analysis beyond total counts, total unauthorised area, and thematic mapping alone. The stability of the VSI under alternative weighting schemes further supports the robustness of the relative severity patterns identified.

These findings remain subject to the limits of the empirical base. The database covers only cases that entered formal declaration and regularisation procedures. Undeclared violations remain unobserved. The national analysis is also affected by the MAUP, and relationships with broader processes such as urban sprawl, tourism, land values, and development pressures were not tested causally.

Overall, the study shifts the analytical focus from where more violations are recorded to how severity, average scale, density, and share in the building stock vary spatially. Distinguishing these dimensions provides a reproducible framework for identifying differentiated spatial profiles and for future comparative and explanatory research on unauthorised construction.

Funding: This research received no external funding.

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

Data Availability Statement: The primary administrative data analysed in this study were provided by the Technical Chamber of Greece following formal requests for research purposes and are not publicly available due to restrictions imposed by the data provider. Requests for access to these data should be addressed directly to the Technical Chamber of Greece and are subject to its approval and applicable terms of use. The supplementary geospatial data from the Hellenic Statistical Authority and the Hellenic Cadastre are publicly available from the sources cited in the reference list.

Acknowledgements: The authors thank the Technical Chamber of Greece for providing the anonymised administrative data used in this study. AI-assisted tools were consulted for language proofreading.

Appendix A.

Table A1. Sensitivity analysis of the VSI weighting scheme

p	Spearman ρ	Kendall's τ_b	Mean absolute rank change	Maximum rank change	Same class
0.50	0.9983	0.9655	12.86	68	97.10%
0.75	0.9996	0.9830	6.42	33	99.03%
1.00	1.0000	1.0000	0.00	0	100.00%
1.50	0.9984	0.9670	12.27	68	97.49%
2.00	0.9942	0.9357	23.57	135	96.33%

Table A2. High–low combinations of the national indicators

Pair	High–High	High–Low	Low–High	Low–Low	Intermediate
VSI–VDI	110	46	40	86	754
VSI–AIFV	113	34	61	59	769
AIFV–VDI	68	82	74	65	747

Note: High $\geq$ Q3, Low $\leq$ Q1.

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