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THE INTUITIONISTIC FUZZY SYNTHETIC MEASURE IN A DYNAMIC ANALYSIS OF THE SUBJECTIVE QUALITY OF LIFE OF CITIZENS OF EUROPEAN CITIES

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ABSTRACT: The paper aims to measure and assess changes regarding the SQoL experienced by the residents of selected European cities over time. An Intuitionistic Fuzzy Synthetic Measure (IFSM) was applied to measure the SQoL. The measure allows taking into account the element of uncertainty expressed in the lack or refusal to answer. The analysis uses the results of studies on the SQoL conducted by the European Commission in the selected European cities. The method of constructing a pattern object proposed in the article allowed for assessing changes in the SQoL level of European city residents over time. The analysis showed that the subjective quality of life of the residents of European cities is systematically increasing during the period 2006-2019. However, we still observe large differences in the level of this phenomenon among the cities. The results of the research can be used to formulate assumptions or modify urban policies in EU cities to improve the quality of life of citizens.

KEYWORDS: complex phenomena measurement, subjective quality of life, European cities, intuitionistic fuzzy sets, aggregated ordinal data

Introduction

One of the most important priorities followed by the European Union is to strengthen economic, social, and territorial cohesion. Eliminating disproportions between regions in terms of economic growth, the competitiveness of enterprises, the labour market, the resident's quality of life, or environmental protection is a long-term process which requires taking action in the economic, social, and environmental areas. Practical implementation of the goals and principles included in the concept of sustainable development at all management levels acts as the instrument supporting and strengthening economic, social, and territorial cohesion. According to the assumptions of this concept, permanent improvement of the quality of life remains the overriding goal of all activities undertaken by people, including the ones carried out by the local community aimed at the development of a particular community. Sustainable improvement in the quality of life of both contemporary and future generations, in accordance with the concept of sustainable development, should be achieved along with maintaining balance in the management of economic, social, and natural capital. Practical implementation of the principles ingrained in the sustainable development concept is of particular importance in local, territorial systems. The quality of an individual's life is highly determined by those aspects of urban life that occur in our immediate environment, e.g., the place of residence. Therefore, the responsibility for local development and the residents' quality of life rests with the local authorities, which should take and implement such decisions and actions that allow optimal use of the social, environmental, and economic potential of a given territorial unit.

There are two approaches to measuring the quality of life on the local level. The objective approach is based on objective indicators, which are calculated from data collected from public statistics sources. The subjective approach is based on subjective indicators which express the opinions of the respondents and are derived from the surveys (Coronicova Hurajova & Hajduova, 2021; Costa, 2015; Diener & Suh, 1997; Garcia-Bernabeu et al., 2021; Głowicka-Wołoszyn et al., 2018; Royuela et al., 2003; Sőrés & Pető, 2015). In the objective approach, a description of the actual state of living conditions or standard of living is obtained, while the subjective approach, provides information on the perceived quality of life. Subjective quality of life indicators relates to the degree of meeting needs. They take the form of assessments evaluating the life of a given individual within a specific system of values, as well as their experiences, desires, and expectations (Diener & Suh, 1997; Diener et al., 1999). In other words, they are an accurate measure of what individuals perceive as important to their well-being and happiness (Costanza et al., 2007). In the subjective approach, the quality of life is, therefore, an individual matter and depends on the individual's perception of life itself. Due to the fact that the subjective quality of life is considered through the prism of meeting material needs ("to have"), the needs related to the sense of security in the physical, economic, and health dimensions ("to be"), as well as the needs of social contact ("to love"), in the research practice it is most frequently determined by the questions about contentment (satisfaction) with particular areas (spheres) of life, as well as the questions regarding the general satisfaction with life. In some studies, the SQoL is approached as a latent variable, which is directly unobservable, measured with the use of specific indicators relating to the particular spheres and areas of the QoL. Based on these individual indicators relating to specific issues (areas) of the quality of life, a synthetic index is determined. Regardless of the research approach, it is worth noting that the subjective quality of life is a dynamic category. This means that it can change over time and space.

Measurement of the SQoL requires conducting primary research with the use of a questionnaire. The respondents assess particular aspects of the quality of life using ordinal measurement scales. These results are later aggregated by the official statistics and made publicly available. Such databases most often constitute the basis of subsequent comparative analyses carried out by the researchers studying the problem of quality of life. Due to the complexity of the construct, i.e. the subjective quality of life, synthetic measures are the tools most frequently used in such analyses.

The measurement of subjective quality of life using synthetic measures and aggregated ordinal data is a new issue. Due to the limited amount of available information in the form of aggregated ordinal data, the classic synthetic measures dedicated to metric data are becoming obsolete. Moreover, the synthetic measures for ordinal data proposed in the source literature require detailed research results at the level of each respondent. Therefore, a new and important direction of the research addressing the measurement of the subjective quality of life refers to the methods for con-

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structing synthetic measures based on aggregated ordinal data, which additionally allows for conducting dynamic comparative analyses.

Roszkowska et al. (2022) proposed a new approach to measuring the subjective quality of life for aggregated data measured on an ordinal measurement scale. In this approach, the Intuitionistic Fuzzy Synthetic Measure (IFSM) was used. It takes into account the uncertainty resulting from the respondents' indecisiveness or refusal to answer in the context of assessing selected aspects (areas) of the quality of life. The source of data used for the article is the results of research on the SQoL in European cities, which have been conducted by the European Commission since 2004 among the inhabitants of capital cities and large cities located in the European Union, European Free Trade Association, Western Balkans, Great Britain, and Turkey. The method of constructing pattern objects proposed by the Authors facilitates conducting dynamic comparative analyses, which allows the observation of the pace and directions of changes in the SQoL experienced by the residents of the European cities.

Approximately 40% of the EU population lives in cities. Urban centres constitute the core of regional development. They represent important agglomerations for the functioning of enterprises, business environment institutions, non-governmental organisations, and public institutions. They offer high potential for the development of innovations and new technologies. They are also important centers of education, science, and culture. As the areas are characterised by high population concentration and dense development, they face some challenges and problems of environmental (air pollution, noise, congestion, chaotic housing construction, waste management) and social (social disproportions, poverty, social exclusion, no sense of local identity, low sense of security or public confidence) nature. Therefore, city authorities have a great responsibility in terms of optimal involvement and use of the potential ingrained in the local systems. Monitoring the subjective quality of life of the residents inhabiting European cities is a valuable source of information regarding satisfaction, both perceived and felt by city dwellers with the particular areas of the urban fabric functioning. It is, in a way, a barometer showing the social mood of city residents. The findings of the SQoL studies in European cities:

- provide information about the direction in which a particular territorial unit is developing,
- allow identification of these areas of city functioning that require improvement,
- and constitute a form of dialogue between the representatives of local authorities and the residents. They can contribute to increasing the involvement of city dwellers in local issues,
- can be used by the local authorities at various stages of shaping and implementing the local development policy (planning, monitoring, improving the effectiveness and efficiency of decision-making and taking actions),
- allow conducting comparative research and identifying these European cities where the quality of life is best. This is important information for both current and potential city residents, as well as entrepreneurs and tourists,
- and can inspire city authorities to exchange mutual experiences and cooperate in the area of implementing the best solutions to improving the subjective quality of life in the city.

The purpose of the article is to measure and assess changes regarding the subjective quality of life experienced by the residents of selected European cities over time by applying an Intuitionistic Fuzzy Synthetic Measure (IFSM). Our empirical study is driven by the following key research questions:

1. Did the level of subjective quality of life differ between European cities?
2. Did the level of subjective quality of life in European cities change in 2006-2019?

This paper is organised as follows. After the introduction, the literature review concerning measuring the quality of life is presented in Section 2. Then, in Section 3 the research methodology is outlined. The concept of Intuitionistic Fuzzy Synthetic Measure is proposed. The results of the dynamic analysis of the SQoL based on a survey questionnaire conducted by the European Commission in the selected European cities in the period 2006-2019 are presented in Section 4. Next, a discussion is given in Section 5. Finally, short conclusions are outlined in Section 6.

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An overview of the literature

The quality of life is the subject of research by many authors. Satisfaction with the quality of life has been found to be positively associated with satisfaction with the place and urban quality of life (Ge & Hokao, 2006; Marans, 2015). Quality of life is also a crucial element for smart city development (Macke et al., 2018).

Cummins (2000) reviewed the studies discussing the quality of life, which referred to the correlations between objective and subjective indicators, and, based on them, formulated the following conclusion: both objective and subjective indicators represent reliable and accurate tools for measuring the quality of life. He also noticed that the intra-group correlations between the objective indicators and the intra-group correlations between the subjective indicators are higher than the inter-group correlations between the objective and subjective indicators. Moreover, Cummins noted that the individuals and populations featuring a very low level of objective well-being will be characterized by a higher correlation between objective and subjective indicators. Strictly speaking, the correlation between objective and subjective quality of life is higher the lower the level of objective quality of life. Angur et al. (2004) compared the importance of objective and subjective indicators of the quality of life on the overall neighbourhood quality. Their study is based on data from two major studies on the quality of neighbourhood life in Flint, Michigan. They showed, i.a., that subjective indicators do not correlate as strongly with objective indicators as they do with each other. Moreover, they recommend using both types of indicators because significant relationships between them and the overall quality of neighbourhood life have been observed. Santos et al. (2007) measured the level of SQoL experienced by the city of Porto residents. They used Factorial Multiple Correspondence Analysis and Ward's hierarchical clustering method to identify homogeneous groups of residents with specific interests and similar sensibilities towards a few aspects related to the quality of life and also to enable their characterisation from a socio-economic perspective. The study by Lee (2008) identified the most important satisfaction domains influencing the subjective quality of life of the city of Taipei residents. The approach based on modelling structural equations was used. The results of the study indicated that the assessments of personal safety and public services primarily determine the satisfaction of living in the city of Taipei. Diener et al. (2009) identified the SQoL predictors based on research conducted in 55 countries. Their findings revealed strong relationships between SQoL and high income, individualism, human rights, and societal equality. Chen and Davey (2009) analysed the level of SQoL of the selected cities' residents. In the case of these authors, the purpose of their research was to establish the quality of life in the city of Zhuhai in southern China. Their measurement tool took the form of the International Wellbeing Index (IWI), constructed based on two subscales: the Personal Wellbeing Index (PWI) and the National Wellbeing Index (NWI). The analysis of the results used, i.a., ANOVA and the exploratory factor analysis. The study was also of a comparative nature because the measurement results of the subjective quality of life of Zhuhai residents were compared against two other cities: Hong Kong and Macau. De la Cruz et al. (2011) investigated the urban quality of life in Alfama, Lisbon (Portugal), taking into consideration the physical, economic, and social aspects of quality of life through objective and subjective measures. The authors used a survey of 69 respondents, and correlation analysis was used to examine the relationship between the two measures. Von Witrh et al. (2015) conducted an Urban Quality of Life study covering 1,693 residents of the Limmattal area, a suburban settlement belt in the agglomeration of Zurich, Switzerland. Their measurement took into account both objective and subjective indicators, which they later modelled using structural equations. The findings indicated i.a., low correlations between objective characteristics and subjective assessments of urban QoL aspects. Sőrés and Pető (2015) examined SQoL experienced by the residents of one of the most popular tourist destinations in Hungary. The conducted survey covered a sample of 804 respondents, the residents of Hajdúszoboszló. The town is the fourth most popular health and holiday resort in Hungary. The purpose of the research was to identify the factors determining the quality of life of the tourist destination residents, including the impact of tourism on the life of the city residents. Haslauer et al. (2015) provided an analytical framework for spatially identifying areas of agreement and discordance between the objectively and subjectively measured quality of life. Two urban indicators, public transit quality and green space availability for the city of Vienna were investigated. Feneri et al. (2015) investigated the urban lifestyle in the urban area of Thessaloniki by applying the Analytical Hierarchy Process, which captures the conditions of

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living and the degree of residents' prosperity, using both objective indicators and subjective criteria. Węziak-Białwolska (2016) analysed several aspects of urban quality of life in European cities using Flash Eurobarometer 366 showing that satisfaction with life in a city varied considerably both inside cities and across Europe. Macke et al. (2018) evaluated the perception of quality of life in a smart city and analysed the main elements of citizens' satisfaction with their home city. The authors applied interviews with 400 residents of the city of Curitiba, in Southern, and identified four quality-of-life domains: socio-structural relationships, environmental well-being, material well-being, and community integration. The purpose of the study by Nanor et al. (2018) was to identify the most important determinants of the SQoL of the city of Kumasi residents. The results of factor analysis showed that the quality of life experienced by these residents is mostly influenced by health, housing, economic status, and neighbourhood assessments. The residents of Kumasi were also asked to rate the importance of individual SQoL domains. According to them, transportation within the city is the relatively most important aspect of their SQoL. De Guimarães et al. (2020) analyze the influence of the factors of Smart Governance regarding the aspects of Transparency, Collaboration, Participation and Partnership, Communication, and Accountability in public perception of the quality of life in the context of smart cities based on a survey applied to 829 inhabitants of a city in the Northeast of Brazil. The analysis of the data was provided using multivariate data techniques, with the application of Structural Equation Modeling methodology.

The results of the source literature review conclude that the subjective quality of life is measured predominantly among city residents. For this purpose, it is common practice to combine subjective indicators with objective indicators to obtain an overall picture of the QoL and to analyse the relationship between these two types of indicators. The general practice of these studies is to include the question/statement about the general QoL level, which allows for conducting exploratory research aimed at, i.a., identifying the QoL determinants. It is worth noting that the comparative aspect is rarely present in the research, and if so, it concerns the residents of other territorial units, most often cities. There are no studies of both methodical and empirical nature, the purpose of which would be to analyse the SQoL changes over time. This study is a proposal to fill in the existing research.

Research methods

The study uses the results of five editions of subjective quality-of-life surveys of residents of selected European cities carried out on behalf of the European Commission. A variable number of cities participated in each of the years covered by the analysis, i.e. 75 in 2006 and 2009, 79 in 2012, 78 in 2015, and 82 in 2019 year.

The cities were evaluated by residents in terms of 10 criteria: satisfaction with public transport (C1), satisfaction with health care services, doctors, and hospitals (C2), satisfaction with sports facilities such as sports fields and indoor sports halls (C3), cultural facilities such as concert halls, theatres, museums and libraries (C4), satisfaction with green spaces such as parks and gardens (C5), satisfaction with public spaces such as markets, squares, pedestrian areas (C6), satisfaction with schools and other educational facilities (C7), satisfaction with the quality of the air (C8), satisfaction with the noise level (C9), satisfaction with the cleanliness (C10). The respondents for assessment of the criteria used a 4-point measurement scale: very satisfied, rather satisfied, rather unsatisfied, very unsatisfied, don't know/no answer. The survey questionnaire and the measurement results from the last edition of the survey can be found: https://ec.europa.eu/regional_policy/information-sources/maps_en.

The Intuitionistic Fuzzy Synthetic Measure (IFSM) was used to measure the subjective quality of life of citizens of European cities and to assess changes in the level of this quality over the years 2006-2019.

First, the notion of the intuitionistic fuzzy set (IFS) and distances on IFSs are defined. Next, IFSM is defined based on IFS. The Intuitionistic Fuzzy Set theory was proposed by Atanassov (1986, 1999) to address uncertainty as an extension of the Fuzzy Set (FS) theory introduced by Zadeh (1965).

Definition 1. (Atanassov, 1999) Let X be a universe of discourse of objects. An intuitionistic fuzzy set A in X is defined as:

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$$A = \{< x, \mu_A(x), \nu_A(x) > | x \in X\}, \tag{1}$$

where:
$\mu_A, \nu_A : X \rightarrow [0,1]$are functions satisfying for every condition,

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1. \tag{2}$$

The number $\mu_A(x)$ denote the degree of membership, $\nu_A(x)$ – the degree of non-membership, $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$ the intuitionistic fuzzy index (hesitation margin) of the element $x \in X$ to the set A. Greater $\pi_A(x)$ represented more vagueness. In the case where the universe X contains only one element x, then the IFS over X is denoted as $A = (\mu_A, \nu_A)$. It is also called an intuitionistic fuzzy value (IFV). Let us notice that the intuitionistic value (1,0) is the largest, while (0,1) is the smallest.

The Euclidean distance is the most popular and frequently used for intuitionistic fuzzy sets (Szmidt, 2014).

Definition 2. (Szmidt, 2014). Let A, B $\in$ IFS with membership functions $\mu_A(x)$, $\mu_B(x)$, and non-membership functions $\nu_A(x)$, $\nu_B(x)$ respectively. The normalised Euclidean distance between two intuitionistic fuzzy sets, A and B is defined as:

$$d(A,B) = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_A(x_j) - \mu_B(x_j)\right)^2 + \left(\nu_A(x_j) - \nu_B(x_j)\right)^2 + \left(\pi_A(x_j) - \pi_B(x_j)\right)^2\right]}. \tag{3}$$

Let us denote by $O = \{O_1, O_2, \ldots, O_m\}$ (i = 1, 2, … , m) the set of objects under the survey evaluation, $C = \{C_1, C_2, \ldots, C_n\}$ (j = 1,2, … , n) the set of criteria. We assumed that the objects are evaluated by the respondents with respect to criteria using an ordinal scale. Finally, let T = {1, … , k} be the set of period times. The respondents' answers are collected in a questionnaire survey and next aggregated into three groups: "a positive opinion about the object", "a negative opinion about the object", and "no opinion or no answer". Positive opinions were the answers "rather satisfied" and "very satisfied". The answers "rather unsatisfied" and "very unsatisfied" were treated as negative opinions. We assumed the equal weights of the criteria, which means the same importance of each criterion in the evaluation of objects.

The Intuitionistic Fuzzy Synthetic Measures (IFSM) is a modification of a less-known variant of Hellwig's measure in a fuzzy environment and is defined in eight steps (Roszkowska et al., 2022).

In the first step the survey data were represented in the form of intuitionistic fuzzy value (μ_{ijt}, ν_{ijt}), where: μ_{ijt} (ν_{ijt}) – the fraction of positive opinions (negative opinions) about *i*-th object with respect to *j*-th criterion in *t*-th period time and π_{ijt} – the fraction of opinion type "don't know", "no answers" for *i*-th object with respect to *j*-th criterion in *t*-th period time. Let us recall that $\pi_{ijt}(x) = 1 - \mu_{ijt}(x) - \nu_{ijt}(x)$.

In step 2 Intuitionistic Fuzzy Decision Matrixes were constructed in the form:

$$D_t = \begin{bmatrix} (\mu_{11t}, \nu_{11t}) & \cdots & (\mu_{1nt}, \nu_{1nt}) \\ \vdots & \ddots & \vdots \\ (\mu_{m1t}, \nu_{m1t}) & \cdots & (\mu_{mnt}, \nu_{mnt}) \end{bmatrix}, \tag{4}$$

where:
(μ_{ijt}, ν_{ijt}) – denote the intuitionistic fuzzy representation survey data of *i*-th object with respect to *j*-th criterion in *t*-th period time and $\pi_{ijt} = 1 - \mu_{ijt}(x) - \nu_{ijt}(x)$.

In step 3 ideal fuzzy object (fuzzy pattern object) I_{IFI} based on maximum value IFV is determined in accordance with the principle:

$$I_{IFI} = [(1,0), ..., (1,0)] \tag{5}$$

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While in step 4 the ant-ideal fuzzy object (anti-fuzzy pattern object) I_{IFAI} based on minimum value, IFV is determined in accordance with the principle:

$$I_{IFAI} = [(0,1), ..., (0,1)] \tag{6}$$

In step 5, the distance measures $d_t^+(O_i)$ between the objects and the intuitionistic fuzzy pattern object using the formula (3) is calculated as follows:

$$d_t^+(O_i) = d_t\,(I_{IFI}, O_i), \tag{7}$$

where:
$i = 1,2, ..., m$,
$t = 1,2, ..., k$.

The Intuitionistic Fuzzy Synthetic Measure is calculated in step 6 using the formula:

$$IFSM_t(O_i) = 1 - \frac{d_t^+(O_i)}{d_0}, \tag{8}$$

where:
d_0 – is the distance measure between intuitionistic fuzzy pattern and anti-pattern, i.e $d_0 = d(I_{IFI}, I_{IFAI})$.

Let us observe that by formula (3) we have $d_0 = d(I_{IFI}, I_{IFAI}) = 1$. Therefore

$$IFSM_t(O_i) = 1 - d_t^+(O_i), \tag{9}$$

where:
$i = 1,2, ..., m$,
$t = 1,2, ..., k$.

In step 7 objects O_i (i = 1, 2, … , m) are rank ordering concerning the value of the coefficient $IFSM_t(O_i)$, in the period time t (t = 1, 2, … , k). The highest value of $IFSM_t(O_i)$ then the highest position of the object O_i (i = 1, 2, … , m) in the period time t.

Finally, in step 8 objects are grouped into five classes, taking into consideration a similar level of development of the studied phenomenon in the period *t* according to the rule:

- IFSM ϵ (0.8; 1] – very high level (Class 1),
- IFSM ϵ (0.6; 0.8] – high level (Class 2),
- IFSM ϵ (0.4; 0.6] – middle level (Class 3),
- IFSM ϵ (0.2; 0.4] – week level (Class 4),
- IFSM ϵ [0.0; 0.2] – very weak level (Class 5).

IFSM measures allow for the comparison of objects in an analysis of complex phenomena across periods using the common ideal pattern and anti-ideal pattern in the calculation. This allows us both to compare the positions of objects in the rankings and compare the values of the measures themselves (calculate the increments of values, descriptive characteristics, etc.). Also, there is no necessity to recalculate all results with the appearance of observations for the next unit of time.

It should be noted here that when measuring the subjective quality of life, the variables most frequently applied have a stimulating effect on the level of this phenomenon. In the case of the subjective quality of life measurement based on destimulants, the degrees of membership and non-membership in the intuitionistic fuzzy sets should be determined in the opposite way to the presented one.

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Results of the research

The application of the proposed approach made it possible to estimate the level of subjective quality of life for each city in the 5 periods covered by the analysis. The values of the IFSM measure determined the assignment of cities to one of the 5 classes in each of the analysed periods. Descriptive statistics for classes estimated based on IFSM values are listed in Table 1.

Table 1. Descriptive statistics for classes estimated from IFSM values

Class	IFSM					
	Descriptive statistics	2006	2009	2012	2015	2019
1	N (%)	1 (1.3)	1 (1.3)	11 (13.9)	13 (16,7)	10 (12,2)
	min	0.807	0.857	0.800	0.801	0.803
	max	0.807	0.857	0.884	0.892	0.884
	mean	-	-	0.883	0.836	0.833
	sd	-	-	0.026	0.027	0.022
2	N (%)	26 (34.7)	37 (49.3)	46 (58.2)	50 (64.1)	54 (65.9)
	min	0.604	0.602	0.621	0.603	0,603
	max	0.748	0.799	0.788	0.799	0.799
	mean	0.675	0.696	0.716	0.712	0.714
	sd	0.045	0.061	0.052	0.062	0.063
3	N (%)	41 (54.7)	32 (42.7)	19 (24.1)	14 (17.9)	17 (20.7)
	min	0.403	0.404	0.424	0.401	0.404
	max	0.598	0.600	0.596	0.599	0.592
	mean	0.516	0.531	0.546	0.509	0.507
	sd	0.056	0.55	0.051	0.062	0.063
4	N (%)	7 (9.3)	5 (6.7)	3 (3.8)	1 (1.3)	1 (1.2)
	min	0.241	0.314	0.349	0.330	0.349
	max	0.398	0.373	0.374	0.330	0.349
	mean	0.323	0.341	0.358	-	-
	sd	0.052	0.019	0.011	-	-

The analysed period is characterized by an increase in both min. and max. values of the IFSM. The maximum value of IFSM in 2006 was closer to the lower limit of the first class grouping the cities which presented the highest subjective quality of life and amounted to 0.807. In 2019, the maximum value of IFSM increased to the level of 0.884, showing a shift towards the middle of the range, marking the limits of the first class. Positive changes can also be observed in relation to the minimum value of the IFSM measure, which went up from 0.241 in 2006 to 0.349 in 2019. The biggest difference between the cities featuring the highest and the lowest levels of SQoL measured by the IFSM was recorded in 2006. The difference between max. and min. values of the IFSM in the remaining years ranged from 0.543 to 0.451. Therefore, the distance between cities showing the highest and the lowest SQoL has been decreasing. The values of IFSM for the European cities ranged between 0.323 and 0.883 throughout the entire analysed period.

Classification of cities into classes of the level of subjective quality of life made it possible to observe cities migrating between classes, as well as those whose SQL level did not change during the period covered by the analysis. The membership of cities to classes is presented in Table 2.

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Table 2. Cities membership to classes estimated on the basis of IFSM values*

Cities	Years				
	2006	2009	2012	2015	2019
Aalborg	2	2	1	1	1
Amsterdam	3	2	2	2	2
Ankara	3	3	2	2	2
Antalya	3	2	2	2	2
Antwerpen	3	2	2	1	2
Athina	4	4	4	3	3
Barcelona	3	3	3	2	2
Belfast	2	2	1	1	2
Białystok	2	2	2	2	2
Berlin	3	3	2	2	2
Bologna	3	3	2	2	2
Bordeaux	2	2	2	1	2
Braga	3	2	2	2	2
Bratislava	3	3	3	3	3
Brussel	3	3	2	2	2
Bucureşti	4	4	3	3	3
Budapest	4	3	3	3	3
Burgas	3	3	3	2	2
Cardiff	2	2	1	1	1
Cluj-Napoca	3	3	2	2	2
Diyarbakır	3	3	3	2	3
Dortmund	2	2	2	2	2
Dublin	3	2	2	2	2
Essen	2	2	2	2	2
Gdańsk	3	3	2	2	2
Glasgow	2	2	2	2	2
Graz	2	2	2	2	2
Groningen	1	1	1	1	1
Hamburg	2	2	2	2	2
Helsinki	2	2	1	1	1
Irakleio	3	3	3	3	3
İstanbul	3	3	3	3	3
København	3	2	2	2	2
Kosice	3	2	3	2	2
Kraków	3	3	3	3	2
Lefkosia	4	3	2	2	2
Leipzig	2	2	2	2	2
Liège	3	3	2	2	2

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Cities	Years				
	2006	2009	2012	2015	2019
Lille	2	2	2	2	2
Lisboa	3	3	3	3	2
Ljubljana	3	2	2	2	2
London	3	3	2	2	2
Luxembourg	2	2	1	1	1
Madrid	3	3	3	3	3
Málaga	3	3	3	2	2
Malmö	2	2	2	2	2
Manchester	3	2	2	2	2
Marseille	3	3	3	3	3
Miskolc	3	3	3	2	2
München	2	2	1	1	1
Napoli	4	4	4	3	3
Ostrava	2	3	3	2	2
Oulu	2	2	2	2	2
Oviedo	2	2	2	2	2
Palermo	4	4	4	4	4
Paris	3	3	2	2	2
Piatra Neamț	2	2	2	2	2
Praha	3	3	2	2	2
Rennes	2	2	1	1	1
Riga	3	3	2	2	2
Roma	3	3	3	3	3
Rotterdam	3	2	2	2	2
Stockholm	2	2	2	2	2
Strasbourg	2	2	2	2	2
Sofia	4	4	3	3	3
Tallinn	3	2	2	2	2
Torino	3	3	2	2	2
Valletta	3	3	3	3	3
Verona	3	3	2	2	2
Vilnius	3	3	2	2	2
Warszawa	3	3	2	2	2
Wien	2	2	1	1	1
Zagreb	3	2	2	2	2
Beograd	0	0	0	0	3
Frankfurt an der Oder	2	0	0	0	0
Geneva	0	0	2	2	1
Newcastle	2	2	1	1	0

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Cities	Years				
	2006	2009	2012	2015	2019
Oslo	0	0	2	2	2
Podgorica	0	0	0	0	3
Reykjavik	0	0	2	2	2
Rostock	0	2	2	2	2
Skopje	0	0	0	0	3
Tirana	0	0	0	0	3
Zurich	0	0	1	1	1

* Numbers are class identifiers. A value of 0 means that the city did not participate in the survey edition.

Out of all the urban centres covered by the study, only 25 cities did not change their class over the entire period of the study. This means that these cities neither moved up to a higher class nor lost their position by dropping to the group of cities characterised by a lower level of SQoL. The following cities were included in this group:

- Groningen, a city in the north of the Netherlands, remained in the first class from 2006 till 2019 and represented this class alone in 2006 and 2009,
- Białystok in Poland, Dortmund, Hamburg, Leipzig, Rostock, and Essen in Germany, Glasgow in Scotland, Graz in Austria, Lille and Strasbourg in France, Stockholm, and Malmo in Sweden, Oulu in Finland, Oviedo in Spain, Reykjavik in Iceland, which from the first to the last round of research remained in the most variable second class that had the highest number of "promotions",
- Bratislava in Slovakia, Iraklion in Greece, Istanbul in Turkey, Madrid in Spain, Rome in Italy, Marseille in France, and Valetta in Malta, all included in the third class. This class is characterised by a large number of cities migrating to the class, presenting a higher level of the measured value, i.e. a higher level of SQoL (second class). In the last edition of the study, as compared to 2006, the size of this class shrank by more than half,
- Palermo in Italy, which is the only city in the ranking did not obtain the result allowing it to leave the fourth class in any of the five survey editions.

Starting from 2006, a positive trend of changes in the SQoL experienced by the residents of European cities has been recorded. It is manifested in declining absolute numbers, and the decreasing percentage frequencies of the European cities included in the third and fourth classes, as well as the growing size of the first and second classes. In 2019, more than ¾ of the European capitals and large cities were qualified in the classes with the highest subjective quality of life. As the latest available data concern 2019, the weakening or reversal of this positive trend may be expected as a result of, i.a., such phenomena and problems as the global coronavirus pandemic, climate change, the war in Ukraine, and their socio-economic consequences. The residents of European cities are and will be affected by them as well.

In the period between 2006 and 2019, exactly 10 cities, mainly from Western Europe and Northern Europe (Scandinavia) (Zurich and Geneva in Switzerland, Vienna in Austria, Rennes in France, Munich in Germany), were included in the first class and maintained their position, Luxembourg – the capital of the Grand Duchy of Luxembourg, Groningen in the Netherlands, Cardiff in Wales, Helsinki in Finland and Aalborg in Denmark). Precisely three cities in the ranking (Belfast in Ireland, Antwerp in Belgium, and Bordeaux in France), due to high IFSM results in 2015, were placed in the first class; however, they did not maintain their place in this class in the last edition of the survey.

In the analysed period, the greatest changes were recorded in relation to the second class, the size of which increased from 26 cities in 2006 to 54 cities in 2019. This means a significant change in the ranking of as many as 28 urban centres. The vast majority of these cities left the third class and were moved to the second class, i.e. found themselves among the cities whose residents are more satisfied with their QoL.

A positive trend of changes can also be observed regarding the fourth class, which included seven cities in 2006 and only one city in the last period of the study. The fourth class consisted of Nicosia –

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the capital of Cyprus, two Italian cities – Naples and Palermo; Bucharest in Romania; Budapest in Hungary; Athens in Greece; and Sofia in Bulgaria. Therefore, the fourth class covered primarily the cities located in the southeastern and central parts of Europe.

In the analysed period, the mean values of the IFSM measure for the first and third classes went up in the period from 2006 to 2012 and then went down in the last two editions of the study. On the other hand, in the second and fourth classes, in the years 2006-2012, an increase in the average value of the IFSM measure was recorded, followed by a decline in its value in 2015 and an increase again in the last edition of the survey.

Among Polish cities, Białystok, Gdańsk, Kraków, and Warszawa participated in the research on the subjective quality of life in European cities. The highest result of the ISFM measure was achieved by Białystok and the lowest by Kraków. Only Białystok was qualified in the second class in all editions of the study. The remaining cities moved up from the third class to the second class, which means that, according to the population of these urban centres, the resident's quality of life keeps improving over time. Gdańsk and Warszawa changed their class in 2012, whereas Kraków did not until 2019.

Discussion, Conclusions and Future Research

The article presents, for the first time, the results of measuring and assessing changes in the SQoL experienced by the residents of selected European cities over time, using the synthetic measure based on the IFSM. The results of periodically conducted research covering the residents' quality of life provide city authorities with important information about the development directions of their units and these areas of functioning that require improvement.

Our study has provided responses to the two research questions outlined in the Introduction. The analysis of the results of all research waves addressing the quality of life in European cities conducted by the European Commission using the IFSM showed that the level of SQoL experienced by the residents of these cities is systematically increasing. However, we still observe large differences in the level of this phenomenon among the cities covered in the study.

Research on the subjective quality of life in European cities conducted by the European Commission since 2004 confirms that many dimensions related to people's quality of life depend on their place of residence. This applies to issues related to housing costs, air purity, access to culture and education, and safety. What counts is the amenities and opportunities offered by a given city and its authorities to its residents. The results of research on the subjective quality of life of residents of European cities can be used by decision-makers at various levels of management as a starting point for defining the goals of public policies, including local sustainable development strategies. The development of European cities is supported, among others, by the cohesion policy, which in 2014-2020 allowed for the implementation of several urban investments, including in the field of social inclusion and revitalisation of urban districts, sustainable transport, circular economy, public services and digital solutions. In the period 2021-2027, the urban dimension of cohesion policy has been further strengthened. The most important goals of cohesion policy, i.e. smarter, greener, more connected, and more social Europe and a Europe closer to citizens – will mobilise substantial investment in urban areas. In addition, 8% of the resources of the European Regional Development Fund in each Member State will be allocated to the implementation of projects and investments that will be identified by the cities themselves based on their sustainable development strategies (Castelli et al., 2022). Strategic planning, which results in various types of public policy documents, including local, sustainable development strategies, allows us to accurately determine the most important directions and goals of city development and plan activities, projects, and investments aimed at improving the quality of life of city residents. To effectively manage the city and make accurate decisions, both decision-makers and the local community must have reliable information about individual areas and factors affecting the perceived quality of life in the city. Information about the place in the ranking or which group of cities a given entity belongs to can be a source of inspiration and drawing from good practices of those cities that are rated higher by their inhabitants. To sum up, it is worth emphasising that drawing on the results of research on the quality of life of residents of European cities allows, on the one hand, to better understand their needs and, on the other hand, to better plan future directions of city development so that residents can live better.

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The article shows that the IFSM measure may turn out to be a useful tool for monitoring the level of subjective quality of life in cities. The application of IFSM required only a simple transformation of aggregate data into the form of intuitionistic fuzzy sets. The presentation of the measurement results in the form of such sets additionally allowed taking into account the uncertainty in the responses provided by the residents of European cities expressed as the absence of/refusal to provide an answer. Additionally, adopting the pattern object taking the form of the max intuitive fuzzy number (1,0) and the method of measuring the measure normalisation allowed comparing the quality of life in cities over time. Determining the coordinates of the ideal and anti-ideal fuzzy objects based on the maximum and minimum intuitionistic values, respectively, has another additional advantage. This approach enables the inclusion of additional objects in the analysis in subsequent waves of the study without affecting the coordinate values of the reference objects. Such a property is not guaranteed by the approach in which the maximum and minimum intuitionistic values observed in the test sample are used to determine the coordinates of reference objects. Moreover, it usually results in higher values of synthetic measures, including IFSM measures. Another special case is connected with the approach proposed by the authors. It concerns the situation when, for two compared objects, the degree of membership will be the same, and the degrees of non-membership and uncertainty will have exactly the opposite values. Then, the values of the IFSM measure for such two objects will be the same, even though the object with the highest position should be the one with the lowest degree of non-membership. However, this is an exceptionally rare case and has not been observed by the authors in the studies conducted so far on the subjective quality of life and other complex socio-economic phenomena. Certainly, this is an open problem and can be an inspiration for further research in the area of measuring the subjective quality of life using synthetic measures and intuitionistic fuzzy sets. A potential solution is to drop the uncertainty parameter and measure the distance between objects using two parameters: membership and non-membership. This is especially true when the measurement scales used do not provide for neutral categories, so the degree of uncertainty can be estimated, in principle, only on the basis of missing data and/or refusals to answer. It may then have such a low value that its inclusion in the measurement of the distance between objects will not have a significant impact on the values of the IFSM measure.

The applied measure can also be used to estimate the subjective quality of lifebased on primary data. In such a case, an earlier transformation of the primary data to the form of intuitionistic fuzzy sets is required, which was thoroughly discussed in the studies by Jefmański (2020), Jefmański et al. (2021), Roszkowska et al. (2021).

A certain imperfection of the IFSM measure in measuring the SQoL, already highlighted in other studies, consists of disregarding, at the transformation stage, the differentiation measurement results of "positive" and "negative" categories, which make up the measurement scales. No simulation studies have been carried out so far to show that this type of transformation may have a significant impact on the results of measuring the subjective quality of life in European cities using the IFSM measure.

A controversial issue in the applied methodological approach may be the subjective way of adopting five classes at the level of SQoL, which were given linguistic values such as "high level of subjective quality of life", etc. This approach facilitated the interpretation of the obtained results, primarily in the context of observing the "movement" of cities between individual classes. However, the source literature also offers other methods for determining the boundaries of class intervals (see Jenks, 1967; Strahl, 2006; Wysocki, 2010; Roszkowska & Filipowicz-Chomko, 2021).

Future research in the area of measuring the SQoL with the use of IFSM could, according to the Authors, focus on at least two aspects related to this phenomenon measurement. The first of them refers to comparing the proposed approach against other synthetic measures, which may be based on the intuitionistic fuzzy sets. The second aspect, undoubtedly constituting a serious research challenge, would be including the objective indicators of the quality of life of city residents in the analysis. It would allow for the development of a holistic "picture" of the quality of life experienced by the residents of European cities.

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The contribution of the authors

Conceptualization, M.K.-J., E.R. and B.J.; literature review, M.K.-J., E.R. and B.J.; methodology, M.K.-J., E.R. and B.J.; formal analysis, M.K.-J., E.R. and B.J.; writing, M.K.-J., E.R. and B.J.; conclusions and discussion, M.K.-J., E.R. and B.J.

The authors have read and agreed to the published version of the manuscript.

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INTUICJONISTYCZNA ROZMYTA MIARA SYNTETYCZNA W DYNAMICZNEJ ANALIZIE SUBIEKTYWNEJ JAKOŚCI ŻYCIA MIESZKAŃCÓW MIAST EUROPEJSKICH

STRESZCZENIE: Celem artykułu jest pomiar i ocena zmian subiektywnej jakości życia (SQoL) mieszkańców wybranych miast europejskich. Do pomiaru SQoL zastosowano Intuicyjną Rozmytą Miarę Syntetyczną (IFSM). Miara pozwala uwzględnić element niepewności wyrażający się w braku lub odmowie udzielenia odpowiedzi. W analizie wykorzystano wyniki badań SQoL przeprowadzonych przez Komisję Europejską w wybranych miastach europejskich. Zaproponowany w artykule sposób konstrukcji obiektu wzorcowego pozwolił na ocenę zmiany poziomu SQoL mieszkańców miast europejskich w czasie. Analiza wykazała, że subiektywna jakość życia mieszkańców miast europejskich systematycznie wzrastała w latach 2006-2019. Nadal jednak obserwujemy duże różnice w poziomie tego zjawiska pomiędzy miastami. Wyniki badań można wykorzystać do formułowania założeń lub modyfikacji polityk miejskich w miastach UE w celu poprawy jakości życia obywateli.

SŁOWA KLUCZOWE: pomiar zjawisk złożonych, subiektywna jakość życia, miasta europejskie, intuicjonistyczne zbiory rozmyte, zagregowane dane porządkowe

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