The Approach to Major Cities Environmental Performance Measurement

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Abstract

In the context of rapid urbanization, major cities in developing countries aspire to economic growth, which provides enhancing the quality of life without harming the environment. Due to this, they urgently need the indicators and tools of environmental performance, aimed at reducing the influence on environment, enhancing environmental condition and taking steps for envrionmental protection. The paper introduces an approach to environmental performance measurement of major cities of developing countries. It is stated that environmental performance is a multidimensional construct and is determined by the relative ecological compatibility of city functioning within the sustainability of city environment and the scope of environmental management activities. A versatile multilevel system of the major cities environmental performance indicators is suggested, which covers the basic characteristics of environmental performance. The method of calculation of the Environmental performance index of major cities is developed. The distinctive feature of the method is the fact that it includes the mechanisms for motivating major cities to reduce negative environmental influence and to enhance environmental protection as well as the mechanisms for monitoring environmental sustainability. As a result of application of the suggested method to the data of the major cities of Russia for 3 years, a practical result is obtained in the form of ranking of the major cities by the composite environmental performance index. Based on the analysis of ranking, the leaders and outsiders are defined among the cities and their main characteristics are determined. Future areas of research are proposed.

Keywords: *environmental performance, urban environment, major cities.*

1. Introduction

By 2025, the top 600 cities (City 600) are expected to generate about 60% of the global GDP, while about a third of the cities in developed-regions will leave the top list and the number of cities in developing-regions will double (Dobbs et. al., 2011).

While developed countries urbanized gradually, which allowed them to implement growth models using “trial and error” approach, developing countries did not have this opportunity due to the rapid urbanization. These countries now aim to the economic growth, which provides the enhancement of the quality of life without harming the environment and natural resources.

In order to achieve high efficiency in the use of natural resources and to minimize the influence on the environment, the principles, indicators and tools of environmental performance are implemented in territorial development management. However, the systems of environmental performance indicators are not widespread independently. The systems of sustainable development indicators are preferred. These systems include a limited number of environmental performance indicators (3-5) and are mainly implied at the level of countries and regions. Most of the environmental performance indices are used for measuring the relative environmental performance. This is valid for the major cities of developed countries with high environmental performance, where the comparison between cities takes the central stage. As for the fast-growing major cities of developing countries, it is important to measure the absolute environmental performance, since there are risks of “exceeding” the limits by the indicators.

This study is aimed at the development of a methodology of quantitative environmental performance measurement for the major cities of developing countries and application of this methodology to the case of major administrative centers of the Russian Federation subjects.

1.1 The definition of environmental performance

Literature does not provide a clear understanding of environmental performance. Furthermore, when measuring environmental performance, many empirical studies do not refer to the definition of environmental performance at all (Schultze, Trommer, 2012).

Two main approaches to the definition of environmental performance can be distinguished according to the concept of eco-efficiency and environmental performance itself.

According to the concept of eco-efficiency, developed by the World Business Council for Sustainable Development, eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth's estimated carrying capacity (Jollands et. al., 2004). The definitions of other major organizations (Ringstrom & Widheden, 2011) are consistent with the given one. Eco-efficiency reflects the specific impact of an organization on the environment per profit or production (e.g. greenhouse gas emissions, tons of CO_2 equivalent/ USD).

Yale Center for Environmental Law and Policy implements another approach. Environmental performance refers to the extent to which countries achieve environmental objectives in the field of state of human environment and resilience of ecosystems (Hsu et. al., 2013). It is noted that this approach can be adapted for the use at the level of regions and major cities.

The family of international standards ISO 14000 has a significant impact on the formation of terminology in the field of environmental quality and management. These standards contain various definitions of environmental performance from "Measurable results of the environmental management system, related to an organization's control of its environmental aspects" to "one of the aspects of sustainability, connecting environmental performance of a product lifecycle with the volume of its production, which can be expressed in terms of value or in physical terms".

Based on the given concepts and definitions, we can determine the following approach to major cities environmental performance measurement. Environmental performance is considered a multidimensional construct. It is determined by the relative environmental compatibility (harmlessness) of city functioning within environmental sustainability (capacity) of the natural environment and by the scope of activities in the sphere of environmental management.

According to this definition, we can formulate the following requirements for the system of indicators and the index of major cities environmental performance:

1. The relative (specific) environmental indicators should include in the numerator or denominator an indicator, which corresponds to the source of a particular environmental problem.
2. Benchmarking (the procedure for determining reasonable threshold levels) should be used when calculating the environmental performance indicators.
3. The system of environmental performance should include the indicators reflecting the main characteristics of environmental performance: environmental performance of city functioning, environmental sustainability and environmental management performance.
4. The mechanisms for aggregation of environmental performance indicators into the specific indices and the composite index should strictly take into account the threshold levels of environmental sustainability indicators and include motivational mechanisms for encouraging the major cities to reduce the negative impact on environment and to enhance environmental protection.

1.2 Literature review

The review was conducted primarily based on the experience of international organizations, leading research groups and rating agencies, which regularly publish indicators and indices of sustainable development, including the environmental performance indicators: Sustainable Cities Index tracked progress on sustainability in 20 largest British cities (Ross, Underwood, 2010); The ACF Sustainable Cities Index (Trigg et. al., 2010); European Green City Index (2013); The Environmental Performance Index (Hsu et. al., 2013); The study "From Moscow to Sao Paulo" (Gray, 2013); The China Urban Sustainability Index (Li X. et al., 2014); The Urban Sustainability Index (Xiao G., Xue L., Woetzel J., 2010); General ranking of the attractiveness of cities (the Russian Union of Engineers, 2014); Integral ranking "TOP 100 Russian cities" (Urbanica, 2014); The Index of Sustainable Urban Development (SGM, 2014); Environmental ranking of the major cities of the Russian Federation (Minprirody of Russia, 2013).

A clear understanding of the approaches to the study and measurement of environmental performance in empirical studies is provided, for example, in the review article of W. Schultze, R. Trommer (2012) and the article of Bi G. et al. (2015).

The analysis of these works allowed making the following conclusions:

- most systems of indicators and indices measure the performance of cities in relation to each other. Even the top cities should continue to enhance;
- the data sources are usually represented by the official available data of the national statistics and the local government authorities. This ensures the comparability of data, high level of transparency and reliability;
- the systems of indicators are developed based on the principle "category – subcategory – indicator" or "theme – subtheme – indicator";
- an index is a weighted arithmetic mean of specific indices: initially the indicators are aggregated within each category, and then the obtained specific indices are aggregated into an integral (composite) index;
- in developing countries, in order to achieve maximum transparency and simplicity, equal weights are usually assigned to indicators and categories. In developed countries, for which the values of city indicators differ insignificantly, and more accurate measurement is required, different weights are set for both indicators and categories with the assistance of independent experts;
- benchmarking is actively used in the leading systems of environmental performance indicators.

The Yale Environmental Performance Index and The Index of Sustainable Urban Development of the "SGM" rating agency comply with the developed requirements to a greater extent. The advantages of these indices include the use of benchmarking (Hsu et. al., 2013) and the separation of environmental indicators into an individual group (SGM, 2014) – the intensity of environmental situations, which makes it possible to measure environmental sustainability.

2. Data and methods

2.1 The system of environmental performance indicators

Let us introduce the following definitions.

An environmental indicator is a measurable or calculated indicator which characterizes environmental compatibility of city functioning (environmental impact); the condition of city environment; the efforts of the authorities to reduce the negative impact on the environment, to maintain or enhance its condition.

The environmental performance indicator is an indicator which reflects the degree of achievement of the target values of environmental indicators. The environmental performance indicators are divided into the environmental performance indicators of city functioning, environmental sustainability and environmental management performance.

Development of the system of major cities environmental performance indicators is carried out in two stages. At the first stage, a multilevel system of environmental performance indicators is built, comprising 4 levels (Fig. 1). At the second stage, this system is filled with the information taking into account the specifics of the major cities of a particular developing country.

The first level of the system is represented by the Environmental Performance Index which aggregates the specific indices.

The second level of the system is represented by the specific indices which are integral characteristics of environmental performance, which aggregate the environmental performance indicators, obtained by the valuation of the most informative environmental indicators.

The third level of the system is represented by the most informative (specific) environmental indicators, selected from the corresponding groups of environmental indicators, distributed by category, using principal component analysis and expert assessment.

The fourth level of the system is represented by the groups of environmental performance indicators which characterize environmental compatibility of city functioning (environmental impact), environmental condition and environmental management, distributed by category: atmosphere, water resources, waste and land resources, and green planting.

A set of environmental indicators is formed according to the content taking into account the general requirements (relevance, reliability and availability of information, representativeness, completeness and update of data, temporal dynamics) and the specific requirement of compatibility with the environmental sustainability limits (the environmental indicators of environmental condition should have threshold values complying with the environmental sustainability limits).

The official publications of the state statistical and local government authorities served as the sources of the initial data.

2.2 The method of calculating the major cities Environmental Performance Index

The method of calculating the major cities Environmental Performance Index implies the following stages:

1. Calculation of the environmental performance indicators. Through using the ideology of "striving for the environmental objective", the environmental indicators are transformed into the environmental performance indicators by valuation.
2. Weighting and aggregation. Weights are assigned at the following aggregation levels: environmental performance indicators, specific indices of environmental performance. The mechanisms for aggregation of indicators and specific indices of environmental performance are selected and implemented.

Calculation of the environmental performance indicators involves the following steps:

1. Processing of the initial statistical data. Calculation of the environmental indicators including the form of specific indicators (e.g. CO_2 emissions per GDP unit, etc.).
2. Conversion of the processed data. Analysis of the distribution of the environmental indicators' values to determine the necessary transformations. For example, data distribution is often right- or left-skewed, which requires logarithm transformation of data.
3. Selection of the most informative indicators (specific environmental indicators) using the principal component analysis, which allows reducing the dimension of environmental indicators space without significant loss of information value, as well as eliminating low volatility of the indicators. This method of selection is used when at least three environmental indicators are included in the group of a certain category. Otherwise, the specific environmental indicators are selected by experts.

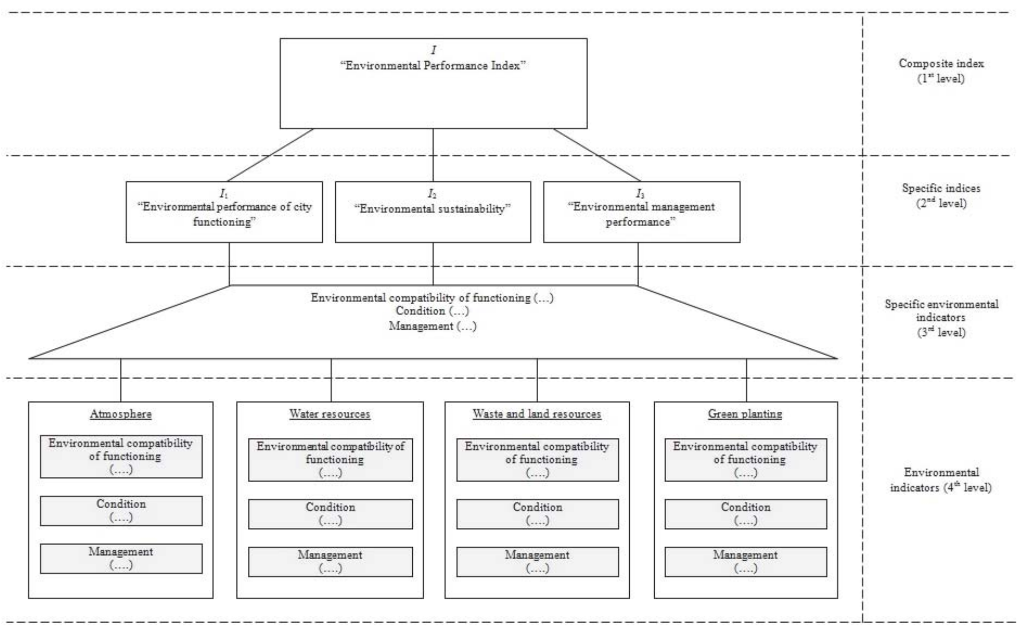

Figure 1. The system of environmental performance indicators

4. Valuation of the specific environmental indicators. Unification of the scales of measurement of the specific environmental indicators, i.e. transition to the dimensionless N – point scale measuring the environmental performance indicators (from 0 to 1 point), where 1 point corresponds to the achievement of the target value of the environmental indicator.

Selection of the specific environmental indices for each year of the analyzed time period is carried out using the principle component analysis:

1. The first principal components, which together account for at least 70 % (Bakumenko, Korotkov, 2008) of the total variance of the analyzed environmental indicators of the corresponding group, which belongs to a certain

category (atmosphere, water resources, etc.), are analyzed.

2. The most informative environmental indicators, which determine the specified first principle components (the correlation coefficient between these indicators and the principal components is maximum), are selected.

Valuation of the specific environmental indicator $x_{il}^{(k)}$ for obtaining the environmental performance indicator $\tilde{x}_{il}$ is conducted according: to the formula (1), if this indicator is correlated with the analyzed integral characteristic of environmental performance (l) by a monotonically increasing dependence:

$$\tilde{x}_{il} = \begin{cases} \frac{x_{il}^{(k)} - x_{il\,min}^{(k)}}{x_{il\,max}^{(k)} - x_{il\,min}^{(k)}} \cdot N \\ 0, \text{ if } x_{il}^{(k)} \le x_{il\,min}^{(k)} \\ 1, \text{ if } x_{il}^{(k)} \ge x_{il\,max}^{(k)} \end{cases}, \quad (1)$$

to the formula (2), if the specific environmental indicator $x_{il}^{(k)}$ is correlated with the analyzed integral characteristic of environmental performance (l) by a monotonically decreasing dependence:

$$\tilde{x}_{il} = \begin{cases} \frac{x_{il\,max}^{(k)} - x_{il}^{(k)}}{x_{il\,max}^{(k)} - x_{il\,min}^{(k)}} \cdot N \\ 0, \text{ if } x_{il}^{(k)} \ge x_{il\,max}^{(k)} \\ 1, \text{ if } x_{il}^{(k)} \le x_{il\,min}^{(k)} \end{cases}, \quad (2)$$

to the formula (3), if the specific environmental indicator $x_{il}^{(k)}$ is correlated with the analyzed integral characteristic of environmental performance (l) by a non-monotonic dependence:

$$\tilde{x}_{il} = \frac{\left| x_{il}^{(k)} - x_{il\text{opt.}}^{(k)} \right|}{max\left\{ \left(x_{il\,max}^{(k)} - x_{il\text{opt.}}^{(k)} \right), \left(x_{il\text{opt.}}^{(k)} - x_{il\,min}^{(k)} \right) \right\}}, \quad (3)$$

where $\tilde{x}_{il}$ ($i = 1, 2, ..., s$) are the values of the i-th environmental performance indicator of the respective integral characteristic l ($l = 1$ – environmental performance of city functioning; $l = 2$ – environmental sustainability; $l = 3$ – environmental management performance); $x_{il}^{(k)}$ ($i = 1, 2, ..., s$) – the values of the i-th specific environmental indicator of the group l ($l = 1$ – environmental compatibility of city functioning; $l = 2$ – environmental condition; $l = 3$ – environmental management) of the category k ($k = 1$ – atmosphere; $k = 2$ – water resources; $k = 3$ – waste and land resources; $k = 4$ – green planting); $x_{il\,min}^{(k)}, x_{il\,max}^{(k)}, x_{il\text{opt.}}^{(k)}$ – the minimum, maximum and optimal threshold values of the specific environmental indicators; $N = 1$.

The threshold values $x_{il\,min}^{(k)}, x_{il\,max}^{(k)}, x_{il\text{opt.}}^{(k)}$ can be set based on international and national regulatory documents, scientific criteria and coordinated expert evaluation. When valuating the specific environmental indicators of environmental condition, the threshold values $x_{il\,min}^{(k)}, x_{il\,max}^{(k)}$ should correspond to the environmental sustainability limits.

If the threshold values cannot be set based on regulative documents, then instead of them order statistics (percentiles) are used. In order to play a catalytic role, i.e. to be actually attainable for most major cities and fundamentally attainable for lagging ones, the threshold value $x_{il\,max}^{(k)}$ is assumed to be equal to the minimum value of the 90-th percentile ($x_{1/90}$) of all observed values of the specific environmental indicator for the analyzed time period. The threshold value $x_{il\,min}^{(k)}$ is determined as the minimum value of all observed values of the specific environmental indicator for the analyzed time period. This approach to the threshold values determination is used when calculating the city functioning environmental performance indicators.

The specific indices of major cities environmental performance I_1 "City functioning environmental performance", I_3 "Environmental management performance" are calculated using the formula:

$$I_l = \sum_{i=1}^{s_l} (\tilde{n}_{il} * \tilde{x}_{il}) \text{, (4)}$$

where $\tilde{x}_{il}$ ($i = 1, 2, ...s_l$) are the i -th environmental performance indicators s_l of the integral characteristic l ($l = 1$ – city functioning performance, $l = 3$ – environmental management performance), and c_i – the "weights" of these indicators, assumed to be equal.

The specific indices I_1, I_3, obtained as a "linear convolution" (4), implement a mechanism of "compensation" of the low values of some indicators by significant exceeding of the threshold values by other indicators. This supports the motivation of major cities to reduce the negative environmental impact and to enhance environmental protection.

The specific index of major cities environmental performance I_2 "Environmental sustainability" is calculated using the formula:

$$I_l = \sqrt[s_l]{\prod_{i=1}^{s_l} \begin{cases} \tilde{x}_{il}, \text{ if } \tilde{x}_{il} \neq 0, \\ \varepsilon \quad \text{otherwise} \end{cases}} \text{, (5)}$$

where $\tilde{x}_{il}$ ($i = 1, 2, ...s_l$) are the i -th environmental sustainability indicators s_l of the integral characteristic l ($l = 2$ – environmental sustainability), ε – a sufficiently small number, which is used, when one of the indicators equals zero, so that the product does not vanish ($\varepsilon = 0{,}01$).

The specific index I_2, obtained as a geometric mean (5), implements a more rigid aggregation mechanism in comparison to (4), which eliminates the compensation effect of the "exceedance" of the environmental sustainability limits by any environmental condition indicators. In theory, the fact of such "exceedance" means a loss of environmental sustainability as a whole.

The composite environmental performance index I is calculated using the formula:

$$I = \sqrt[3]{I_1 * I_2 * I_3} \text{, (6)}$$

where I_1 – the specific index of city functioning environmental performance; I_2 – the specific index of environmental sustainability; I_3 – the specific index of environmental management performance.

The composite environmental performance index I, obtained as a geometric mean (6), implements a rigid aggregation mechanism, which eliminates the effect of compensation of zero values of the specific environmental sustainability index.

3. Results

3.1 Empirical study

The proposed method for calculating the environmental performance index I was applied to the major cities, which are the administrative centres of the subjects of the Russian Federation.

The official statistical data of Rosstat (2009, 2011, 2013) and Roshydromet (2009, 2011) for 2008, 2009 and 2011 served as the initial data. The analyzed time period was chosen due to the availability of complete official statistical data.

Taking into account the specified requirements, a set of 15 environmental indicators of the 4th level was formed for 31 administrative centres of the Russian Federation subjects (Table 1). The values of these indicators are not presented in the article in order to save the space. The group does not include such major cities as Astrakhan, Nizhny Novgorod, Novokuznetsk and Tolyatti since for these cities there is no available data on many environmental indicators.

Table 1. The set of environmental indicators for major cities of Russia

Section	Type of indicator	Indicator
1	2	3
1 Atmosphere	1 Environmental capability of city functioning	$x_{1.1}^{(1)}$ – Specific emissions of harmful substances in atmosphere from fixed sources: the total per a unit of industrial production volume (in comparable prices, 2009 = 1), tons per ruble
		$x_{2.1}^{(1)}$ – Specific emissions of harmful substances from fixed sources: solids per a unit of industrial production volume (in comparable prices, 2009 = 1), tons per ruble
		$x_{3.1}^{(1)}$ – Specific emissions of harmful substances from fixed sources: sulfur dioxide (SO_2) per a unit of industrial production volume (in comparable prices, 2009 = 1), tons per ruble
		$x_{4.1}^{(1)}$ – Specific emissions of harmful substances from fixed sources: nitrogen oxides (NO_2) per a unit of industrial production volume (in comparable prices, 2009 = 1), tons per ruble
		$x_{5.1}^{(1)}$ – Specific emissions of harmful substances from fixed sources: carbon oxide (CO) per a unit of industrial production volume (in comparable prices, 2009 = 1), tons per ruble
		$x_{6.1}^{(1)}$ – Specific emissions of harmful substances in the atmosphere from vehicles: the total per capita, kg per capita
		$x_{7.1}^{(1)}$ – Specific emissions of harmful substances in the atmosphere from vehicles: solids per capita, kg per capita
		$x_{8.1}^{(1)}$ – Specific emissions of harmful substances in the atmosphere from vehicles: sulfur dioxide (SO_2) per capita, kg per capita
		$x_{9.1}^{(1)}$ – Specific emissions of harmful substances in the atmosphere from vehicles: nitrogen oxides (NO_2) per capita, kg per capita
		$x_{10.1}^{(1)}$ – Specific emissions of harmful substances in the atmosphere from vehicles: carbon oxide (CO) per capita, kg per capita
	2 Environmental condition	$x_{11.2}^{(1)}$ – Level of pollution, points
	3 Environmental management	$x_{15.3}$
2 Water resources	1 Environmental capability of city functioning	$x_{12.1}^{(2)}$ – Specific polluted water discharged in surface water-bodies per a unit of industrial production volume (in comparable prices, 2009=1), thousand cubic meters/million rubles
	2 Environmental management	-
	3 Environmental condition	$x_{15.3}$
3 Waste and land resources	1 Environmental capability of city functioning	$x_{13.1}^{(3)}$ – Municipal waste transported by special vehicles form city territories per capita, cubic meters per capita
	2 Environmental condition	-
	3 Environmental management	$x_{15.3}$
4 Green plantings	1 Environmental capability of city functioning	$x_{14.1}^{(4)}$ – The proportion of green planting areas in the total area of land within cities, percent
	2 Environmental condition	-
	3 Environmental management	$x_{15.3}$

$x_{15.3}$ – The share of current costs for environmental protection in the volume of industrial production, % – the common environmental indicator for all categories of the group “Environmental management”.

When calculating the specific emissions of harmful substances in the atmosphere from fixed sources, the specific polluted wastewater discharge in surface water-bodies and the share of current costs for environmental protection in the volume of industrial production, the emissions, discharge and current costs were referred to the indicator of the volume of industrial production, since the GDP is not officially calculated for municipal entities. When calculating the specific emissions of harmful substances in the atmosphere from vehicles, the emissions were referred to the city population, which approximates the number of vehicles. In accordance with international practice, municipal waste, transported by special vehicles from the city territories, was referred to the population.

Due to the fact that the values of the current (operating) costs for environmental protection by the components of environment (the atmosphere, water resources, etc.) are not available in the official statistics, the environmental indicator $x_{15.3}$ "The share of current costs for environmental protection in the volume of industrial production" is common for the group "Management" of all categories, and was moved into the category of the specific environmental indicators without selection.

Analysis of the distribution of the values of the environmental indicators showed that the indicators $x_{1.1}^{(1)}$, $x_{2.1}^{(1)}$, $x_{3.1}^{(1)}$, $x_{4.1}^{(1)}$, $x_{5.1}^{(1)}$, $x_{6.1}^{(1)}$, $x_{7.1}^{(1)}$, $x_{8.1}^{(1)}$, $x_{9.1}^{(1)}$, $x_{10.1}^{(1)}$, $x_{13.1}^{(3)}$, $x_{12.1}^{(2)}$, $x_{15.3}$ require a log transformation. The values of the natural logarithms were used in further analysis.

Selection of the specific environmental indicators of the 3rd level was carried out using the principal component analysis, the results of which are represented in the Table 2.

Table 2. Factor loadings of the environmental indicators of the group "Environmental compatibility of city functioning", which belongs to the category "Atmosphere" (2008)

Initial indicator	Principal components				
	f_1	f_2	f_3	f_4	f_5
$x_{1.1}^{(1)}$	**-0,973**	**-0,167**	-0,001	-0,063	-0,144
$x_{2.1}^{(1)}$	-0,785	0,491	-0,293	-0,235	0,045
$x_{3.1}^{(1)}$	-0,890	-0,192	-0,173	0,374	0,041
$x_{4.1}^{(1)}$	-0,696	-0,667	0,157	-0,203	0,076
$x_{5.1}^{(1)}$	-0,973	-0,167	-0,001	-0,063	-0,144
$x_{6.1}^{(1)}$	-0,728	0,566	0,380	0,073	0,022
The share of f_k in the aggregated variance. %	67,36	21,43	5,69	4,90	0,61

Since the first two principal components account for 88,79 % of the aggregated variance of the environmental indicators, the further analysis was conducted within the first two principal components f_1 and f_2.

The considered principal components f_1 and f_2 make the largest total contribution to the variance of the indicator $x_{1.1}^{(1)}$ (this contribution is equal to ($(-0{,}973)^2+(-0{,}167)^2=0{,}975$), i.e. the indicator $x_{1.1}^{(1)}$ is the most informative among the 5 analyzed indicators. The same indicator was selected for 2009 and 2011.

Similarly, the selection of the specific environmental indicators was carried out, which characterized the specific emissions of harmful substances in the atmosphere from vehicles per capita. For 2008 2009 and 2011, the environmental indicators $x_{10.1}^{(1)}$, $x_{9.1}^{(1)}$ and $x_{6.1}^{(1)}$ respectively were selected as the specific indicators

The reduced set of the specific indicators, the valuation type and threshold values are represented in the Table 3.

Table 3. The reduced set of the specific environmental indicators for the major cities of Russia

	Specific environmental indicator	Transformation	Valuation	Threshold values x_{min}	Threshold values x_{max}
	1 City functioning performance				
1	$x_{1.1}$ – Specific emissions of harmful substances in atmosphere from fixed sources: the total per a unit of industrial production volume (in comparable prices, 2009 = 1), tons per ruble	$ln(x_{il} * 1000)$	(1)	5,202	7,449
2	$x_{2.1}$ – Specific emissions of harmful substances in the atmosphere from vehicles: sulfur dioxide (SO_2) per capita, kg per capita	$ln(x_{il} * 1000)$ (for 2011)	(1)	0,426 (7,380)	2,027 (5,772)
3	$x_{3.1}$ – Specific emissions of harmful substances in the atmosphere from vehicles: nitrogen oxides (NO_2) per capita, kg per capita	$ln(x_{il} * 1000)$ (for 2011)	(1)	6,600 (9,947)	32,801 (8,556)
4	$x_{4.1}$ – Specific emissions of harmful substances in the atmosphere from vehicles: carbon oxide (CO) per capita, kg per capita	$ln(x_{il} * 1000)$ (for 2009, 2011)	(1)	55,134 (11,478)	107,500 (10,493)
5	$x_{5.1}$ – Specific polluted water discharged in surface water-bodies per a unit of industrial production volume (in comparable prices, 2009=1), thousand cubic meters/million rubles	$ln(x_{il} * 100)$	(1)	0,351	5,263
6	$x_{6.1}$ – Municipal waste transported by special vehicles form city territories per capita, cubic meters per capita	$ln(x_{il})$	(1)	5,704 (European Green City Index, 2013)	6,908 (European Green City Index, 2013)
7	$x_{7.1}$ – The proportion of green planting areas in the total area of land within cities, %	-	(2)	40 (Construction Standards and Regulations, 1989)	46 (Construction Standards and Regulations, 1989)
	2 Environmental sustainability				
8	$x_{8.2}$ – Level of pollution, points	-	(1)	1 (Roshydromet, 2009, 2011; Rybalskiy N. et. al., 1992)	4 (Roshydromet, 2009, 2011; Rybalskiy N. et. al., 1992)
	3 Environmental management performance				
9	$x_{9.3}$ – The share of current costs for environmental protection in the volume of industrial roduction, %	$ln(x_{il} * 10)$ (for 2011)	(2)	0,13 (0,26)	2 (Vasilyeva, 2002)

The set of the environmental performance indicators includes 7 indicators of city functioning environmental performance, 1 indicator of environmental sustainability and 1 indicator of environmental management performance.

The specific index of the environmental performance of city functioning I_1 was calculated according to the formula (4). The specific indices of environmental sustainability I_2 and environmental management performance I_3 are represented by the environmental performance indicators $x_{8.2}$ and $x_{9.3}$ respectively.

3.2 Results of empirical study

The composite environmental performance index I was calculated using the formula (6). The results of calculation for 2008, 2009 and 2011 are presented in the Table 4 as a rating.

Table 4. Rating of the major cities of Russia by the Environmental Performance Index I

No.	City	I (2008)	I Rating position	I (2009)	Rating position	I (2011)	Rating position
1	Barnaul	0,313	20	0,089	28	0,318	22
2	Vladivostok	0,384	12	0,341	11	0,390	19
3	Volgograd	0,394	10	0,108	27	0,470	9
4	Voronezh	0,392	11	0,293	19	0,232	24
5	Ekaterinburg	0,087	28	0,067	30	0,135	28
6	Izhevsk	0,441	4	0,500	2	0,588	1
7	Irkutsk	0,091	27	0,085	29	0,122	29
8	Kazan	0,435	5	0,387	8	0,503	6
9	Kemerovo	0,338	16	0,329	12	0,142	26
10	Kirov	0,331	19	0,262	21	0,197	25
11	Krasnodar	0,170	24	0,159	23	0,356	20
12	Krasnoyarsk	0,112	25	0,111	26	0,100	30
13	Lipetsk	0,371	14	0,317	15	0,514	2
14	Moscow	0,053	30	0,059	31	0,082	31
15	Novosibirsk	0,499	2	0,475	3	0,448	13
16	Omsk	0,309	21	0,351	9	0,413	16
17	Orenburg	0,293	22	0,315	16	0,448	14
18	Penza	0,263	23	0,300	18	0,511	3
19	Perm	0,428	6	0,396	6	0,497	7
20	Rostov-on-Don	0,351	15	0,120	25	0,450	12
21	Ryazan	0,413	7	0,439	4	0,458	10
22	Samara	0,335	17	0,328	14	0,420	15
23	Saint Petersburg	0,040	31	0,276	20	0,349	21
24	Saratov	0,111	26	0,345	10	0,478	8
25	Tula	0,332	18	0,229	22	0,394	17
26	Tyumen	0,061	29	0,133	24	0,243	23
27	Ulyanovsk	0,447	3	0,427	5	0,505	4
28	Ufa	0,404	9	0,394	7	0,391	18
29	Khabarovsk	0,407	8	0,313	17	0,456	11
30	Chelyabinsk	0,381	13	0,329	13	0,136	27
31	Yaroslavl	0,564	1	0,624	1	0,504	5

The Tables 5, 6 show the leaders (6 cities) and outsiders (5 cities) which are consistently included in the first ten and the last ten cities in the ranking over the period under consideration (3 years).

Table 5. Leaders of the city ranking

Leaders	2008			2009			2011		
	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
Izhevsk	0,363	0,333	0,708	0,374	0,333	1,000	0,614	0,333	0,991
Kazan	0,505	0,333	0,490	0,375	0,333	0,465	0,541	0,333	0,704
Perm	0,743	0,333	0,317	0,589	0,333	0,317	0,744	0,333	0,496
Ryazan	0,325	0,333	0,651	0,387	0,333	0,657	0,369	0,333	0,781
Ulyanovsk	0,456	0,333	0,586	0,325	0,333	0,721	0,482	0,333	0,802
Yaroslavl	0,269	0,667	1,000	0,243	1,000	1,000	0,383	0,333	1,000

Table 6. Outsiders of the city ranking

Outsiders	2008			2009			2011		
	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
Ekaterinburg	0,203	0,010	0,330	0,115	0,010	0,259	0,345	0,010	0,707
Irkutsk	0,131	0,010	0,570	0,079	0,010	0,769	0,223	0,010	0,824
Krasnoyarsk	0,208	0,010	0,667	0,175	0,010	0,783	0,123	0,010	0,823
Moscow	0,390	0,010	0,039	0,314	0,010	0,066	0,513	0,010	0,109
Tyumen	0,197	0,010	0,115	0,021	0,333	0,332	0,103	0,333	0,418

4. Discussion

Apart from the current negative influence on the environment, the obtained rating of the major cities of Russia reflects the accumulated environmental problems and the scope of activities in the field of environmental management.

The list of the leaders included the cities of the Volga region and the European part of Russia. Having a well-developed industrial base, Izhevsk, Kazan, Perm, Ryazan, Ulyanovsk and Yaroslavl are characterized by the medium values of environmental performance of the city functioning (0,442 points), environmental sustainability (0,389 points) and high values of environmental management performance (0,624 points).

The cities of Siberia and the Ural region of Russia as well as Moscow became the outsiders. Low positions of Ekaterinburg, Irkutsk, Krasnoyarsk and Tyumen are mainly due to low environmental performance of city functioning (0.209 points) and significant accumulated environmental problems (0,053 points). Having the average environmental performance of city functioning, (0,405 points), Moscow cannot withdraw from the list of outsiders primarily because of the poor environmental condition (0,01 points). The lagging cities respond to tough environmental situation by increasing aggregated current costs for environmental protection. However, the environment is not affected yet. The solution of accumulated environmental problems requires time and investment in fixed capital aimed at environmental protection and rational natural resource management.

In order to identify the problem fields in maintaining environmental performance of a particular major city and to determine the options of the threshold (target) values of the environmental performance indicators, achievement of which will allow enhancing environmental performance, it is planned to present the approach to the analysis of the dynamics of the specific indices and the composite index of environmental performance of the city in relation to the same city in previous years and in comparison to other cities of the group under consideration. For the dynamics it is implied to use two-factor analysis of variance with one observation in a cell.

Besides, it is necessary to conduct verification of the proposed method of quantitative measurement of major cities environmental performance and to calculate the sustainability of specific and composite indices of environmental performance. Verification is supposed to be conducted using the methods of cluster analysis.

5. Conclusion

The paper introduces a new approach to the environmental performance measurement of major cities of the developing countries. It is established that environmental performance is a multidimensional construct and is determined by the relative ecological compatibility of the city functioning within environmental sustainability (capacity), the natural environment of the city and the scope of activities in the sphere of environmental management. The requirements are formulated for the system of indicators and for the Environmental Performance Index of the major cities. A versatile multilevel system of the major cities environmental performance indicators is suggested, which covers the basic characteristics of environmental performance (environmental performance of the city functioning, environmental sustainability, environmental management) and allows analyzing the interrelations between these characteristics. After filling in with the specific information content, the system of indicators can be used or the analysis of the major cities environmental performance in a particular developing country. The method of calculation of the Environmental Performance Index in the context of rapid urbanization is developed. The method of calculation involves the mechanisms for motivating the major cities to reduce the negative environmental influence and to enhance environmental activity, as well as the mechanisms for monitoring environmental sustainability.

Following the results of application of the method suggested for the actual data of the major cities of Russia for 3 years, the specific indices and composite index of environmental performance were obtained. The rankings of the major cities of Russia were made in terms of the composite environmental performance index for each year. Based on the analysis of rankings, the leaders and outsiders were identified among the cities and their main characteristics were determined. The ranking of the major cities by the composite environmental performance index is a qualitative analytical tool for evaluation of prospects and opportunities for the development of the major cities of a particular developing country. Based on the analysis of specific environmental performance indices, both general recommendations and specific proposals can be given to enhance environmental performance. The ranking results can be used for planning of strategic development of the municipality in order to ensure the development in terms of environmental performance.

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