Method for forecasting pollution of urban areas

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Abstract. A model for substantiating the parameters of regression models for a comprehensive indicator of environmental pollution has been developed. A distinctive feature is the separate consideration of the influence of factors of the natural and industrial environment, as well as the linear nature of the interaction of nonlinear variables. The resulting model will allow us to analyze the current state of the environment depending on the quantity and quality of environmental indicators, and also identify critical changes in it. In the urban development industry, this model will help in planning the possibility of placing objects with a high environmental burden in a particular area.

1 Introduction

The development of urban areas, for the most part, is due to the progressive growth of city-forming industrial enterprises, utilities and transport hubs, affecting the economic, environmental and social components of the city and the country as a whole. With the growth and development of technological progress, the natural environment is experiencing a load on a relative scale, more and more polluting substances enter the environment, contributing to cause geo-ecological instability. Many human activities, and in particular industrial production, produce a huge amount of waste and pollution, which require the development of basic technologies for controlling emissions, processes, implementation and costs of which should be justified by the degree of achieved results [1-3]. In order to answer the question about the state of environmental pollution, it is necessary to conduct systematic observations and assess the technogenic impact on natural objects of urban agglomerations. Many scientists consider the geoecological problems of urban areas, trying to find new forecasting methods and methods for assessing the current situation, under the influence of technological progress [4-9]. Globally, adverse effects on human health and air quality can be considered as a result of anthropogenic activities responsible for economic development and energy dependence [10-14].

Many objects located in or near the city do not fulfill the required environmental safety measures, which entails the accumulation and spread of harmful substances in the surrounding space. All kinds of pollutants accumulate and settle on the surface, getting into bodies of water, groundwater, and also with water and air into the organisms of living beings, which leads to a decrease in the number of natural resources suitable for use, to an increase in the incidence of the population, and as a result a reduction in life expectancy [15-18]. In order to suspend the launched process of anthropogenic impact and not aggravate the current situation, it is necessary to look for new methods for predicting the development of environmental pollution from stationary sources and vehicles. The most relevant pollution prediction methods today are monitoring, GIS, mapping, modeling, which allow us to assess the environment with an increase in the number of components [19-27].

Thus, if it is necessary to draw dependencies and find patterns between the actual state of the environment and potential sources of pollution, it is possible to create a new technique based on a mathematical model.

2 Methods

This article discusses the methodology of predictive modeling, depending on the number of components of anthropogenic and natural environments. The construction of models is a necessary measure due to the inability to explore a real object in all its complexity. Naturally, the simplification should not concern the most important elements from the point of view of the tasks being solved.

The goal was set as part of the study - to develop a forecast model with which you can compare the quantitative data received from monitoring stations with the actual number of considered objects emitting harmful substances, thereby assessing areas in which objects are harmful that affect the environment and predict the development of urban areas so as not to aggravate the environmental situation.

Initial data and unknown variables for created procedure are specified in Table 1. Calculated characteristics of the procedure are specified in Table 2.

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Table 1. Initial data and unknown variables for created procedure.

No.	Name of the initial data element	Meas. unit	Designation / expression
1	**Initial data**		
1.1	Initial data for optimization model		
1.1.1	General initial data		
1.1.1.1	Total number of indicators for natural environment	units	m
1.1.1.2	Total number of indicators for industrial environment	units	n
1.1.1.3	Total number of studied geographical areas	units	D
1.1.1.4	Largest absolute difference of indicators Q^I_d and Q^N_d	conv. units	M
1.1.1.5	Minimal values of the coefficients w^I_d and w^N_d	-	W^{min}
1.1.1.6	Minimal values of the coefficients w^I_d and w^N_d	-	W^{max}
1.1.2	Indexes		
1.1.2.1	Index for indicator connected to natural environment	-	i
1.1.2.2	Index for indicator connected to industrial environment	-	j
1.1.2.3	Index for studied geographical area	-	d
1.1.3	Initial data for the indicator connected to natural (industrial) environment;		
1.1.3.1	Name of indicator for natural (industrial) environment	-	-
1.1.3.2	Minimal proportion of the influence coefficient to natural (industrial) environment	-	
1.1.3.3	Maximal proportion of the influence coefficient to natural (industrial) environment	-	
1.1.4	Initial data for studied geographical area		
1.1.4.1	Name of geographical area	-	-
1.1.5	Initial data for the indicator connected to natural (industrial) environment in geographical area; ;		
1.1.5.1	Absolute value of the indicators for natural (industrial) environment	MU*	
1.2	Initial data for pollution forecast model		
1.2.1	Index of geographical area to be considered	-	d°
1.2.2	Value for the indicator of natural (industrial) environment corresponding to present state** of the geographical area d°; ;	MU*	
1.2.3	Value for the indicator of industrial environment corresponding to future state of the geographical area d°; ;	MU*	
2	**Unknown variables of optimization model**		
2.1	Coefficient of influence of the particular indicator of the natural (industrial) environment on the complex indicator;	-	
2.2	Absolute positive (negative) deviation of the complex indicator for industrial environment from the complex indicator for natural environment in geographical area	conv. units	
2.3	Indicator of excess of indicator Q^I_d related to indicator Q^N_d	-	

Note:
* invidual (in general case) measure unit determined by the nature of the indicator under consideration
** usually

Table 2. Calculated characteristics for created procedure.

No.	Name of the initial data element	Meas. unit	Formula
1	**Calculated characteristics of optimization model**		
1.1	Calculated characteristics for the indicator connected to natural (industrial) environment in geographical area ; ;		
1.1.1	Normalized value of the indicator*	-	
1.2	Calculated characteristics for geographical area ;		
1.2.1	Complex indicator for natural (industrial) environment	-	
1.3	Calculated characteristics for the indicator connected to natural (industrial) environment;		
1.3.1	Value of the indicator for the most favorable region	MU**	if increase of the indicator i(j) determines a favorable environmental impact; otherwise.
1.3.2	Value of the indicator value for the least favorable region	MU**	if increase of the indicator i(j) determines a favorable environmental impact; otherwise.
1.3.3	Minimal value of the coefficient of influence of the particular indicator for the environment on the complex indicator	-	
1.3.4	Maximal value of the coefficient of influence of the particular indicator for the environment on the complex indicator	-	
1.4	Aggregated calculated characteristics		
1.4.1	The coefficient of determination of	-	

	the complex indicator of industrial (natural) environment on the complex indicator of natural (industrial) environment		
2	**Calculated characteristics for pollution forecast model**		
2.1	Calculated characteristics for the indicator i(j) connected to natural (industrial) environment in geographical area d; i=1,2,…,m (j=1,2,…,n); d=1,2,…,D		
2.1.1	Proportion in the complex indicator of natural (industrial) environment, for the indicator of natural (industrial) environment	-	null otherwise
2.2	Calculated characteristics for the indicator i(j) connected to natural (industrial) environment		
2.2.1	Average value of proportion in the complex indicator of natural (industrial) environment for particular indicator of natural (industrial) environment	-	
2.2.2	Minimal value of proportion in the complex indicator of natural (industrial) environment for particular indicator of natural (industrial) environment	-	
2.2.3	Maximal value of proportion in the complex indicator of natural (industrial) environment for particular indicator of natural (industrial) environment	-	
2.2.4	Normalized value of the indicator for the current state of the geographical area d° under consideration d°	-	
2.2.5	Normalized value the indicator j of industrial environment corresponding to the future state of the geographical area d° under consideration d°	-	
2.2.6	Change of absolute value of indicator for the geographical area d° under consideration d°	-	=
2.2.7	Change of normalized value of indicator for the geographical area d° under consideration d°	-	=
2.2.8	Normalized value for the indicator *i* of natural environment corresponding to the future state of the geographical area d° under consideration d°	-	
2.2.9	Absolute value for the indicator *i* of natural environment corresponding to the future state of the geographical area d° under consideration d°	-	
2.3	Calculated characteristics for geographical area d° under consideration; d°		
2.3.1	Complex indicator of natural (industrial) environment for current state	-	
2.3.2	Complex indicator of industrial environment for current state	-	
2.3.3	Change of complex indicator for industrial environment	-	
2.3.4	Change of complex indicator for natural environment	-	
2.3.5	Complex indicator of natural environment for future state		+

Note:
* Calculated characteristic is based on the results of calculation for the characteristics in lincs 1.3.1 and 1.3.2 of Table 2.
** Individual (in general case) measure unit determined by the nature of the indicator under consideration.
*** Calculated characteristic is based based on the results of calculation for the characteristics 2.3.1-2.3.5 of Table 2.

For the consciousness of the optimization model, initial data are needed (Table 1), for the recognition of factors of the natural and technogenic environment. In this model, the natural environment is the level of compounds in the air.

The data on the natural environment were taken from monitoring stations located in each district of the city. Environmental indicators are industrial and municipal facilities divided by hazard classes, as well as the transport load on the motorways closest to the monitoring stations.

Environmental indicators are arithmetic mean data for each pollutant (carbon monoxide, ozone, suspended particles, etc.). The industrial environment indicators are industrial enterprises divided by hazard classes, and this also includes the transport load calculated by the arithmetic mean number of cars per hour passing through the perpendicular AB section on the busiest highways near monitoring stations All source data is indicated by a letter or expression for further calculations (table 1).

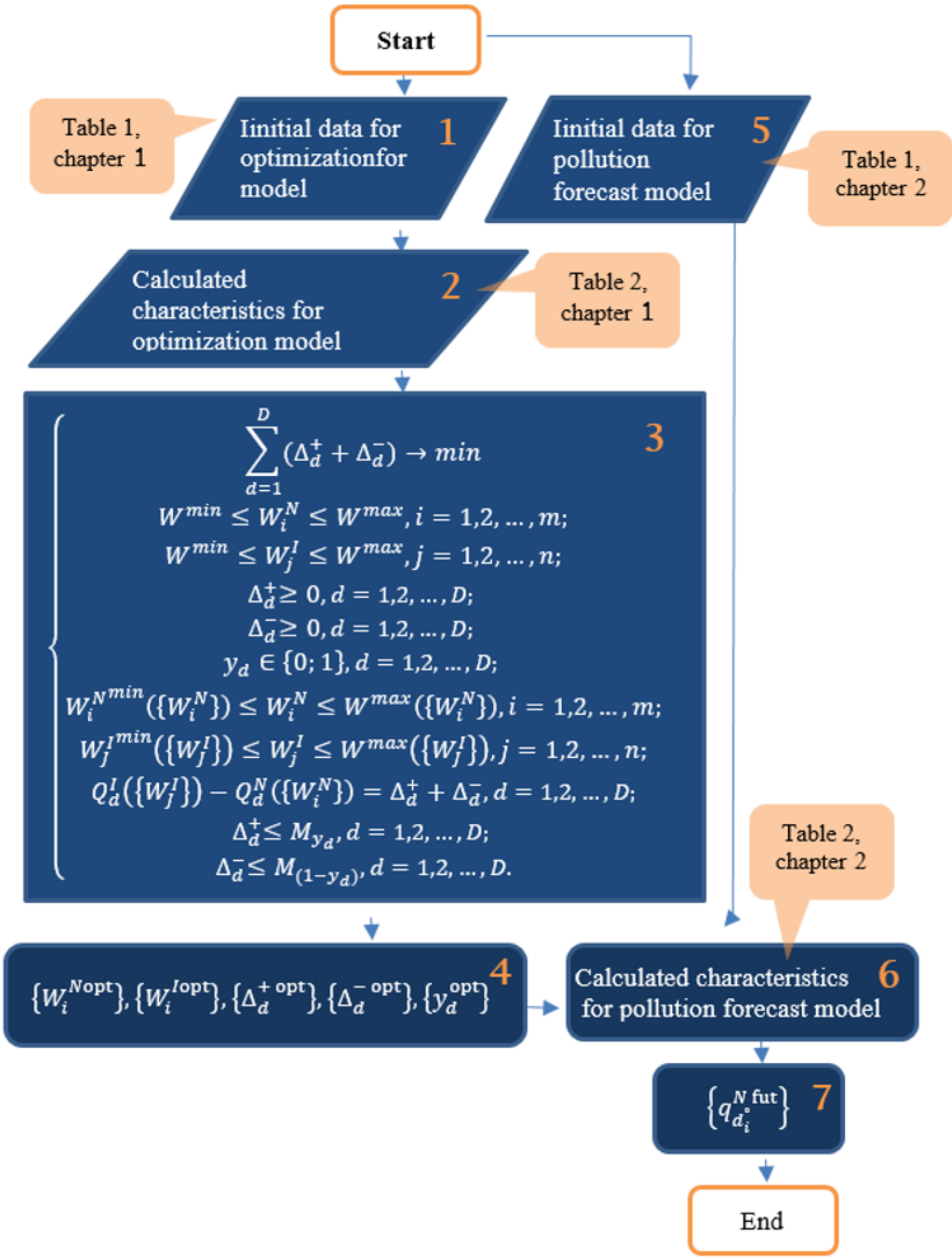


Fig. 1. Procedure for determination of predictive values for characteristics connected to assessment of environmental pollution

The essence of the mathematical model is that the quantity and quality of objects polluting the environment should correspond to the real picture obtained from monitoring stations, that is, to natural indicators. Hence, we can use this mathematical model as a predictive one, showing changes in the natural environment depending on changes in the industrial environment, finding unknowns.

Figure 1 presents a flowchart of the procedure for determining forecast values for characteristics associated with the assessment of environmental pollution, which is the result of a methodology for substantiating the characteristics of environmental pollution.

3 Results and Discussion

As a result of the creation of the methodology, it is possible to achieve the practical application of such a tool in the framework of monitoring and controlling the pollution of specific objects under study, for this the methodology should be implemented using standard computational algorithms in programs such as “Microsoft Excel”, “Mathcad”, “MatLab” and others. Figures 2,3 and 4 show the application of the methodology for substantiating the characteristics of environmental pollution in Excel. Table 3 and 4 show the resulting formulas with links to the formulas in the previous figures and tables introduced in Excel to simplify the use of the model.

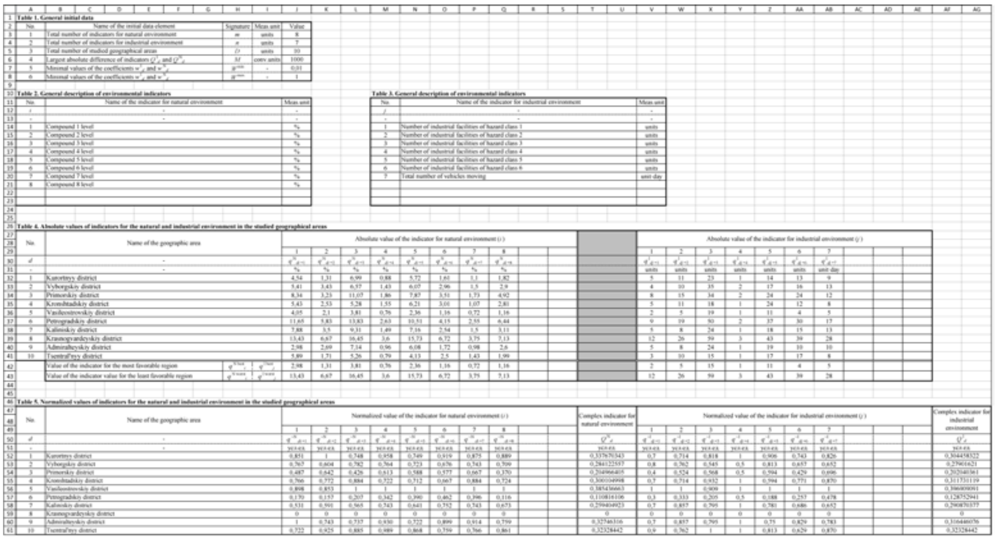


Fig.2. Initial given for the optimization model

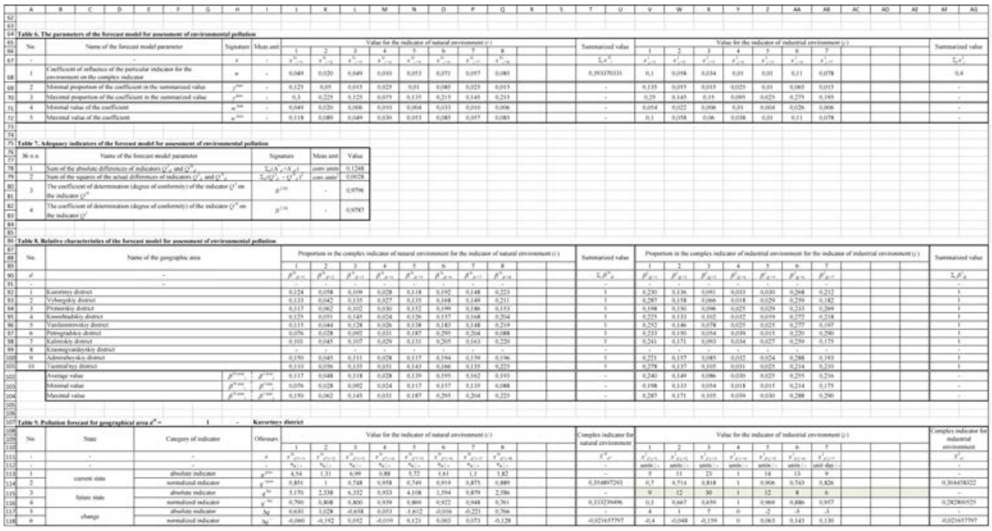
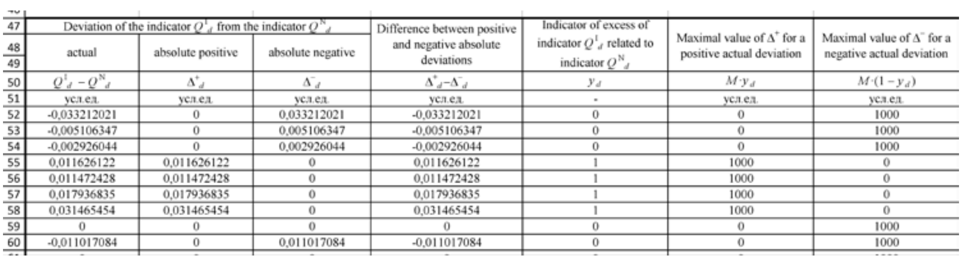


Fig.3. Calculated values of the optimization model



47–49	Deviation of the indicator Q^1_d from the indicator Q^N_d: actual	absolute positive	absolute negative	Difference between positive and negative absolute deviations	Indicator of excess of indicator Q^1_d related to indicator Q^N_d	Maximal value of Δ^+ for a positive actual deviation	Maximal value of Δ^- for a negative actual deviation
50	$Q^1_d - Q^N_d$	Δ^+_d	Δ^-_d	$\Delta^+_d - \Delta^-_d$	y_d	$M \cdot y_d$	$M \cdot (1 - y_d)$
51	усл.ед.	усл.ед.	усл.ед.	усл.ед.	-	усл.ед.	усл.ед.
52	-0,033212021	0	0,033212021	-0,033212021	0	0	1000
53	-0,005106347	0	0,005106347	-0,005106347	0	0	1000
54	-0,002926044	0	0,002926044	-0,002926044	0	0	1000
55	0,011626122	0,011626122	0	0,011626122	1	1000	0
56	0,011472428	0,011472428	0	0,011472428	1	1000	0
57	0,017936835	0,017936835	0	0,017936835	1	1000	0
58	0,031465454	0,031465454	0	0,031465454	1	1000	0
59	0	0	0	0	0	0	1000
60	-0,011017084	0	0,011017084	-0,011017084	0	0	1000

Fig.4. Calculated characteristics for pollution forecast model

Table 3. Principles of worksheet formation in “Microsoft Excel” software

Address of cell(s)	“Microsoft Excel” formula / comment	Optimization model element
Table 1		
J3	value of initial data element	Table 1, line 1.1.1.1
J4	value of initial data element	Table 1, line 1.1.1.2
J5	value of initial data element	Table 1, line 1.1.1.3
J6	value of initial data element	Table 1, line 1.1.1.4
J7	value of initial data element	Table 1, line 1.1.1.5
J8	value of initial data element	Table 1, line 1.1.1.6
Table 2		
B14:I21	values of initial data elements	Table 1, line 1.1.2.1

Table 3		
B14:I21	values of initial data elements	Table 1, line 1.1.2.1
Table 4		
B32:I41	values of initial data elements	Table 1, line 1.1.3.1
J32:Q41	values of initial data elements	Table 1, line 1.1.4.1
V32:AB41	values of initial data elements	Table 1, line 1.1.4.1
J42(:S42)	=IF(J29<>"";MIN(OFFSET(J32;;;$J$5;));"")	Table 2, line 1.3.1
V42(:AE42)	=IF(V29<>"";MIN(OFFSET(V32;;;$J$5;));"")	Table 2, line 1.3.1
J43(:S43)	=IF(J29<>"";MAX(OFFSET(J32;;;$J$5;));"")	Table 2, line 1.3.2
V43(:AE43)	=IF(V29<>"";MAX(OFFSET(V32;;;$J$5;));"")	Table 2, line 1.3.2
Table 5		
J52(:S61)	=IF(И($A52<>"";J$49<>""); (J32-J$43)/(J$42-J$43);"")	Table 2, line 1.1.1
T52(:U61)	=IF(A52<>"";SUMPRODUCT(OFFSET(J52;;;;$J$3);OFFSET($J$68;;;;$J$3));"")	Table 2, line 1.2.1
V52(:AE61)	=IF(AND($A52<>"";V$49<>""); (V32-V$43)/(V$42-V$43);"")	Table 2, line 1.1.1
AF52(:AG61)	=IF(A52<>"";SUMPRODUCT(OFFSET(V52;;;;$J$4);OFFSET($V$68;;;;$J$4));"")	Table 2, line 1.2.1
AH52(:AH61)	=AF52-T52	Figure 1, block 3, line 9, left part of expression
AI52:AJ61	values of unknown variables	Table 1, line 2.2
AK52(:AK61)	=AI52-AJ52	Figure 1, block 3, line 9, right part of expression
AL52:AL61	values of unknown variables	Table 1, line 2.3
AM52(:AM61)	=$J$6*AL52	Figure 1, block 3, line 10, right part of expression
AN52(:AN61)	=$J$6*(1-AL52)	Figure 1, block 3, line 11, right part of expression
Table 6		
J68:S68	values of unknown variables	Table 1, line 2.1
T68	=SUM(OFFSET($J$68;;;;$J$3))	-
V68:AE68	values of unknown variables	Table 1, line 2.1
AF68	=SUM(OFFSET($V$68;;;;$J$4))	-
J69:S69	values of initial data elements	Table 1, line 1.1.2.2
V69:AE69	values of initial data elements	Table 1, line 1.1.2.2
J70:S70	values of initial data elements	Table 1, line 1.1.2.3
V70:AE70	values of initial data elements	Table 1, line 1.1.2.3
J71(:S71)	=IF(J$66<>"";$T$68*J69;"")	Table 2, line 1.3.3
V71(:AE71)	=IF(V$66<>"";$AF$68*V69;"")	Table 2, line 1.3.3
J72(:S72)	=IF(J$66<>"";$T$68*J70;"")	Table 2, line 1.3.4
V72(:AE72)	=IF(V$66<>"";$AF$68*V70;"")	Table 2, line 1.3.4
Table 7		
L78	=SUM(OFFSET(AI52;;;J5;2))	Figure 1, block 3, line 1, left part of expression
L79	=SUMXMY2(OFFSET(T52;;;J5;); OFFSET(AF52;;;J5;))	-
L80	=IF(NOT(ISERROR(1-L79/(VAR.S(OFFSET(T52;;;J5;))*J5))); 1-L79/(VAR.S(OFFSET(T52;;;J5;))*J5);"-")	Table 2, line 1.4.1
L82	=IF(NOT(ISERROR(1-L79/(VAR.S(OFFSET(AF52;;;J5;))*J5))); 1-L79/(VAR.S(OFFSET(AF52;;;J5;))*J5);"-")	Table 2, line 1.4.1
Table 8		
J92(:S101)	=IF(AND($A92<>"";J$89<>"");IF($T52>0; J52*J$68/$T52;"-");"")	Table 2, line 2.1.1
T92(:U101)	=IF(A92<>"";IF(T52>0;SUM(OFFSET(J92;;;;$J$3)); "-");"")	-
V92(:AE101)	=IF(AND($A92<>"";V$89<>""); IF($AF52>0;V52*V$68/$AF52;"-");"")	Table 2, line 2.1.1
AF92(:AG101)	=IF(M92<>"";IF(AF52>0; SUM(OFFSET(V92;;;;$J$4));"-");"")	-
J102(:S102)	=IF(J$89<>"";AVERAGE(OFFSET(J$92;;;$J$5;));"")	Table 2, line 2.2.1
V102(:AE102)	=IF(V$89<>"";AVERAGE(OFFSET(V$92;;;$J$5;)); "")	Table 2, line 2.2.1
J103(:S103)	=IF(J$89<>"";MIN(OFFSET(J$92;;;$J$5;));"")	Table 2, line 2.2.2
V103(:AE103)	=IF(V$89<>"";MIN(OFFSET(V$92;;;$J$5;));"")	Table 2, line 2.2.2
J104(:S104)	=IF(J$89<>"";MAX(OFFSET(J$92;;;$J$5;));"")	Table 2, line 2.2.3
V104(:AE104)	=IF(V$89<>"";MAX(OFFSET(V$92;;;$J$5;));"")	Table 2, line 2.2.3
Table 9		
G107	value of initial data element	Table 1, line 1.2.1
J113:Q113	values of initial data elements	Table 1, line 1.2.2
V113:AB113	values of initial data elements	Table 1, line 1.2.2
J114(:S114)	=IF(NOT(ISERROR(VLOOKUP($G$107;$A$52:$AE$61;9+J$110))); VLOOKUP($G$107;$A$52:$AE$61;9+J$110);"")	Table 2, line 2.2.4
T114	=SUMPRODUCT(OFFSET(J114;;;;$J$4);OFFSET($V$68;;;;$J$4))	Table 2, line 2.3.1

V114(:AE114)	=IF(NOT(ISERROR(VLOOKUP($G$107;$A$52:$AE$61;21+V$110))); VLOOKUP($G$107;$A$52:$AE$61;21+V$110);"")	Table 2, line 2.2.4
AF114	=SUMPRODUCT(OFFSET(V114;;;;$J$4); OFFSET($V$68;;;;$J$4))	Table 2, line 2.3.1
J115(:S115)	=IF(J110<>"";J116*(J42-J43)+J43;"")	Table 2, line 2.2.9
V115:AB115	values of initial data elements	Table 1, line 1.2.3
J116(:S116)	=IF(J$110<>"";$T$116*J102/J68;"")	Table 2, line 2.2.8
T116	=T114+T118	Table 2, line 2.3.5
V116(:AE116)	=IF(V110<>"";IF(V$66<>""; (V115-V$43)/(V$42-V$43);0);"")	Table 2, line 2.2.5
AF116	=SUMPRODUCT(OFFSET(V116;;;;$J$4); OFFSET($V$68;;;;$J$4))	Table 2, line 2.3.2
J117(:S117)	=IF(J$110<>"";J115-J113;"")	Table 2, line 2.2.6
V117(:AE117)	=IF(V$110<>"";V115-V113;"")	Table 2, line 2.2.6
J118(:S118)	=IF(J$110<>"";J116-J114;"")	Table 2, line 2.2.7
T118	=AF118	Table 2, line 2.3.4
V118(:AE118)	=IF(V$110<>"";V116-V114;"")	Table 2, line 2.2.7
AF118	=AF116-AF114	Table 2, line 2.3.5

Table 4. Values of “Solver” add-in setting parameters for created procedure

“Solver” setting parameter	Parameter value	Procedure element
Objective cell	L78	Figure 1, block 3, line 1
Type of optimization problem	Minimum	
By changing variable cells	J68:Q68;	Table 1, line 2.1
	V68:AB68;	Table 1, line 2.1
	AI52:AJ61;	Table 1, line 2.2
	AL52:AL61	Table 1, line 2.2
Constraints	J68:Q68 >= J7;	Figure 1, block 3, line 2
	J68:Q68 <= J8;	
	V68:AB68 >= J7;	Figure 1, block 3, line 3
	V68:AB68 <= J8;	
	AI52:AJ61 >= 0;	Figure 1, block 3, lines 4, 5
	AI52:AJ61 = binary;	Figure 1, block 3, line 6
	J68:Q68 >= J71:Q71;	Figure 1, block 3, line 7
	J68:Q68 <= J72:Q72;	
	V68:AB68 >= V71:AB71;	Figure 1, block 3, line 8
	V68:AB68 <= V72:AB72;	
	AH52:AH61 = AK52:AK61;	Figure 1, block 3, line 9
	AI52:AI61 <= AM52:AM61;	Figure 1, block 3, line 10
	AJ52:AJ61 <= AN52:AN61	Figure 1, block 3, line 11
Solving method	Simplex LP	

A distinctive feature of this model is the linear nature of the relationship of nonlinear variables, that is, regression models with the optimality criterion - the sum of the squares of the absolute deviations of the predicted values of the complex indicator. A comprehensive indicator is an indicator of pollution for a given dataset of natural and industrial environments.

If this model is applied in practice, it is possible to obtain a program that analyzes the current state of the environment, depending on the quantity and quality of technogenic factors. Also, as a result of changes in quantitative indicators, this model will indicate critical changes in the natural environment.

4 Conclusions

A methodology was developed to justify the characteristics of environmental pollution, the result of which is a flowchart of the procedure for determining forecast values for the characteristics associated with the assessment of environmental pollution. Based on this technique, a model was obtained for predicting the pollution of the city, a distinctive feature of which is to separately account for the influence of factors of the natural and industrial environment, as well as the linear nature of the relationship of unknown variables representing the parameters of the regression model with the optimality criterion, which is the sum of the squares of the absolute deviation of the value a complex indicator of pollution for a given set of parameters of both considered environments. This model, to simplify working with it, was introduced into Microsoft Excel for automatic calculations according to given formulas and obtained indicators of the natural and technogenic environment.

Obviously, the resulting model will allow us to analyze the current state of the environment depending on the quantity and quality of environmental indicators, as well as determine critical changes in it. In the urban development industry, this model will help in planning the possibility of placing objects with a high environmental burden in a particular area. Also, in the case of finalizing this model, it is possible to predict the security measures taken, depending on the level of increase in the pollution indicator, taking into account certain factors.

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