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Fuzzy Indicators of the Forecast of Environmental Safety Taking into Account the Impact of Natural and Technosphere Factors

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ABSTRACT

The emergence and uncontrolled development of environmental hazards in the processes of life in the absence of appropriate response measures in many cases leads to the emergence of man-made emergencies with dangerous consequences for public health and the environment. It is proposed to evaluate the results of complex monitoring and forecasting of these dangerous processes in a new format of creating a fuzzy scale of indicators of the level of environmental safety of life support of territories based on the theory of fuzzy sets. The study aims to develop a fuzzy scale of indicators for predicting the state of environmental protection. Protection of the population and territories from environmental threats and possible man-made emergencies. Within the framework of the purpose of the study, a fuzzy scale of threshold levels of environmental safety of territories and economic objects has been developed based on the theory of fuzzy sets and the mathematical apparatus of soft computing. The practical significance of the developments is confirmed by the successful application of the proposed scale of indicators and indicators in assessing the environmental hazard of life support systems of settlements and industrial enterprises affecting the environment.

INTRODUCTION

The analysis of information on emergencies (emergencies) with dangerous environmental consequences has shown that natural disasters, as well as dangerous technogenic processes and accidents, are the main causes of emergencies and pose a significant threat to the environmental safety of the world community, the population, socio-economic development (Oltyan et al. 2020). In this regard, achieving Sustainable Development Goals determines the relevance of scientific and methodological tasks to substantiate mechanisms for improving the forecasting of environmental threats and emergencies for timely prevention. The most important task is the development of effective environmental safety systems that ensure the protection of the natural environment, population, and territories from the negative impact of technosphere objects, the main ones being toxic waste, emissions, and discharges into the natural environment (Tshovrebov et al. 2018a).

As a positive example of preventing environmentally hazardous situations associated with the formation and placement of life results in solid toxic waste, the experience of the Southeast Asian countries should be highlighted. For a long time, such waste has served as a dangerous socio-ecological problem for the environment and the health of the population of these countries (Liu et al. 2000, Bredel 1995).

To gradually solve the current urgent problem, in 2010, the States of the Pacific zone (China, Indonesia, and Australia) created the Asian Coal Ash Association (Asian Coal Ash Association), which was then joined by other countries. As a result, through joint efforts, a well-structured strategy, an effective legal framework, and management models for achieving the task were formed. The legislation of India and other countries provides for a dynamically changing value, depending on economic conditions, for the mandatory use of fuel slag as the main material for the construction of embankments, in road works, the production of wall materials, block structures at facilities located within a radius of 25-100 km from thermal power plants and CHP. A similar legal norm regulates the use of waste in other areas. As a result of environmentally and economically justified actions over the past decade in India, China, and the countries of Southeast Asia, the level of ash and slag processing from the total volume of such waste generation has reached over 75-80%.

In 2014-2019 India successfully implemented a nationwide program to clean the country of garbage, “Swah Bharat”, to popularize a resource-saving and environmentally friendly lifestyle. In Panaji and Alappuzha, facilities have been liquidated, and the territories of former waste disposal have been recultivated. Effective implementation of systems for the selective collection of municipal waste is underway, considering that their composition contains over 60% organic matter. New and innovative biocomposting technologies are being introduced as part of this initiative. Similar decisions are being made in the world regarding the disposal and recycling of waste from electronic and household equipment (Baldé et al. 2017, Zeng et al. 2018), solid municipal and construction waste (Sereda & Kostarev 2021, Sereda et al. 2022), and a number of other hazardous technosphere objects from products used in the life process. Such solutions serve as the basis for the prevention of natural hazards, hydrometeorological and other processes: smog, dust storms, landslides, subsidence of soils, loss of forests, shortage of drinking water as a result of water poisoning, and destruction of biological resources irretrievably lost for water supply of underground aquifers (Hertwich et al. 2020, Liu et al. 2016, Omar et al. 2019, Varughese 2017).

The adoption of scientifically sound system management, organizational, technical, and technological solutions to reduce technosphere hazards contributes to the comprehensive solution of social problems, ensuring environmental, economic, and food security, availability of necessary drinking water supplies, and groundwater purification (Bhagawati et al. 2017, He et al. 2017, Rosalia & Hakim 2021), the implementation of a closed-cycle economy, the return of safe, natural resources to the environment (Domenech et al. 2019, Hart & Adam 2019, Kirchherr et al. 2017).

In 2015, the Prime Minister of India and the Head of the Ministry of Emergency Situations of Russia reached agreements on cooperation in the field of emergency prevention and response, exchange of information on hazards and threats, including environmental ones, obtained using space monitoring methods. The main threats to natural and man-made nature include the death of forests, desertification of territories, smog, reduction of biodiversity, dangerous effects of agrochemicals, and toxic waste on soils and water bodies.

In the given context of the pressing issue, the utilization of advanced forecasting techniques for environmental threats and emergencies is of paramount importance. This approach aims to assess the likelihood of emergencies’ emergence, occurrence, and progression by systematically analyzing potential causes and conditions that could lead to an uncontrolled escalation of environmental hazards, thereby reaching hazardous levels.

However, at present, the formation of a forecast can be based only on a limited set of incomplete data that make up information in the field of protection of the population and territories from emergencies, the composition of which is determined by the framework of information exchange between the Ministry of Emergency Situations of Russia, other agencies, and at the international level - with other countries. At the same time, the effectiveness of emergency forecasting largely depends on the accuracy of related forecasts of the state, dynamics of changes in natural and man-made factors, and sources of environmental hazards, which are not always and not fully provided. The revealed contradiction formed the need to develop a new approach to forecasting environmental hazards based on the application of fuzzy set theory and fuzzy logic.

The issues of using artificial intelligence in forecasting environmental threats and assessing the state of technosphere security of territories based on a systematic analysis of monitoring data are relevant in solving global problems of socio-economic development that do not have state borders.

MATERIALS AND METHODS

The research methods are based on the application of system analysis, the theory of fuzzy sets, realizing the possibilities of soft computing when calculating the levels of environmental safety of the population and territories, thereby providing an opportunity for a comprehensive assessment and analysis of trends and interrelated processes of the state of protection of the natural environment and vital human interests from the dangerous impacts of technosphere objects, taking into account various factors, conditions, and restrictions.

The strategy of this study correlates with the concepts accepted in the world community: “Zero waste” (Elgizawy et al. 2016, Murray 2002), “Circular economy” based on the materials of many years of research, the results of the author’s own research in the field of environmental safety, environmental protection, prevention of environmentally hazardous situations at life support facilities technosphere territories (Tshovrebov et al. 2018b, 2021).

RESULTS AND DISCUSSION

In the course of the study, the authors took into account the materials of generalization, analysis of the scientific and practical results achieved in the world in the subject area under study (Anisimov et al. 2017, Oltyan et al. 2020, Saurenko et al. 2018), indicating the following features and trends.

Firstly, the existing methods of assessing the state of technosphere danger of an object or territory and forecasting possible adverse consequences are insufficiently interconnected in a single system, which, in turn, reduces the effectiveness, validity, and reliability of the forecast, as well as the completeness, timeliness, and effectiveness of management decisions to prevent man-made emergencies based on the establishment of causal investigative links.

Secondly, the starting point of the vector of the development of an emergency situation from an unfavorable one has not been established and characterized.

Thirdly, the totality of various factors, limitations, conditions, and causes of the origin, course, and development of environmentally hazardous processes is not sufficiently taken into account, and consequently, the ability to make a reliable forecast of the assessment of hazardous environmental consequences is limited.

The presence of not fully researched aspects of the subject area that do not allow the effective use of accurate forecasting methods in solving state tasks of preventing man-made emergencies required the development of a fundamentally new approach to the methodology of forecasting the occurrence and development of environmental hazards.

Taking into account that in the formation of environmental forecasts, there are no strict approaches that allow for obtaining an unambiguous result for the optimal time in vaguely expressed conditions for the preparation of project, organizational, technical, and managerial decisions, the research methodology is based on the theory of soft computing using inaccurate and mathematically not strictly conditioned methods, algorithms that implement the achievement of goals and research tasks.

The use of the theory of fuzzy sets and the method of soft computing provides an analytical platform for the presence of a threshold for estimating changes in the studied indicators in the interval {0;1}. In other words, the formed threshold model of environmental forecasting (*EF*) assumes the presence of a threshold (level) below or above which the factor studied in the course of forecasting does not function:

$$EF = F\,(P_f/P_p), \qquad \ldots(1)$$

P_p - is a safe limiting threshold level of exposure (permissible, background or temporarily agreed concentration, the volume of allocated pollution during the operation of an object, process in normal mode, or the amount of discharge, emission as a function of these indicators;

P_f - actual impact taking into account changing factors and conditions;

F is the Heaviside function ($F(P_f - P_p) = 0$ at $(P_f - P_p) \leq 0$ and $F(P_f - P_p) = 1$ at $(P_f - P_p) > 0$).

An acceptable information and analytical basis for the proposed approach can serve as a restrictive system of maximum permissible concentrations (MPC) of pollutants in the components of the natural environment: waters, soils, and atmospheric air. Firstly, compliance with the level of safety in relation to public health and the natural environment is guaranteed when using this system. Secondly, the threshold principle is fully implemented, which applies to all factors of a negative impact, and thirdly, the level of danger of the pollutant, the effects of summation, and the joint presence of various substances are taken into account. Taking into account the limiting indicators of the harmfulness of various groups of pollutants.

Taking into account that the MPC of pollutants has been approved to assess the safety of three groups of components of the natural environment, we present a classification of the potentially possible threshold impact of various technosphere emergencies on these natural components (Table 1).

According to the criteria adopted in Russia, an emergency is characterized by a ratio (R_f/R_p) = 5 or 50 when exposed to chemicals on soils and atmospheric air or water resources. Such gradation does not fully reflect the level of both danger and toxicity of specific pollutants, the effects of summation, the conditions and intensity of pollution, and the types and severity of the consequences.

For a more complete and accurate justification of the processes and phenomena under consideration, within the framework of a conditionally deterministic approach, modeling of the predictive state of changing stepwise processes characterizing the dynamics of environmental hazard of the technosphere objects under study can be characterized by a function of the form:

$$P(T) = \sum_{j=1}^{n} . \sum_{i=1}^{n} \Delta ij \; n(\mathrm{T} - \mathrm{T}ij) \qquad \ldots(2)$$

P(*T*) – forecast of the hazard level of the object (territory) by time *T*;

Δij – the predicted magnitude of the negative impact on the *i*-th component of the natural environment (a. water, b. soil, c. atmospheric air), which determines the threshold of the *j*-th event or situation (a. regular (normative, safe); b. unfavorable (potentially dangerous); c. emergency (extreme));

Tij – the predicted (expected) moment of occurrence of the *j*-th event due to the time-continuing impact on the *i*-th component of the natural environment;

Table 1: Threshold impact of technospheric emergencies on natural components.

Technosphere emergencies	Threshold effect on natural components		
	Water (*kв*)	Soil quality (*ke*)	Atmospheric air (*ko*)
Accidents of freight and passenger trains with the release, spillage, scattering, and dumping of hazardous chemicals	1	1	1
Accidents of cargo and passenger ships	1	1	0
Aviation disasters	0	1	1
Major car accidents	0	1	0
Accidents on oil pipelines	1	1	1
Accidents on main gas pipelines	0	0	1
Accidents on electric power systems	0	1	0
Accidents on utility systems	1	1	1
Accidents on heating networks	0	0	1
Hydrodynamic accidents	1	0	0
Accidents with the release (threat of release) of chemically hazardous substances	0	0	1
Accidents at agricultural facilities	1	1	0
Explosions in buildings in populated areas	0	1	1
Explosions at industrial facilities	0	1	1
Explosions on communications	1	1	1
Sudden collapse of buildings	0	1	1
Sudden collapse of rocks, dumps, embankments	0	1	1
Poisoning and pollution of water bodies	1	0	0
Forest fires and forest arson	0	0	1
Fires in landfills	0	0	1
Infiltration is the translocation of toxicants from the body of landfills and landfills into the environment	1	1	1

$n(T\text{-}Tij)$ – fuzzy view function:

$$n(T\text{-}Tij) = \begin{cases} 1, \text{ if } (T\text{-}Tij) > 0 \\ 0, \text{ if } (T\text{-}Tij) \le 0 \end{cases} \qquad I = \{1;3\},\ j = \{1;3\} \qquad ...(3)$$

Depending on (2), a relationship is achieved between the specific forms of manifestation of environmental hazards, their quantitative expression, and the intensity of propagation in time and space.

The process of the origin, formation, accumulation, and impact of dangerous factors and their development in dangerous situations has certain stages (stages). The accumulation of dangerous environmental and related factors to a certain level precedes the emergence of a dangerous environmental situation, which, in turn, if proper preventive measures are not taken, precedes the occurrence of all these types of accidents, catastrophes, and emergencies. The accumulation of dangerous factors, their development into dangerous situations and further into environmental emergencies can be schematically represented as follows:

Dangerous factor (+ Dangerous Factor) + Conditions that create (generate) danger → Danger → Unfavorable (environmentally dangerous, threatening) situation → Environmental emergency

Taking into account this causal relationship scheme, a model of a composite criterion for the environmentally safe (*ES*) condition of the territories of enterprises and regions in relation to potential sources of ecologic impact has been formed (Fig. 1).

The formation of these indicators into a composite criterion is carried out through a system of sequential transformations:

$$\boldsymbol{ke^0\, ko^0\, k\text{в}^0} \Rightarrow ke^0\, \boldsymbol{ko^1}\, k\text{в}^0 \Rightarrow \boldsymbol{ke^1}\, ko^0\, k\text{в}^0 \Rightarrow ke^0\, \boldsymbol{ko^2}\, k\text{в}^0 \Rightarrow \boldsymbol{ke^2}\, ko^0\, k\text{в}^0$$

$$\boldsymbol{ke^0\, ko^0\, k\text{в}^0} \Rightarrow \boldsymbol{ke^1}\, ko^0\, k\text{в}^0 \Rightarrow ke^0\, ko^0\, \boldsymbol{k\text{в}^1} \Rightarrow \boldsymbol{ke^2}\, ko^0\, k\text{в}^0 \Rightarrow ke^0\, ko^0\, \boldsymbol{k\text{в}^2}$$

$$\boldsymbol{ke^0\, ko^0\, k\text{в}^0} \Rightarrow ke^0\, \boldsymbol{ko^1}\, k\text{в}^0 \Rightarrow ke^0\, ko^0\, \boldsymbol{k\text{в}^1} \Rightarrow ke^0\, \boldsymbol{ko^2}\, k\text{в}^0 \Rightarrow ke^0\, ko^0\, \boldsymbol{k\text{в}^2}$$

As a result, the composite *ES* criterion is defined as follows:

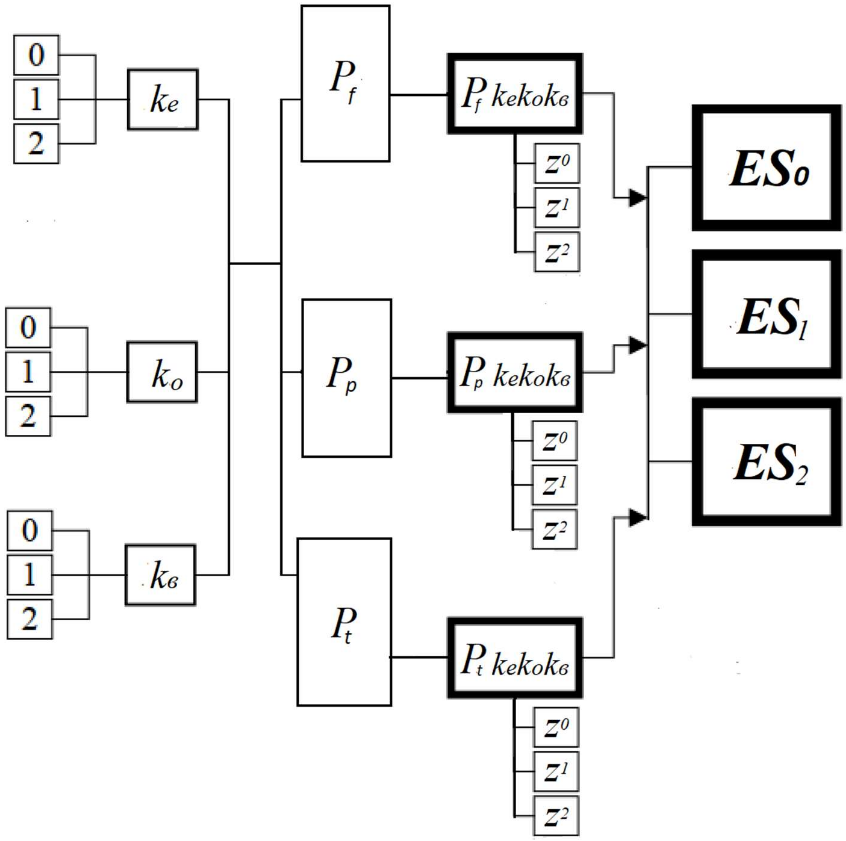

Fig. 1: Scale of composite criteria for assessing the level of environmental hazard.

ES^{0} | ES^{1} | ES^{2}

$\boldsymbol{ke^{0}\, ko^{0}\, k\textit{в}^{0}} \Rightarrow ke^{0}\, \boldsymbol{ko^{1}}\, k\textit{в}^{0} \,|\Rightarrow \boldsymbol{ke^{1}}\, ko^{0}\, k\textit{в}^{0} \Rightarrow ke^{0}\, ko^{0}\, \boldsymbol{k\textit{в}^{1}} \Rightarrow ke^{0}\, \boldsymbol{ko^{2}}\, k\textit{в}^{0} \,|\Rightarrow \boldsymbol{ke^{2}}\, ko^{0}\, k\textit{в}^{0} \Rightarrow ke^{0}\, ko^{0}\, \boldsymbol{k\textit{в}^{2}}$

Each of the criteria is determined by a set of characteristics determined by a set of parameters or a specific parameter. The initial set of alternatives is described by three indicators (*Pf, Pp, Pt*) and weight features (*ke, ko, kв*) having ordered threshold scales of discrete estimates: P_f ={0,1,2}; P_p ={0,1,2}; P_t ={0,1,2} and their products as resultant indicators expressing both factors ($Z^0; Z^1; Z^2$).

Many alternatives are grouped into three ordered classes: ES_0, ES_1, ES_2 - "Environmental safety" with assessments of levels: 0 – (safe); 1 – unfavorable; 2 - extreme (dangerous), corresponding to the gradations of the scale of the composite criterion of the upper-level $Z = \{Z^0, Z^1, Z^2\}$. The indicators of the fuzzy assessment scale correspond to the above three composite criteria for predictive assessment of the possible escalation of a standard (regular situation) through an unfavorable one into an emergency and form a fuzzy scale of the level of environmental safety of territories. For the quantitative interpretation of the fuzzy assessment of the level of environmental safety, a point assessment of the weight of indicators is proposed, followed by a ranking of threshold levels by the sum of the assigned points as a result of an expert assessment based on an analysis of the environmental situation (Fig. 2).

The factors determining the "critical" indicator are assigned a numerical value of "-0.2", "unacceptable – "-0.04", "normative" - "0", comfortable – "0.2", taking into account the transition from one threshold level to another within the boundaries of the fuzzy rating scale [-1;1] with the designations: a – lower the boundary of the critical level (-1); b – unfavorable (-0.2); c - normative (0); d – safe (1). The permissible zero level determines the starting point of the safe state of the life support system. It is assumed that the total balance of indicators determining the minimum level of environmentally safe condition of the territory, the object should have a positive value, satisfactory - exceed the value of "0.2", average – "0.5", high – "0.7", the highest - one. In this case, the environmentally safe level will correspond to finding an indicator of the state of the territory in the range of fuzzy estimates [0;1] according to the proposed fuzzy scale.

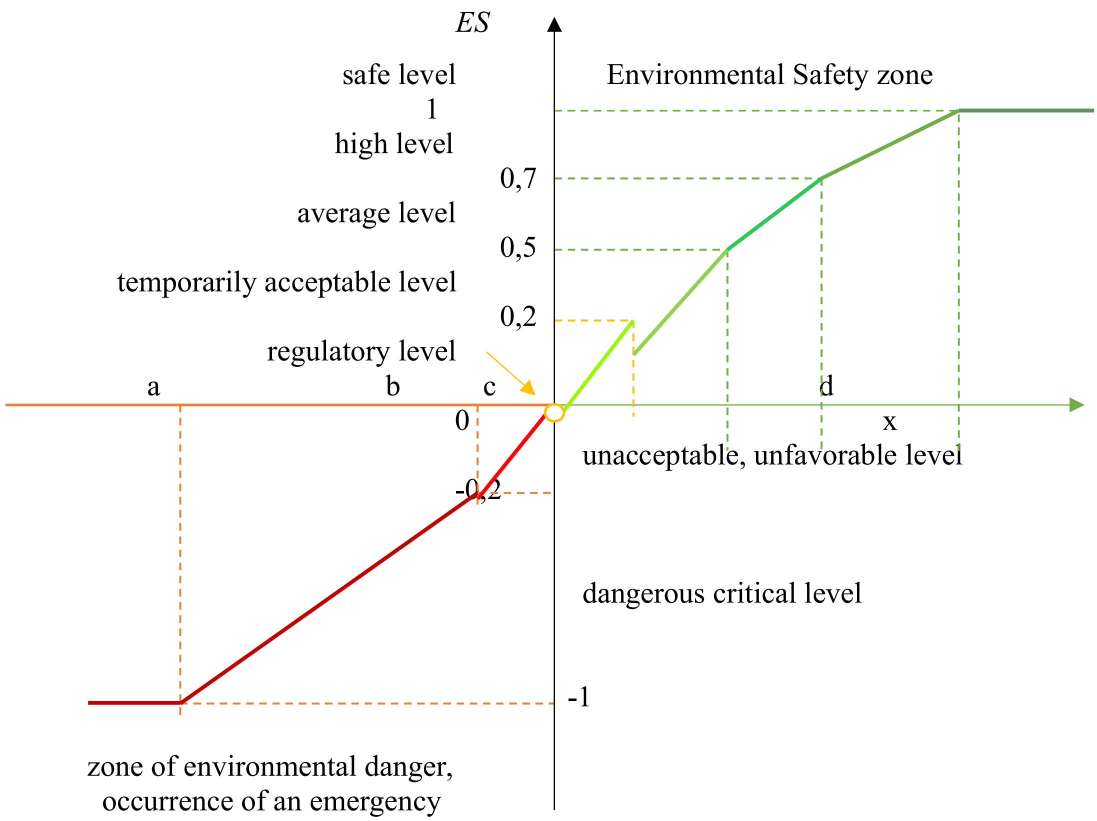

Fig. 2: Graphical interpretation of the membership function of assessments of environmental safety indicators of a fuzzy point scale.

Operational, medium- and long-term forecasts of the state of protection of the natural environment from the effects of technosphere objects are proposed to be carried out based on the use of mathematical logic methods to assess groups of environmental conditions: safe, unfavorable, dangerous, catastrophic (emergency) in accordance with the developed indicators.

CONCLUSION

A fuzzy scale of indicators is presented, which makes it possible to apply the numerical apparatus of soft computing. It displays in a formalized form the current state, development scenarios, and forecast of environmentally safe life support of territories based on a fuzzy scale of levels reflecting the quantitative interpretation of the weight of the established indicators using a point assessment.

The scientific and applied significance of the developed fuzzy scale of environmental safety indicators is confirmed by a wide range of practical implementation possibilities: when assessing the safety of facilities; within the framework of updating legal acts in the field of forecasting and prevention of emergencies; as criteria for both technospheric emergencies and environmental assessment of territories; analyzing the effectiveness of government agencies and business by introducing a fuzzy indicator, reflecting the situation and the measures taken in the field of environmental safety and emergency prevention.

Forecasting of the five emergency levels adopted in many countries of the world (federal, interregional, regional, municipal, facility), in the format of the proposed fuzzy system for assessing environmental safety indicators in scientific and methodological terms should be based on the possibilities of the use of integrated monitoring databases that allow you to monitor the development of the situation at all territorial levels at once; work with large data sets, detailing the numerical values of factors of natural and man-made sources of emergencies, as well as with the maximum number of characteristics of protected objects of the economy; construction of mathematically calculated digital models of the prospects and visualization of the development of emergencies in relation to state information systems and emergency warning systems.

REFERENCES

Anisimov, V.G., Zegzhda, P.D., Anisimov, E.G., Saurenko, T.N. and Prisyazhnyuk, S.P. 2017. Indices of the effectiveness of information protection in an information interaction system for controlling complex distributed organizational objects. Autom. Contr. Comp. Sci., 51(8): 824-828.

Baldé, C.P., Forti, V., Gray, V., Kuehr, R. and Stegmann P. 2017. The Global E-waste Monitor. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna. p. 53.

Bhagawati, R., Bhagawati, K., Jini, D., Alone, R.A., Singh, R., Chandra, A., Makdoh, B., Sen, A. and Shukla, K.K. 2017. Review on climate change and its impact on agriculture of Arunachal Pradesh in the Northeastern Himalayan region of India. Nat. Environ. Pollut. Technol., 6(2): 535-539.

Bredel, G. 1995. Tackling India's coal ash problem. Mining Eng., 10: 51.

Domenech, T. and Bahn-Walkowiak, B. 2019. Transition Towards a Resource Efficient Circular Economy in Europe: Policy Lessons from the EU and the Member States. Ecological Economics, 155: 7-19.

Elgizawy, S., El-Haggar, S. and Nassar, K. 2016. Slum development using zero waste concepts: Construction waste case study. Proceed. Eng., 145: 1306-1313.

Hart, J. and Adam, K. 2019. Barriers and drivers in a circular economy: the case of the built environment. Procedia CIRP, 80: 619-624.

He, X., Wada, Y., Wanders, N. and Sheffield, J. 2017. Intensification of hydrological drought in California by human water management. Geophys. Res. Lett., 44(4): 1777-1785. https://doi.org/10.1002/2016GL071665/

Hertwich, E., Lifset, R., Pauliuk, S. and Heeren, N. 2020. Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future. A Report of the Int. Resource Panel. United Nations Environment Programme, Kenya; https://www.unep.org/resources/report/resource-efficiency-and-climate-change-material-efficiency-strategies-low-carbon.

Kirchherr, J., Reike, D. and Hekkert, M. 2017. Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation & Recycling, 127: 9.

Liu, H., Yuan, F. and Yang, D. 2000. The strength varieties of the seibsurface made of lime and fine coal ash of the Hingwaj from Changba to Baichengt. Dongbei linye daxue. J. Nort-East Forest. Univ., 28(1): 45.

Liu, X.F., Wang, S.X., Zhou, Y., Wang, F.T., Yang, G. and Liu, W.L. 2016. Spatial analysis of meteorological drought return periods in China using Copulas. Natural Hazards, 80(1): 367-388. https://doi.org/10.1007/s11069-015-1972-7/

Murray, R. 2002. Zero waste. Greenpeace Environ. Trust. 11: 211

Oltyan, I.Y., Arefyeva, E.V. and Kotosonov, A.S. 2020. Remote assessment of an integrated emergency risk index. IOP Conference Series: Materials Science and Engineering. International Conference on Construction, Architecture and Technosphere Safety, ICCATS 2020. Sochi. 1: 042053.

Omar, P.J., Gaur, S., Dwivedi, S.B. and Dikshit, P.K.S. 2019. Groundwater modeling using an analytic element method and finite difference method: An insight into Lower Ganga river basin. J. Earth Syst. Sci., 128(7): 195. https://doi.org/10.1007/s12040-019-1225-3.

Rosalia, A.C. and Hakim, L. 2021. Spatial analysis of the impact of flood and drought on food security index. Nature Environ. Pollut. Technol., 20(2): 721-727. https://doi.org/10.46488/NEPT.2021.v20i02.031

Saurenko, T., Anisimov, E., Anisimov, V. and Levina, A. 2018. Comparing Investment Projects of Innovative Developing Strategies of Municipalities, Based on a Set of Indicators. MATEC Web of Conferences: International Science Conference (SPbWOSCE-2017): Business Technologies for Sustainable Urban Development, 20-22 December 2017, St. Petersburg, Russia, Curan Associates, Inc., NY, US, pp. 01038.

Sereda, T.G. and Kostarev, S.N. 2021. Development of the automated workstation for the operator of the solid municipal waste landfill. IOP Conference Series: Earth and Environmental Science, 677(4): 042107.

Sereda, T.G., Kostarev, S.N., Novikova, K.O.V. and Ivanova, I.E. 2022. Study of solid municipal waste accumulation rates in penitentiary facilities in Perm Krai during the pandemic of 2020. IOP Conf. Ser. Earth Environ. Sci., 1043(1): 012005.

Tshovrebov, E. Velichko, E. and Shevchenko, A. 2018b. □ethodological approaches to a substantiation resource - and energetically effective economic model of the object of placing of a waste. Adv. Intell. Syst. Comp., 692: 1296-1305.

Tshovrebov, E., Velichko, E. and Niyazgulov, U. 2018a. □lanning measures for environmentally safe handling of extremely and highly hazardous wastes in industrial, building, and transport complexes. Mater. Sci. Forum, 945: 988-994.

Tshovrebov, E.S., Velichko, E.G., Kostarev, S.N. and Niyazgulov, U.D. 2021. Mathematical model of environmentally friendly management of construction waste and waste of urban economy. IOP Conf. Ser. Earth Environ. Sci., 937(4): 042062.

Varughese, A. 2017. Analysis of historical climate change trends in Bharathapuzha River Basin, Kerala, India. Nature Environ. Pollut. Technol., 16(1): 237-242.

Zeng, X., Mathews, J.A. and Jinhui, L. 2018. Urban mining of e-waste is becoming more cost-effective than virgin mining. Environ. Sci. Technol. Publ., 4: 121-125.