ENVIRONMENTAL MONITORING IN ITALIAN CITIES A MULTIDIMENSIONAL ANALYSIS WITH COMPOSITE INDICES

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1. Introduction

Environment quality and social well-being are closely interconnected on a collective and individual level. It is, in fact, a relationship that invests values of primary importance, such as those relating to human health and safety, heritage and resources to be passed on to future generations. Therefore, statistical information, for an in-depth knowledge of environmental issues, it is relevant for everyone. The effectiveness of any action in the environmental field implies an awareness of citizens and the choice of appropriate behaviours (Lecardane and Arcarese, 2009; Lecardane, 2013).

Complex and multidimensional nature of environmental phenomena requires the identification and measurement of indicators for the implementation of more effective and incisive information programs. Due to the number of indicators that represent the different dimensions of the state of the urban environment to be measured, it is also necessary to find a synthesis process to improve comparison and analysis of the observed phenomena. In fact, the synthesis has the advantage of performing simpler and faster analyzes especially in comparative terms and in addition of summarize heterogeneous and multidimensional phenomena.

In this paper, we will proceed to experimental comparison of some main weighting approaches for the composite indicator-construction methods referring to the data on urban environmental quality on issues such as water, air, energy, noise, waste, mobility and urban green for 110 provincial capitals (Istat, 2020).

The aim of this work is not to establish which approach is preferable to another but to analyze the robustness and sensitivity of the results from the different composite methods used. Analysis of the state of the urban environment therefore provides useful measuring tools with the appeal to an awareness of the need for a change of course towards planning a more urban sustainability.

The paper is structured as follows: description and application of the main composite methods used; comparison of the results obtained through cograduation matrices of the rankings, correlation matrices and dispersion matrices of the values obtained with the different methods; summary conclusions.

2. Methodology

The multidimensionality of the environmental phenomenon and its measurability through a system of elementary indicators allows the targeted construction of a composite technique which is able of acquiring the multiple aspects (OECD, 2008). Therefore, there is a need to experiment composite methods of elementary data to improve the measurement and communicability of the results.

Table 1 – *Environmental indicators selected, survey Istat "Environmental data of cities". 2020.*

Environmental Issues	Environmental indicators and polarity (+/-)
Water	a1(-). Household water bill per capita *(liters per day).* a2(-). Household water bill total per capita *(liters per day).* a3(-). Water network losses *(%).*
Air	b4(+). Fixed air quality monitoring stations *(per 100,000 inhabitants).* b5(-). Composite indicator of atmospheric pollution *(average values exceeding threshold limit concentration of PM10, PM2,5, NO2 and O3).*
Energy	c6(+). Extension of the thermal solar panels installed on the municipal buildings *(m^2 per 1,000 inhabitants).* c7(+). Total power of photovoltaic solar panels owned by the municipal administration *(kW per 1,000 inhabitants).* c8(+). Charging columns for electric cars by type *(per 10 km^2).*
Mobility	d9(-). Motorization rates for cars by municipality *(vehicles in circulation per 1,000 inhabitants).* d10(+).Electric vehicle circulating by municipality *(per 1.000 vehicle circulating).* d11(-).Pollution potential index of vehicle circulating by municipality *(high/medium pollution potential vehicle per 100 medium/low pollution potential vehicle).*
Municipal waste	e12(+).Door-to-door municipal waste collection for households *(%).* e13(-).Municipal road waste collection for households *(%).*
Noise	f14(+).Complaint presented by citizens on noise pollution by municipality *(per 100,000 inhabitants).*
Urban green	g15(+). Tree cadastre by municipality *(Tree per 100 inhabitants).* g16(+). Density of urban green in the municipalities *(% on the municipal area).* g17(+). Urban green in the municipalities *(m^2 per inhabitants).*

Source: Istat

Regarding the latest data on the urban environmental (Istat 2020), a set of elementary indicators on environmental themes (water, air, energy, noise, waste, mobility, and urban green) were selected (Tab. 1).

These indicators have a high variability and little correlation with each other, characteristics suitable to achieve the aims. It's the basis for the aggregation process through the construction and comparability of some main composite methods.

Elementary indicators have been normalized and standardized to obtain data purified from units of measurement and comparison process.

Standardized deviation in the composite index allows the construction of a robust measure and not very sensitive to remove a single elementary index (Mazziotta and Pareto, 2013).

In addition, *polarity* (positive or negative) of the relationship between indicator and phenomenon was specified. Finally, standardized indicators were aggregated. Following, steps to calculate composite index by comparing the following methods.

Given the matrix $X=\{x_{ij}\}$ with n rows (units) and m columns (indicators), composite methods have the following mathematical properties:

Mean Z-scores *(MZ)*

$Mz_i = \frac{\Sigma_{j=1}^{m} z_i j}{m}$ $Z=\{z_{ij}\}$ transformed matrix for unit *i* and indicator *j*

with $z_{ij} = \pm \frac{(x_{ij}-M_{xj})}{s_{x_j}}$ if the indicator *j* has positive or negative polarity.

M_{xj} e S_{xj} arithmetic mean and deviation standard of indicator j.

The *MZ* allows transformation of indicators j into standardized deviations and aggregation with the arithmetic mean.

Mean R-Indices *(MR)*

$Mz_i = \frac{\Sigma_{j=1}^{m} r_i j}{m}$ $R=\{r_{ij}\}$ transformed matrix for unit i and indicator j

with $r_{ij} = \begin{cases} \frac{(x_{ij}-Min_{xj})}{(Max_{xj}-Min_{xj})} \\ \frac{(Max_{xj}-x_{ij})}{(Max_{xj}-Min_{xj})} \end{cases}$ Min_{xj} e Max_{xj} indicator j

The *MR* allows standardization with min-max method of the j indicators and aggregation with the arithmetic mean.

Adjusted MPI *(AMPI)*

$$MPI_{ci}^{\pm} = M_{ri} \pm S_{r_i} cv_i$$

$$\text{with } r_{ij} = \begin{cases} \frac{(x_{ij}-Min_{xj})}{(Max_{xj}-Min_{xj})} 60 + 70 & \text{if the indicator } j \text{ has positive polarity} \\ \frac{(Max_{xj}-x_{ij})}{(Max_{xj}-Min_{xj})} 60 + 70 & \text{if the indicator } j \text{ has negative polarity} \end{cases}$$

$$M_{r_i} = \frac{\Sigma_{j=1}^{m} r_{ij}}{m} \quad S_{r_i} = \sqrt{\frac{\Sigma_{j=1}^{m} (r_{ij}-M_{ri})^2}{m}} \quad cv_i = \frac{S_{ri}}{M_{r_i}}$$

The *AMPI* is a non-compensatory (or partially compensatory) composite index and allows min-max standardization of the indicators j and aggregation with the arithmetic mean penalized by the "horizontal" variability of the indicators themselves. Normalized values are approximately in the range (70; 130), where 100 is the reference value[1].

3. Results

From the exploratory data analysis, indicators show a pronounced variability (many CV values are close to 1) and little correlated with each other (-0.55 and 0.47), characteristics suitable to achieve the aims (Tabb. 2 and 3).

To identify a composite index that represents multidimensionality of the urban environment, some main methods were compared using the transformation of the indicators to obtain data purified from units of measurement and their variability (Tab. 4). Figure 1 shows cartograms of the four approaches used in 110 provincial capitals. Result of the analysis is almost uniform for all methods, with the subdivision of decreasing territorial trialism Northern, Center and Southern Italy.

However, some exceptions with good environmental performance occur in some central and southern areas. In fact, appreciable values are recorded in Sardegna (Nuoro and Oristano), Marche (L'Aquila), Puglia (Brindisi and Lecce), Basilicata (Matera) and Sicily (Messina).

[1] In the Bienaymé-Cebycev theorem, terms of the distribution within the interval (70; 130) constitute at least 89 percent of the total terms of the distribution.

Table 2 – *Average and variability measures of environmental indicators. Provincial capitals. 2020.*

	a1	a2	a3	b4	b5	c6	c7	c8	d9	d10	d11	e12	e13	f14	g15	g16	g17
Arithmetic mean	206,9	150,8	37,3	2,7	19,4	4,4	259,3	2,4	668,1	1,5	129,0	72,0	47,0	12,2	14,8	14,0	42,7
Standard deviation	37,5	27,8	15,2	2,0	19,8	18,4	261,7	5,7	69,9	0,8	18,8	34,4	40,4	20,5	14,3	14,7	61,0
Coefficient of variation	0,2	0,2	0,4	0,7	1,0	4,2	1,0	2,4	0,1	0,5	0,1	0,5	0,9	1,7	1,0	1,1	1,4

Source: Istat data processed

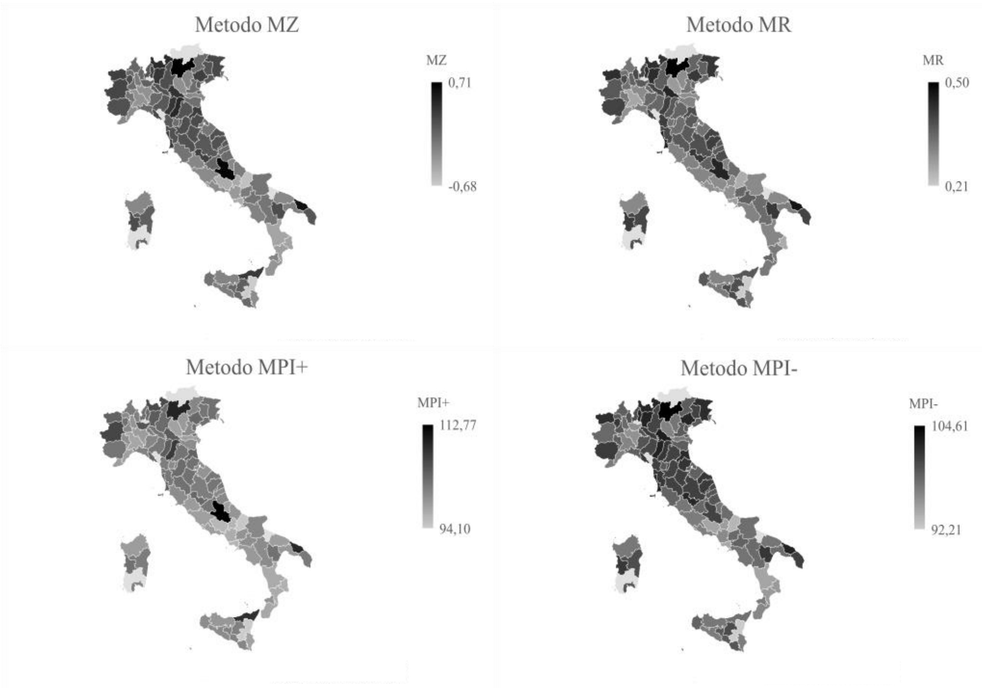
From the ranking of the four composite indicators, it is possible to observe the positioning of the Italian municipalities based on the state of environment which decreases towards the higher ranks. Trento has the best urban environmental performance while Catania is the city with the highest negative impact.

Table 3 – *Correlation matrix of environmental indicators. Provincial capitals. 2020*.

	a1	a2	a3	b4	b5	c6	c7	c8	d9	d10	d11	e12	e13	f14	g15	g16	g17
a1	1	0,38	-0,23	-0,05	0,38	-0,01	-0,27	0,34	-0,19	0,33	-0,12	0,21	-0,10	0,05	-0,01	0,09	0,05
a2		1,00	-0,16	-0,10	0,33	-0,06	-0,32	0,39	-0,16	0,23	-0,02	0,24	-0,18	0,08	-0,05	0,06	0,00
a3			1,00	0,09	-0,42	0,07	-0,02	-0,20	0,24	-0,30	0,31	-0,20	-0,01	0,07	-0,35	0,02	-0,03
b4				1,00	-0,09	0,09	0,15	-0,16	0,14	-0,05	0,00	0,26	-0,09	-0,12	-0,05	-0,10	0,15
b5					1,00	-0,12	-0,14	0,35	-0,33	0,47	-0,51	0,13	0,10	0,04	0,38	0,07	0,01
c6						1,00	0,05	-0,05	0,20	-0,03	0,03	0,03	-0,02	-0,04	-0,09	0,19	-0,01
c7							1,00	-0,24	0,24	-0,20	0,05	0,02	-0,06	-0,18	-0,02	-0,17	-0,05
c8								1,00	-0,33	0,30	-0,15	0,03	-0,12	0,08	0,10	-0,03	-0,07
d9									1,00	-0,27	0,27	0,20	-0,31	-0,10	-0,10	-0,24	0,05
d10										1,00	-0,55	0,13	0,02	0,09	0,28	0,08	0,30
d11											1,00	-0,03	-0,21	-0,07	-0,37	-0,02	-0,12
e12												1,00	-0,42	-0,10	0,01	-0,05	0,14
e13													1,00	0,19	0,18	0,08	0,04
f14														1,00	0,07	0,32	0,02
g15															1,00	-0,02	0,08
g16																1,00	-0,11
g17																	1,00

Source: Istat data processed.

Figure 1 – *Map of composite indicators. Provincial capital. 2020 (*).*



Source: Istat data processed.
(*) Chromatic provincial areas refer to their provincial capitals.

In ranking of the top five cities with low environmental impact, Bolzano, Sondrio, Mantova and Bergamo are also distinguished, cities of small and medium population size in Northern Italy.

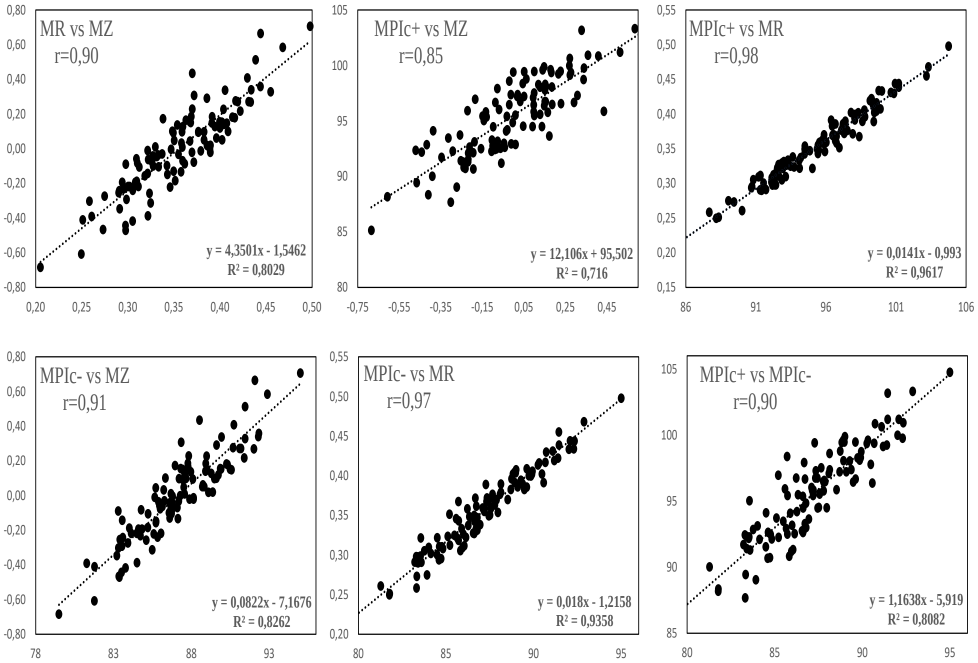
At the bottom of the ranking with a greater environmental pressure Isernia, Napoli, Frosinone and Campobasso in Southern Italy (Tab. 5).

Table 4 – *Syntetics methods matrix - Provincial capital. 2020.*

Provincial Capital	MZ	MR	MPIc+	MPIc-	Provincial Capital	MZ	MR	MPIc+	MPIc-	Provincial Capital	MZ	MR	MPIc+	MPIc-
Agrigento	-0,14	0,32	95,03	83,56	Foggia	-0,09	0,30	92,43	83,30	Pistoia	-0,04	0,33	94,09	85,89
Alessandria	-0,30	0,26	87,68	83,32	Forli	0,19	0,37	96,50	87,77	Pordenone	0,13	0,36	95,61	87,57
Ancona	0,15	0,40	97,79	90,48	Frosinone	-0,47	0,30	92,35	83,38	Potenza	-0,10	0,34	94,47	86,62
Andria	0,14	0,40	99,61	88,91	Genova	-0,01	0,32	92,93	85,64	Prato	0,10	0,36	95,84	87,21
Aosta	0,27	0,43	100,63	91,09	Gorizia	-0,05	0,33	93,00	86,79	Ragusa	-0,01	0,38	97,37	88,13
Arezzo	0,16	0,37	96,75	87,32	Grosseto	-0,08	0,31	92,48	84,77	Ravenna	0,29	0,39	96,68	89,61
Ascoli Piceno	-0,02	0,37	96,47	87,88	Imperia	-0,22	0,35	95,93	85,58	Reggio di Calabria	-0,31	0,32	93,47	85,48
Asti	-0,08	0,33	93,18	85,99	Isernia	-0,44	0,30	92,19	83,51	Reggio nell'Emilia	0,34	0,41	98,74	89,94
Avellino	-0,09	0,36	96,67	86,73	La Spezia	0,23	0,40	99,47	88,97	Rieti	0,01	0,36	95,53	87,56
Bari	-0,22	0,30	91,55	84,49	L'Aquila	0,18	0,44	101,20	92,08	Rimini	-0,06	0,32	92,53	86,14
Barletta	0,03	0,36	96,76	86,22	Latina	-0,24	0,29	91,30	83,59	Roma	-0,24	0,31	90,82	85,83
Belluno	-0,03	0,36	95,43	87,19	Lecce	0,12	0,40	98,28	89,73	Rovigo	-0,23	0,30	90,72	84,72
Benevento	-0,13	0,35	95,37	86,61	Lecco	0,27	0,43	99,99	92,02	Salerno	-0,19	0,31	93,13	84,02
Bergamo	0,34	0,43	99,77	92,29	Livorno	0,33	0,46	103,17	91,44	Sassari	-0,22	0,30	92,11	84,13
Biella	0,19	0,39	98,06	88,92	Lodi	0,05	0,35	94,53	87,51	Savona	-0,25	0,29	91,41	83,41
Bologna	0,14	0,35	94,49	87,96	Lucca	0,10	0,41	99,47	89,61	Siena	0,15	0,37	96,75	87,43
Bolzano-Bozen	0,51	0,44	101,20	91,45	Macerata	0,15	0,41	99,88	89,00	Siracusa	-0,26	0,32	93,73	85,10
Brescia	0,17	0,36	95,77	87,78	Mantova	0,36	0,44	100,93	92,33	Sondrio	0,41	0,43	100,85	90,72
Brindisi	0,18	0,47	103,32	92,87	Massa	-0,10	0,33	92,75	86,56	Taranto	-0,16	0,32	92,50	85,72
Cagliari	0,02	0,39	97,22	89,09	Matera	0,18	0,42	99,62	90,31	Teramo	-0,02	0,39	98,60	88,13
Caltanissetta	0,00	0,39	99,41	87,28	Messina	0,11	0,37	97,30	87,34	Terni	0,27	0,42	99,14	91,18
Campobasso	-0,61	0,25	88,17	81,77	Milano	0,04	0,37	98,38	85,71	Torino	0,23	0,37	96,57	87,82
Carbonia	0,05	0,40	99,45	88,82	Modena	0,44	0,37	95,87	88,52	Trani	-0,39	0,26	90,02	81,27
Caserta	-0,35	0,29	91,72	83,21	Monza	-0,07	0,36	96,03	87,10	Trapani	-0,08	0,37	97,92	86,67
Catania	-0,68	0,21	85,14	79,49	Napoli	-0,47	0,27	89,44	83,33	Trento	0,71	0,50	104,76	95,00
Catanzaro	-0,39	0,32	94,12	84,50	Novara	-0,13	0,36	95,81	87,14	Treviso	0,28	0,42	99,38	90,67
Cesena	0,10	0,38	97,52	87,65	Nuoro	0,06	0,40	98,79	88,74	Trieste	-0,11	0,31	92,26	85,22
Chieti	-0,15	0,34	95,43	85,73	Oristano	0,18	0,41	99,36	90,25	Udine	0,22	0,42	99,25	91,39
Como	0,13	0,39	98,05	89,28	Padova	-0,04	0,33	92,62	86,61	Varese	0,02	0,39	97,38	89,37
Cosenza	-0,42	0,31	92,86	83,77	Palermo	-0,19	0,31	92,13	84,83	Venezia	0,09	0,35	94,49	87,45
Cremona	0,16	0,40	98,11	89,85	Parma	0,10	0,35	95,49	86,33	Verbania	0,01	0,33	92,89	86,69
Crotone	-0,41	0,25	88,35	81,78	Pavia	-0,29	0,30	92,29	83,54	Vercelli	-0,03	0,34	94,20	86,27
Cuneo	0,15	0,40	98,31	89,90	Perugia	0,10	0,38	96,44	89,47	Verona	-0,27	0,27	89,05	83,92
Enna	0,05	0,38	97,22	88,70	Pesaro	-0,10	0,33	93,29	86,72	Vibo Valentia	-0,18	0,35	96,96	85,20
Fermo	0,10	0,38	97,10	88,09	Pescara	-0,22	0,31	91,32	86,04	Vicenza	-0,19	0,29	90,67	84,60
Ferrara	-0,06	0,31	91,19	85,95	Piacenza	0,00	0,35	94,85	86,79	Viterbo	-0,21	0,31	92,65	84,62
Firenze	0,17	0,34	93,64	86,95	Pisa	0,15	0,39	96,38	90,57					

Source: Istat data processed.

Figure 2 – *Linear relationship compared between composite methods used.*



Source:Istat data processed

Table 5 - *Ranking of the five best and worst environmental performances - Provincial capital. 2020.*

Provincial capital	MZ		MR		MPIc+		MPIc-	
	N.	Rank	N.	Rank	N.	Rank	N.	Rank
Better environmental performance								
Trento	0,71	1	0,50	1	104,76	1	95,00	1
Bolzano-Bozen	0,51	2	0,44	6	101,20	5	91,45	7
Sondrio	0,41	3	0,43	10	100,85	7	90,72	12
Mantova	0,36	4	0,44	5	100,93	6	92,33	3
Bergamo	0,34	5	0,43	7	99,77	11	92,29	4
Worse environmental performance								
Isernia	-0,44	106	0,30	98	92,19	92	83,51	100
Napoli	-0,47	107	0,27	105	89,44	105	83,33	103
Frosinone	-0,47	108	0,30	97	92,35	89	83,38	102
Campobasso	-0,61	109	0,25	109	88,17	108	81,77	108
Catania	-0,68	110	0,21	110	85,14	110	79,49	110

Source: Istat data processed.

Table 6- *Sum of ranking differences between composite methods used.*

Measures	Ranking differences					
	MZ-MR	MZ-MPIc+	MZ-MPIc-	MR-MPIc+	MR-MPIc-	MPIc+-MPIc-
Absolute average rank diff.	11,60	14,35	10,44	5,19	6,36	11,29
Cograduation index ρ	0,89	0,83	0,91	0,98	0,96	0,89

Source: Istat data processed.

Table 6 shows rank differences compared by means of the absolute difference and Spearman's rank correlation coefficient.

Sensitivity analysis shows similar results in the comparison between MR-$MPIc_+$ method and the MR-$MPIc_-$ method with absolute average rank differences 5.19 and 6.36 positions respectively with a strength of the relationship directly proportional and close to 1 (0.98 and 0.96).

Linear relationship with R-values is very high too (fig. 2).

4. Conclusions

The (provisional) conclusions focus on the methodological assumptions useful for developing the research, reflecting on how to produce increasingly "refined" indicators and comparison systems to satisfy two of the basic functions of benchmarking in environmental policies: providing knowledge and opportunities for understanding of many variables on territorial performance; facilitate the task of local administrations in the decision-making processes of intervention on the actual territorial gaps.

Study on the multidimensional aspects of the urban environmental through comparison of some composite methods offer an important contribution to the interpretation of the phenomenon.

The work offers a critical vision in the universe of synthetic indexes and has been prepared according to a "journey in itinere" scheme with the aim of creating conditions for research to evolve and improve knowledge to develop increasingly effective and sustainable to offer to policy maker.

The construction of a synthetic index is a delicate task and there are no consolidated solutions.

This study tries to concretely emphasize that, regardless of the methodological choices, if one pursues the sole objective of seeking a summary indicator, sometimes, one loses sight of the dimension of reality.

However, synthetic indices are widely used and are a current and evolving analysis tool. In the implementation phase of the indices, an attempt was made to limit arbitrariness by focusing, for the standardization of elementary indicators, on simple and understand statistical tools to eliminate units of measurement and variability. Therefore, with purely exploratory purposes, 4 principal synthetic indices were compared and the results responded similarly in the synthesis of a set of elementary indicators at the territorial level. In addition, a high concordance between the rankings obtained from the application of the synthesis methods with a cograduation index (between 0.83 and 0.98) and shifts in the ranking between one application and the other on average very content.

This conclusion is relevant because, starting from the assumption that for the study of a multidimensional and complex phenomenon such as the environmental one, the comparison of several weighting techniques is necessary, the nature and information content of the elementary indicators analyzed are so strong and decisive that they condition practically the uniformity of the results at a territorial level in the 4 different synthesis methods applied. In this case not one but 4 methods gave similar answers.

A good result for those who have to deal with a study of the phenomenon and must give an interpretation that is as representative as possible of the environmental reality.

Geography of the environmental state and urban anthropic pressure highlights an unbalanced and negative configuration for most of the southern cities.

At the other end of distribution, higher environmental performances are recorded, especially in the northern small and medium-sized urban areas where investments in environmental projects are constantly growing.

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SUMMARY

The consequences of climate change, depletion of water resources, urban pollution and other aspects of environmental crisis of environmental crisis negatively interact with human life and activity.

In this work, some main statistical methods are compared for the synthesis of indicators representative of environmental phenomena. A multidimensional study through a territorial comparison on the state of environmental health in the urban area.

The proposed approach normalizes the indicators by a specific criterion that deletes the unit of measurement and the variability effect (Method of the average of values standardized MZ, Method of mean of relative indices MR and Corrected MPI index method). The obtained index is easily computable and interpretable or comparable. As an example of application, we consider a set of indicators on urban environmental quality such as water, air, energy, noise, waste, mobility, urban green in the 110 provincial capitals (Istat, 2020).

The results show that the negative impact on the environment is in all Italian regions but is stronger in southern Italy. In addition, the result of the analysis is almost uniform for the methods used, returning the decreasing territorial subdivision of North, Central and Southern Italy.

The analysis of the environment in the urban context therefore provides useful tools for measuring the phenomenon and development policies and environmental sustainability.

The paper is structured as follows: description and application of the main synthesis methods used; comparison of the results obtained through cograduation matrices of the rankings, correlation matrices and dispersion matrices of the data with the different methods; conclusions.

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