Forecasting of Environmental Pressure Indicators as Part of the Monitoring of the Ecological and Socio-Economic Development of the Extracting Region

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Abstract—One of the components of monitoring of ecological-socio-economic development of the extracting region is forecasting. To assess the ecological-socio-economic development of Orenburg region, which is the extracting region, a system of indicators developed by the authors is used based on the "Pressure - State - Reaction" model. The indicators of the "state" and "reaction" blocks are relatively inert: time is needed in order for sharp changes to occur. Given the specifics of the indicators of the "pressure" block, which can fluctuate sharply due to environmental disasters, forecasting is proposed to be based on adaptive models that can quickly adapt to changing conditions and are quite effective in the short term. The article presents the results of applying the models of exponential smoothing with drift and adaptive Holt models to a number of indicators of environmental pressure in Orenburg region.

Keywords—forecasting, adaptive models, "pressure-state-reaction" model.

I. Introduction

In a number of regions of the Russian Federation, business is based on extraction. This type of economic activity has a significant impact on the environment and social spheres. On the one hand, extraction is the main source of income for such regions, on the other hand, extraction leads to environmental pollution, increased morbidity and mortality, and other negative consequences for the region's population [1].

The large-scale, prolonged impact of environmental pollution on the social sphere raises serious concerns. Existing measures to ensure environmental safety raise a number of issues in connection with the general deterioration of public health. A possible reason for this may be an insufficient reflection of the current state of affairs in the field of environmental and social security. For an objective display of the situation, monitoring is used, the object of which may be phenomena and processes that are different in their essence, strength and direction of display.

For an objective and complete presentation of the processes of social and economic development that are in a complex relationship, taking into account the environmental component, we introduced the concept of ecological-socio-economic development in relation to regions in which Mineral Extraction as the type of economic activity prevails.

In our earlier studies, we proposed a method for classifying regions as extractive, and also developed a methodology for monitoring the ecological-socio-economic development of an extracting region in the framework of the OECD "Pressure-State-Reaction" model [2, 3]. Such monitoring includes the stages of short-term forecasting of indicators of the system developed by us within the framework of the "Pressure-State-Reaction" model. It is proposed to develop forecasts based on adaptive models based on one-dimensional time series.

II. Literature review

Scientists such as Vasilev S.L., Pleshko M.S., Rossinskaya M.V., Shelomentsev A.G., Yurina V.S., Yandarbaeva L.A. et al. devoted their work to the development of monitoring methods in the field of ecological-socio-economic development of the regions. [4,5,6,7,8]. In the works of these authors, improved methods are proposed, as well as the results of monitoring the ecological-socio-economic development of the regions. For example, in the works of Vasenev S.L. a group of indicators is proposed, based on which ratings are assigned to federal districts and regions of the Russian Federation according to data for more than ten years [4]. To identify the relationship between economic development, the well-being of the population and the state of the environment, a correlation analysis is used, on the basis of which the author proves the validity of the statement that these groups of indicators are interrelated.

Monitoring includes not only observation, but analysis and forecasting [9]. The subject to rapid change is the environmental impact block. Indeed, emissions can vary significantly from year to year, for example, in the case of environmental disasters, which have a one-time significant impact on the environment, which over a long period of time will affect demographic indicators. Indicators of economic well-being are also quite inert compared to indicators of environmental impact. Thus, the task is to forecast indicators that reflect the impact on the environment, allowing for possible leaps in their dynamics.

In the studies of Aralbaeva G.G. methods of monitoring the regional socio-economic system are presented, aimed at the quality of life of the population, tested on the example of the Orenburg region [9]. However, in our opinion, the environmental component is poorly reflected in them.

In early studies, we showed the advantage of a system of indicators of the ecological-socio-economic development of the extracting region, based on the "Pressure-State-Reaction" model [3].

Since the system of indicators we developed includes several dozens of indicators in each block of the "Pressure-State-Reaction" model, for convenience we will present it in the form of a diagram (Figure 1).
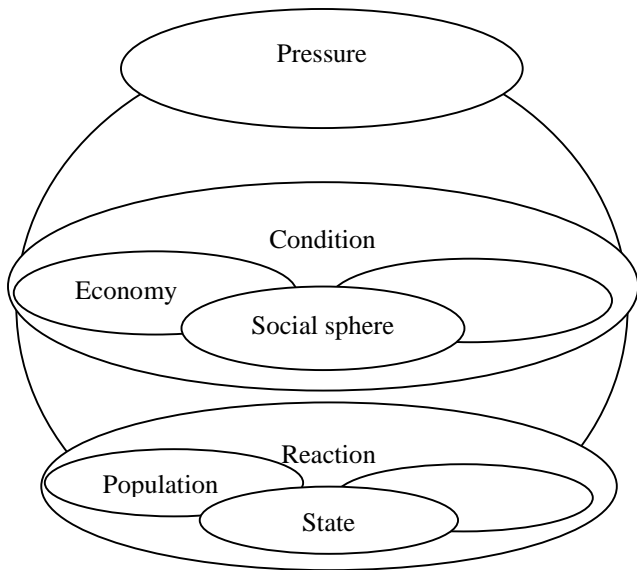

Fig. 1. Scheme of the relationship of factors in the proposed system of indicators in the framework of the model "Pressure - state - reaction"

In the part of the "Pressure" block, we will consider the indicators:

- emissions of pollutants into the atmosphere from mobile sources, kt;

- emissions of pollutants into the air from stationary sources, kt;

- abstraction of water from natural water sources for use, million cubic tons;

- volume of discharged contaminated wastewater (without treatment and insufficiently treated), million cubic tons;

- generation of production and consumption wastes, kt;

- generation of high hazard class waste, kt.

Each of the indicators is represented by time series for the period from 2000 to 2017.

III. RESEARCH METHODOLOGY

To predict time series, both multidimensional and one-dimensional time series can be used. The advantage of methods using one-dimensional time series is their relative simplicity, as well as the assumption that all factors that influence the indicator are predicted as if in absentia (automatically). Which is quite justified in those cases when multifactor models cannot be used due to the fact that many factors of multidirectional influence impact the effective indicator, while a number of them is not observed at all.

Methods for forecasting one-dimensional time series, in turn, are divided into methods based on discounting information, and conventional methods. Conventional methods, as a rule, are based on the use of linear and nonlinear time regression models (growth curves). The use of growth curves when forecasting within the framework of the indicators we are considering is impractical from the point of

view of the fact that such models do not take into account possible sharp changes associated with changes in technologies, legislation, environmental disasters, etc. The use of adaptive models (models discounting information) will allow you to quickly take into account and adapt to changing conditions, which should improve the quality of forecasts.

For forecasting, we use adaptive Holt models and simple exponential smoothing with drift.

The general form of exponential smoothing with drift has the form:

$$S_t = \alpha X_{t-1} + \beta S_{t-1} + a, \qquad (1)$$

where S_t is the smoothed level;

α – adaptation parameter, and $0 < \alpha < 1$, $\beta = 1 - \alpha$;

a – the coefficient of the angle of inclination, calculated over the entire row.

We substitute sequentially instead of its expression for the moments $t - 1, t - 2, \ldots$:

$$S_t = \alpha X_{t-1} + \beta(\alpha X_{t-2} + \beta S_{t-2} + a) + a \qquad (2)$$

$$s_t = \alpha \sum_{i=1}^{\infty} \beta^{i-1} x_{t-i} + a \sum_{i=0}^{\infty} \beta^i + \sum_{i=1}^{\infty} \beta^i s_{t-i} =$$
$$\alpha \sum_{i=1}^{\infty} \beta^{i-1} x_{t-i} + \frac{a}{\alpha} + \sum_{i=1}^{\infty} \beta^i s_{t-i} \qquad (3)$$

For long time series, the first and third members of this expression tend to 0. The coefficient of the growth angle has a weight equal to 1 for the current t, and as it recedes into the past its weight (influence) decreases. The closer the adaptation parameter to unity α, the more the model adapts to changing conditions [10]. For pressure indicators that can simultaneously take on large values (for example, due to emissions from environmental disasters), the use of adaptive models is justified.

More complex than the drift exponential smoothing model is the Holt model, the general view of which is:

$$\begin{cases} \hat{x}_{t+L} = \lambda_t + L * b_t \\ \lambda_t = \alpha x_t + (1 - \alpha)(\lambda_{t-1} + b_{t-1}) \\ b_t = \beta^*(\lambda_t - \lambda_{t-1}) + (1 - \beta^*) b_{t-1} \end{cases} \qquad (4)$$

where λ_t, b_t are the coefficients of the model, which, in turn, also change according to the exponential smoothing scheme with adaptation parameters α and β^*;

L – the period of time for which the forecast is made.

The first expression in (4) is a first-order linear autoregression with constant growth; the second expression is a Brown model.

If $\beta^* = \alpha$, the model of double smoothing is obtained [11].

The choice of adaptation parameters is based on the calculation of forecast accuracy indicators [12]. As an indicator of forecast accuracy, we use the average absolute percentage error, which is calculated by the formula:

$$MAPE = \frac{1}{T} \sum_{t=1}^{T} \frac{|y_t - \hat{y}_t|}{y_t} \cdot 100 \qquad (5)$$

If the value of the average absolute percentage error does not exceed 10%, then it is considered that the forecast is of high quality.

IV. RESULTS

For convenience, we present the simulation results in the form of table 1. The value of the adaptation parameter is found by enumerating in the range from 0 to 1 inclusively in increments of 0.05. A value is selected that gives a minimum of the average absolute percentage error. The initial value is taken equal to the first observation. The growth coefficient is averaged over all observations.

TABLE I.   RESULTS OF THE ESTIMATION OF THE MODEL OF SIMPLE EXPONENTIAL SMOOTHING WITH DRIFT

Indicator name	The value of the adaptation parameter	Initial values	The value of the coefficient of growth angle	Average absolute percentage error, %
The volume of discharged contaminated wastewater (without treatment and insufficiently treated), million cubic tons	0.7	130	-2.82	1.62
Production and consumption waste generation, thousand tons	0.6	9200	1.66	3.6
Water abstraction from natural water sources for use, million cubic tons	0.7	1850	3.1	7.1
Pollutant emissions into the atmospheric air from stationary sources, kt	0.8	530	1.9	4.6
Air pollutant emissions, from mobile sources, kt	0.9	133	1.75	4.9

According to the results obtained, for each series of dynamics, the forecast quality indicator does not exceed 10%, which indicates a high predictive quality of the exponential drift model. The adaptation indicators in this case take values from 0.6 to 0.9; which is considered quite high values. For example, the author of the method of exponential smoothing suggested taking the adaptation parameter depending on the volume of observations, in particular, according to his technique, the adaptation parameter should be no more than 0.12. However, such adaptation parameter values can be suitable only for stationary series of dynamics, the average value of which does not change over time. In our case, the series of dynamics of the considered indicators contain a

tendency to decrease or increase, which forces us to increase the adaptation parameter and add the magnitude of the drift.

Similarly, smoothing of the series of dynamics on the basis of the Holt model was carried out. The Holt model implies the presence of an increasing or decreasing trend without a periodic component. Indeed, according to annual data, a seasonal periodic component is not possible, and a cyclic periodic component for the series in question was not found (testing was carried out on the basis of the "peaks and pits" criterion).

The values of the Holt model parameters, as well as the forecast quality indicator, are presented in Table 2.

TABLE II.   THE RESULTS OF THE EVALUATION OF THE PARAMETERS OF THE HOLT MODEL

Indicator Name	The value of the adaptation parameter α	The value of the adaptation parameter β^*	Initial values	Average absolute percentage error, %
The volume of discharged contaminated wastewater (without treatment and not sufficiently treated), million cubic tons	0.95	0.1	154.4	1.59
production and consumption waste generation, kt	0.75	0.05	7692	20.2
Water abstraction from natural water sources for use, million cubic tons	0.45	0.75	1894	7.16
air pollutant emissions from stationary sources, kt	0.95	0.35	531.6	14.31
air pollutant emissions, from mobile sources, kt	0.95	0.05	128.6	13.97

Adaptation parameter for intermediate level α is mostly higher than for the autoregressive adaptation parameter β^*.

The latter varies from 0.1 to 0.75; and for two rows takes the value of 0.05; which indicates that the autoregressive part does not undergo significant changes over time, that is, the growths remain relatively constant in the period under review. According to the data presented in Table 2, the Holt model is inferior in terms of predictive qualities to the model of exponential smoothing with drift. The values of the forecast accuracy indicator presented in the last column of Table 2 are much higher than the similar values from the last column of Table 1. Therefore, we use the model of exponential smoothing with drift for forecasting, the results are presented in Table 3.

TABLE III.   THE RESULTS OF FORECASTING INDICATORS OF PRESSURE ON THE ENVIRONMENT IN THE ORENBURG REGION UNTIL 2021

Years	Production and consumption waste generation, kt	Air pollutant emissions, from stationary sources, kt	Water abstraction from natural water sources for use, million cubic tons	The volume of discharged contaminated wastewater (without treatment and not sufficiently treated), million cubic tons	Air pollutant emissions from mobile sources, kt
2019	59647.50	470.22	952.72	104.12	283.07
2020	59582.67	469.88	948.98	104.06	283.21
2021	59550.26	469.71	947.11	104.03	283.29

According to the forecasts, in the next three years the pressure on the environment will decrease. For example, waste generation will decrease by 2021 to the level of 59550.26 thousand tons. For comparison: in 2017, this figure was 60555 thousand tons. We will demonstrate the possibilities of adapting the model for the scenario of a significant (1000 thousand tons, for comparison: in 2004 their volume amounted to 905 thousand tons) of pollutant emissions into the air from stationary sources in 2015 (Fig. 2).
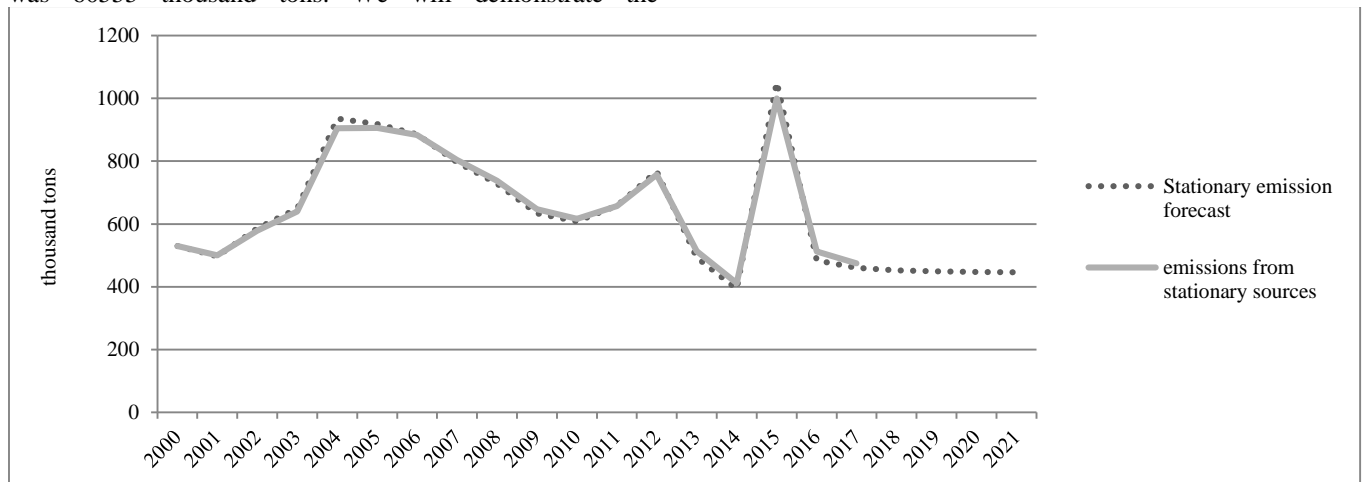

Fig. 2. Results of modeling and forecasting emissions from stationary sources for the significant emission scenario in 2015

The proposed scenario would actually reflect an environmental disaster. As we can see, the model quickly adapted to the changing conditions: model values (shown by a dashed line) approximate real values well. At the same time, a significant emission in one year did not affect further forecast values.

V. Conclusion

For regions where the type of economic activity "Mineral Extraction" has developed significantly, monitoring of ecological-socio-economic development is of particular relevance. In world practice, the model "Pressure - State - Reaction" is generally accepted, on the basis of which we developed a system of indicators for assessing the ecological-socio-economic development of the extracting region. Monitoring, in addition to observing and analyzing indicators, also includes forecasting their levels. The indicators of the "state" and "reaction" blocks are relatively inert in dynamics: significant changes in the social and economic sphere do not occur in one or two years. The indicators of the "pressure" block, on the contrary, can fluctuate sharply, for example, due to environmental disasters (emissions, oil spills, other technological disasters). For this reason, it is undesirable for such indicators to apply forecasting methods that assume a continuation of the current trend for the future and do not take into account the importance of the age of information. It is advisable to build forecasts based on adaptive forecasting models that can quickly adapt to changing conditions.

As a result of applying the models of exponential smoothing with drift and adaptive Holt models to a number of environmental pressure indicators in Orenburg region of the Russian Federation, where the type of economic activity "Mineral extraction" is developed, forecasts of their levels up to 2021 were obtained.

The types of exponential smoothing used in the study when developing similar forecasts for other extracting regions of the Russian Federation can be replaced by others depending on the characteristics of the series of dynamics. When new information is received for 2018-2019, the data can be added to the model to refine the forecasts for 2020 and 2021.

In further studies, forecasts will be developed for indicators of other blocks within the framework of the "Pressure–State–Reaction" model. For the "State" block for complex socio-economic processes taking place within it, multifactor forecasting models will be used that take into account the variety of relationships between various indicators of economic and social development [13].

References

[1] O. A. Kozlova, A. G. Shelomentsev, and E. A. Trushkova, "Influence of environmental factors on life expectancy in the Sverdlovsk region," Social aspects of population health, No. 6 (64), pp. 12, 2018. (in russ.)

[2] L. V. Kirchmeer, "Extraordinary regions: criteria for application and development features," Ehkonomika i menedzhment sistem upravleniya (Economics and Management Systems Management), Vol. 28, No. 2-2, pp. 222-229, 2018. (in russ.)

[3] L. V. Kirchmeer, "Monitoring of ecological and socio-economic development of the extracting region," Azimuth of scientific research: economics and administration, Vol. 8, No. 1 (26), pp. 173-175, 2019. (in russ.)

[4] S. L. Vasenev, "Ecological, socio-economic monitoring of Russian regions," Inzhenernyj vestnik Dona (Engineering Bulletin of the Don), No. 2 (20), pp. 527-536, 2012. (in russ.)

[5] M. V. Rossinskaya and M. S. Pleshko, "Develop effective ways of sustainable development in the region based on the data of socio-ecological-economic monitoring," Modern fundamental and applied researches, No. S1, pp. 77-80, 2013. (in russ.)

[6] N. I. Perminova and A. G. Shelomentsev, Guidelines for the organization of socio-economic monitoring of coal-mining territories. Yekaterinburg: Institute of Economics, Ural Branch of RAS, 2004. (in russ.)

[7] V. S. Yurina, "Scientific and methodological foundations of regional environmental and economic monitoring," Vestnik SamGUPS (Bulletin of SamGUPS), No. 2-1 (28), pp. 117-124, 2015. (in russ.)

[8] L. A. Yandarbayeva, A. Yu. Adzhieva, L. A. Tsuruva, A. V. Misakov, and Z. Kh. Molamusov, "Theoretical and methodological foundations of the regional social-ecological-economic system polyfactor monitoring," The Turkish Online Journal of Design, Art and Communication, Vol. 8, No. S-MRCHSPCL, pp. 39-44, 2018.

[9] G. G. Aralbaev, The main directions of monitoring the regional socio-economic system. Moscow: Economics, 2009. (in russ.)

[10] R. J. Hyndman and B. Billah, "Unmasking the Theta method," International Journal of Forecasting, Vol. 19, No. 2, pp. 287-290, 2003. https://doi.org/10.1016/S0169-2070(01)00143-1

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[11] I. S. Svetunkov and S. G. Svetunkov, Methods of socio-economic forecasting in 2 volumes. Vol. 2 models and methods: a textbook and workshop for academic undergraduate. Moscow: Yurayt Publishing House, 2019. (in russ.)

[12] V. P. Kovalevsky, "About approaches to verification of forecasts of mathematical models of socio-economic processes [Electronic resource," Orenburg: Orenburg State University, pp. 2669-2672, 2019. (in russ.) [University complex as a regional center of education, science

and culture: materials of All-Russian. scientific method. conf. (with international participation), January 2019]

[13] O. Kosorukov Forecast of separate indicators for socio-economic development of the Russian Federation up to 2020," World Applied Sciences Journal, Vol. 18, No. SPL.ISSUE. 18, pp. 18-26, 2012. (in russ.)