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CONTENT

CHAPTER 5
INNOVATIONS IN THE SECTORAL ECONOMIC MODELLING AND MONITORING

5.1 LEGAL REGULATORY ASPECTS OF LAND MONITORING IN UKRAINE

Introduction

The natural and resource potential of Ukraine is represented by a wide range of land, water and biological resources. Land resources of Ukraine is one of the important environmental and economic assets of the state. It is a reliable basis for the country's socioeconomic development. The use of land is associated with significant problems that have arisen because of a violation of ecological balance and the imbalance between districts of arable lands, natural lands, forest and water resources. The state of land use in Ukraine is very critical; further degradation of the natural potential of land resources can have catastrophic consequences.

The study of the technogenic pollution of lands, the conservation of degraded and unproductive lands and the economic stimulation of rational land use are important issues. It contributes to the development and improvement of state lands monitoring; whose results are important in management decisions making on the rational land use. The formation of balanced nature management is possible with an integrated approach to assessing the intensity of natural and economic land use.

The *aim of our research* is the study of the intensity of natural and economic land use based on the environmental assessment and determination key points of its effective monitoring. The *objectives of our study* are: (1) the study of the state of land use in Ukraine; (2) the analysis of the intensity of land use; (3) the description of the legal framework for land monitoring in Ukraine. A systemic approach has been used during the study.

Literature review

Land use affects the land cover; vice versa, changes in land cover affect the land use. Changes in land use/cover are widespread and spurious process, mainly due to natural phenomena and anthropogenic activities. Hansen & Loveland (2011, p. 66) reviewed a large-scale monitoring of land cover changes using Landsat data. Current methods of monitoring large districts of land cover using images of average spatial resolution (10-50 m) usually use Landsat data. With the help of the Landsat archive, which is open for easy access to the data corrected on the territory, future monitoring will be correct. Such methods should use high-performance computing capabilities for monitoring land cover. Technologies for detecting digital changes through the use of multi-dimensional satellite images help to understand landscape dynamics.

Rawat & Kumar study (2015, p. 78) illustrates the processes of spatial-temporal dynamics of land use. The image of the investigated district of the Almora district, Uttarakhand (India) was divided into the five different classes, viz. vegetation, agriculture, infertile, built-up and water body. The results show that over the past two decades, vegetation and built-up lands have been increased by 3.51% (9.39 km^2) and 3.55% (9.48 km^2), while agriculture is barren land and water body have decreased by 1.52% (4.06 km^2), 5.46% (14.59 km^2) and 0.08% (0.22 km^2).

Moudon & Hubner (2000, p. 187) conducted research in the field of monitoring land use in cities. The research covered a broad literature review on the land monitoring, as well as interviews with numerous scientists and practitioners in this field. The authors studied urbanization processes and their negative impact on the urban land.

According to Krueger, Gotthard & and Ulrich (2013 p. 812), it is necessary to reduce the land allocated district for the development. To achieve sustainable land use development, the German government announced a significant reduction in the consumption of open space for human settlements and transport infrastructure. To achieve such goals, planning bodies should provide up-to-date and accurate information on land use. Nowadays, spatial analysis of topographic reference data is automated process. Thus, geoprocessing procedures can be repeated constantly. Nex, Delucchi, Gianelle, Neteler, Remondino & Dalponte, M. (2017) have stated that remote sensing can provide accurate information on large districts and is widely used for these tasks.

The intensity of anthropogenic pressure on land resources depends to a large extent on the general economic development level of the territory, negatively affects the state of the environment (Litvak, 2014, p. 288). The largest environmental problem due to the use of land resources and economic activities is land degradation (Yatsuk, 2014, p. 108). Kingwell & Robertson (2007, p. 51) have justified in their study a land degradation and pointed out the need to control salinization of arid origin. Popova (2012, p. 93) has paid attention to the land resources' state in Ukraine and estimated it critical. Awotwi, Anornu, Quaye-Ballard & Annor (2018) used a double cumulative curve and a technique for interpreting images to select Landsat spatial-temporal data to assess land degradation from anthropogenic activities in the Pra River Basin (PRB), Ghana. Their assessment showed that the river basin is subjected to six different rates of land degradation due to the increase in settlements, cultivation and extraction of minerals (130%, 198% and 304% respectively). Land degradation is significant in the western and eastern parts, where agriculture and forest are transformed into mining activities. According to Vishivaniuk (2011, p. 4) land monitoring should be based on the principles of completeness, unity, reliability, timeliness, legality and systemic character.

Provided Land Monitoring in Ukraine

Surveys of land management show that Ukraine has a significant land and resource potential. As of January, 01, 2017, the land fund of Ukraine is 60.35 mln (i.e. 6% of the territory of Europe). Land resources of Ukraine are characterized by high bioproductivity potential, in the structure of which fertile black soils predominate (60.2% of arable land), accounting for about 7% of world reserves (Land Monitoring in Ukraine, 2014-2015). The main problem in land use in Ukraine is the ineffective distribution of the available land fund for its intended use. Most of all plowed land in Ukraine are in Kherson (90.3%), Cherkasy, Dnipro, Zaporozhe, Kirovograd, Vinnitsa and Mykolaiv regions (85-87%). In these regions, the balance between the number of pastures, hayfields and districts designated for the cultivation of agricultural crops is disturbed. The imbalance between districts of certain land categories leads to excessive anthropogenic and technogenic load on the land; it leads to a violation of the quality and ecological state of soils (Semeriak, 2011). In Ukraine, there are over 1.1 million of hectares of degraded, unproductive and technologically polluted lands subject to conservation, 143.4 thousand hectares of disturbed lands are requiring reclamation and 315.6 thousand hectares of unproductive lands need improvement (Strategy for the improvement of the management mechanism in the field of use and protection of agricultural land of state ownership and their disposal, 2017). Water and wind erosion of soils are the most significant factors in the land productivity decline and the growth of agricultural lands' degradation. The total district of agricultural lands exposed to the harmful effects of water erosion is 13.3 million hectares. Important mechanism to fight against the wind erosion is the field-protective forest belts' creation and other protective plantations. The quality of land resources is also affected by other negative factors, viz. salinity, acidity, reverberation and rockiness. Intensive agricultural land use leads to decrease in soil fertility due to over-consolidation of black soils; loss of water permeability and aeration capacity with all environmental consequences.

Over the past 20 years, the average humus content in Ukraine has decreased by 0.22% that is a significant deviation, since it is needed 25-30 years (or even more) in natural conditions to increase it in soil by 0.1%. The decrease in soil fertility is caused by the violation of crop rotation. Sunflower in some districts covers a district over 30% of arable land. In most cases, the culture returns to its original field in 3 years (recommended 6-7 years). Violation of the requirements for crop rotation, in addition to increasing the level of debris and the development of crop diseases, leads to soil depletion and soil toxicosis. The processes of soil cover degradation have intensified that is caused by technogenic pollution. The greatest danger to the environment is contamination of soils with radionuclides, heavy metals, pathogens. Hydrometeorological and dangerous exogenous geological processes (mudslides, landslides, karst, soil subsidence, abrasion, destruction of the reservoirs banks, etc.) are significantly affected the quality of land resources and a number of facilities in the economic sectors; they are distributed over 50% of the territory [ibid].

Particularly serious problems in recent years have arisen in connection with the redistribution of land, land denationalization and privatization in Ukraine, which led to the violation of crop rotations, grinding of land massifs of agricultural lands, loss of elements of contour-ameliorative organization of the territory. Agrarian enterprises established on the basis of short-term lease relations, are ineffective. In their activity, they exhaust the fertility of soils and worsen the land quality. Thus, the land state in Ukraine requires improvement, as well as the land use.

To date, in countries with different socio-political structures, there are various legal forms of the land use and the land resources' ownership. The analysis of the legislation of a number of countries shows that there are various restrictions on the land use in each of them. Limitations related to the size of land parcels are characteristic of countries with transition economies and countries with limited land resources. As a rule, such restrictions are set at the municipal or regional level, viz. in Hungary no more than 300 hectares; in Romania no more than 300 hectares; in Denmark no more than 30 hectares.

Comparative characteristics of the land use state in the EU, European countries and Ukraine are given in *Table 5.1.1*.

Table 5.1.1

Comparative characteristics of the land use

Indicator	Ukraine	%	European countries	%	The EU countries	%
Land district, million ha	60,4	100,0	1015,6	100,0	437,4	100,0
Black soil district, million ha	28	46,4	84	8,3	18,0	4,1
Agricultural land district, million ha	42,7	70,7	474,8	46,8	177,7	40,6
Area of agricultural land certified as organic, million ha	0,3	0,7	11,6	2,4	5,3	3,0
The district of agricultural land per inhabitant, ha per person	0,7	100,0	0,6	85,7	0,4	57,1
Area of leased agricultural land,%	41,4	97	26,5	62,0	94,2	53,0
Arable land district, million ha	32,5	53,8	277,8	27,4	115,7	26,5
Area of irrigated land, million ha	0,5	1,2	20,8	4,4	11,1	6,2
Investment price, th. USD per ha	1,0	18,2	4,0	72,7	5,5	100,0
Grain export, million tons	34,8	26,8	130	100,0	38,5	29,6
Price per 1 ha of agricultural land, th. USD	-	-	3,7	51,4	7,2	100,0

Source: formed by authors according to Strategy for the improvement of the management mechanism in the field of use and protection of agricultural land of state ownership and their disposal (2017)

The main principles of the EU land ownership policy including agricultural land, is to ensure the right to free flow of capital, the opening and running of private business and the absence of discrimination. In most of the EU member countries there are no legal restrictions on the ownership of agricultural land. Anyone can legally acquire agricultural land and own it. Countries became the EU members later, as a rule, restrictions are imposed on the agricultural land possession for foreigners, including citizens of EU member states. E.g., in the Czech Republic and Slovakia there are restrictions on foreign individuals and legal entities that cannot buy agricultural land, is aimed at preventing speculation by agricultural lands in the EU member states. Having considered the EU experience of land management, in Ukraine attention should be paid to the organization of permanent land monitoring. It will give the opportunity to form an information database on the state of the land fund in Ukraine. Received information will be the basis for managerial decisions making on the organization the effective land use.

According to the Land Code of Ukraine (2002), *land monitoring* is defined as a system for monitoring the land state to identify changes in time, assess them and eliminate the consequences of negative processes. The implementation of land monitoring is regulated by Law of Ukraine "On Environmental Protection" (1991), Land Code of Ukraine (2002), Law of Ukraine "On State Control over the Lands Use and Protection" (2003), Resolution of the Cabinet of Ministers of Ukraine "On the approval of the Regulations on monitoring of land" (1994), Provision "On the Regulation on the State system of Environmental monitoring" (1998), Provision "On the order of information interaction of bodies of Ministry of Ecology and Natural Resources of Ukraine and others environment monitoring system in carrying out routine observations of the environment" (2002).

Land monitoring involves technical and information analytical work with the use of technical control means and through monitoring the land quality, sampling implementation of soil geo-botanical and other necessary surveys, analyzes and measurements of the chemical and biological composition of soils, their physical condition, evaluation and analysis of lands condition, the formation of forecasts of the manifestation of the main negative processes on lands belonging to different categories in the nearest and long-term perspective, development their prevention. The implementation of monitoring involves conducting observations on the land use, identifying cases of misuse, which especially worsen the land quality, as well as the overall environmental situation. Based on the current legislation of Ukraine, it can be concluded that land monitoring is part of the state environmental monitoring system, which is a system for observing, collecting, processing, transmitting, storing and analyzing information on the environmental state, predicting its changes and developing scientifically based recommendations to take decisions on preventing negative changes in the environmental state and compliance with environmental safety requirements. Land monitoring should fulfill a basic role for other monitoring types and cadaster of natural resources. The data obtained in the implementation of land monitoring should be the informational basis for monitoring other types of natural resources, as well as for maintaining state cadasters of various resource types, primarily the land cadaster state. Data obtained in the land monitoring process can be used in land management, land conservation, development planning of territories, land control. According to Resolution "On Approval of the Regulations on Land Monitoring" (1994) and depending on the purpose of observations and the extent of coverage of territories, such land monitoring in Ukraine is carried out: (1) national (on all lands within the territory of Ukraine); (2) regional (in territories characterized by the unity of physic, geographical, ecological, economic conditions); (3) local (on separate land plots and parts of landscape-ecological complexes).

Land monitoring is carried out by the State Service of Ukraine for Geodesy, Cartography and Cadaster, the Ministry of Environmental Protection, the Ministry of Agrarian Policy and Food, the Ukrainian Academy of Agrarian Sciences.

The information obtained during observations on the land state is summarized by districts, cities, regions, individual natural complexes and transferred to the collection points of the automated information system of the regional and city land administration departments. Based on the results of the assessment of the land state, reports, forecasts and recommendations are submitted to the local authorities and the State Service of Ukraine for Geodesy, Cartography and Cadaster to prevent and eliminate the consequences of negative processes. The basis of land monitoring is the assessment of characteristics that take into account the interaction and their interdependence; makes possible to ensure the maximum assessment reliability.

Cherkasy region was chosen to assess the intensity of natural and economic land use, as it is located in the central forest-steppe part of Ukraine. Soils of Cherkasy region are considered to be among the most fertile. In the soil cover, black soils predominate. The natural potential of the land resources of the Cherkasy region is characterized as one of the best in Ukraine (Cherkasy in numbers, 2016).

The main characteristics of intensity of natural and economic land use were signs: ecological stability of agro-landscape, anthropogenic load, plowing of the territory, plowing of agricultural land, agricultural development of the territory and recreational capacity. These indicators are characterized by certain coefficients, which are proposed by (Tretiak, 2011).

The evaluation is conducted in several stages.

At the first stage, coefficients were calculated according to formulas (5.1.1-5.1.2).

The *coefficient of ecological agro-landscape stability (X_1)* is defined by formula (5.1.1), where X_i is coefficient of ecological land stability of the *i-th* species; S_i is the land district of the *i-th* species, ha; *n* is the land plurality:

$$X_1 = \frac{\sum_{i=1}^{n} X_i \times S_i}{\sum_{i=1}^{n} S_i} \qquad (5.1.1)$$

The coefficients values for assessing the environmental properties of land are given in *Table 5.1.1*. If the obtained value of the coefficient of ecological agro-landscape stability is less than 0.33 (the land use is environmentally unstable), if it changes from 0,34 to 0,50 (stably unstable), if it changes from 0,51 to 0,66 (the middle of the average stability), if it exceeds 0.67, the land use is environmentally sustainable.

The *coefficient of anthropogenic load* (X_2) characterizes the impact of human activities on the state of the environment, including land resources. It is calculated by formula (5.1.2), where B_i is the point of anthropogenic loading of the *i-th* land type:

$$X_2 = \frac{\sum_{i=1}^{n} B_i \times S_i}{\sum_{i=1}^{n} S_i} \qquad (5.1.2)$$

The value of coefficients of land stability and anthropogenic load are given in *Table 5.1.2*.

Table 5.1.2

The value of coefficients of land stability and anthropogenic load points

Name	Coefficient of ecological agro-landscape stability, X_i	Points of anthropogenic loading, B_i
Built-up district and roads	0.00	5
Lands of industry	0.00	5
Arable land	0.14	4
Hayfields	0.62	3
Pasture	0.68	3
Inland water	0.79	2
Forests of natural origin	1.00	2

Source: formed by authors according to (Tretiak, 2011)

In order to assess the intensity of the natural and economic land use, it is also advisable to calculate the *coefficient of plowed district*, the *coefficient of plowed agricultural land*, the *coefficient of agricultural development of the territory* and the *recreational capacity* by formulas (5.1.3-5.1.6).

The *coefficient of plowed district* (X_3) is defined as the ratio of the arable land district (S_a) to the total land district (S_l) by formula (5.1.3). The *coefficient of plowed agricultural land* (X_4) are defined as the ratio of the arable land district (S_a) to the agricultural land district (S_c) by formula (5.1.4). The *coefficient of agricultural development of the territory* (X_5) is defined as the ratio of the agricultural land district (S_c) to the total land district (S_l) by formula (5.1.5). *Recreational capacity* (X_6) is the ratio of districts of natural and biological reserves (S_b) to the total land district (S_l) by formula (5.1.6).

$$X_3 = \frac{S_a}{S_l} \tag{5.1.3}$$

$$X_4 = \frac{S_a}{S_c} \times 100\% \tag{5.1.4}$$

$$X_5 = \frac{S_c}{S_l} \times 100\% \tag{5.1.5}$$

$$X_6 = \frac{S_b}{S_l} \tag{5.1.6}$$

Natural and biological reservations include lands occupied by forests, tree shrub plantations, hayfields, pastures, swamps and territories under water. Based on our calculations of abovementioned coefficients, *Table 5.1.3* has been generated.

The value of the ecological stability of the districts' agro-landscape is shown in *Table 5.1.3*. The lands of Cherkasy region have the highest ecological stability ($X_1 = 0{,}66$), between them the smallest ecological stability have lands of Khrystynivska, Drabiv and Zhashkiv districts ($X_1 = 0.24\text{-}0.26$). The discrepancy in the indicators is 63% that indicates the need for preventive measures to improve the ecological status of land with a low indicator of the ecological stability of the agro-landscape. According to the analysis, 3 levels of land use intensity were identified in Cherkasy region: high, medium and moderate. 3 districts are in the moderate level of land use intensity, the middle – 7, the high – 10 districts (*Table 5.1.4*).

The quantitative limits of indicators for each level of land use intensity have been formed (*Table 5.1.5*).

The results show that the districts that entered the *first level* have a moderate land use intensity, their coefficient of ecological stability of the agro-landscape is over 0.5; anthropogenic load factor less than 3 points; the rate of plowing is less than 50%; the rate of agricultural lands plowing is less than 85%; coefficient of agricultural development of the territory is less than 60%; recreational capacity is over 0.5. At the same time, the ecological conditions of these regions lands are medium-stable.

Table 5.1.3

Indicators of land valuation by districts in Cherkasy region

Indicators / District names, Ri	X_1	X_2, points	X_3, %	X_4, %	X_5, %	X_6
Group 1						
Cherkasy	0,66	2,55	37,27	85,17	43,76	0,60
Kaniv	0,59	2,79	45,57	83,20	54,78	0,52
Chyhyryn	0,57	2,81	48,95	76,88	63,67	0,57
Group 2						
Smila	0,46	3,15	59,64	88,62	67,30	0,36
Korsun-Shevchenkivskyi	0,44	3,22	60,32	84,06	71,75	0,36
Zolotonosha	0,43	3,11	68,45	86,84	78,82	0,34
Horodyshche	0,41	3,24	63,64	86,08	73,93	0,31
Zvenyhorodka	0,40	3,29	67,16	90,09	74,55	0,29
Kamyanka	0,40	3,31	66,23	87,56	75,64	0,30
Chornobai	0,38	3,24	82,45	92,90	88,75	0,32
Group 3						
Lysianka	0,33	3,47	73,47	86,89	84,55	0,24
Shpola	0,31	3,49	77,90	94,44	82,48	0,19
Monastyryshche	0,30	3,46	78,56	92,74	84,71	0,16
Katerynopil	0,30	3,49	77,74	91,06	85,38	0,17
Mankivka	0,30	3,50	79,01	92,38	85,52	0,16
Uman	0,29	3,53	80,59	96,72	83,32	0,16
Talne	0,29	3,55	81,69	95,50	85,54	0,15
Khrystynivka	0,26	3,53	83,31	96,90	85,98	0,11
Zhashkiv	0,26	3,57	85,33	94,42	90,37	0,11
Drabiv	0,24	3,64	85,32	93,60	91,16	0,10

Source: calculated by authors according to the Land Monitoring in Ukraine (2014-2015)

Table 5.1.4

Levels of land use intensity of Cherkasy region

Groups	Levels	Districts
1	Moderate	Cherkasy, Kaniv, Chyhyryn
2	Middle	Smila, Korsun-Shevchenkivskyi, Zolotonosha, Kamyanka, Zvenyhorodka, Chornobai, Horodyshche
3	High	Lysianka, Shpola, Katerynopil, Monastyryshche, Mankivka, Uman, Talne, Khrystynivka, Zhashkiv, Drabiv

Source: graded by authors

Table 5.1.5

The boundaries of quantitative values of indicators by intensity levels

Indicators	Levels of land use intensity		
	Moderate	Medium	High
	Limits of quantitative values		
Coefficient of ecological stability of the agro-landscape (X_1)	> 0,5	0,35 – 0,50	< 0,35
Anthropogenic load factor (X_2)	< 3,0	3,0 – 3,4	> 3,4
Coefficient of plowing the territory (X_3), %	< 50	50 – 70	> 70
Coefficient of plowing agricultural land, (X_4), %	< 85	85 – 90	> 90
Coefficient of agricultural reclamation of the territory (X_5), %	< 60	60 – 80	> 80
Recreational capacity (X_6)	> 0,50	0,25 – 0,50	< 0,25

Source: created by authors

For the *second level* of land use intensity, the districts with the coefficient of ecological stability of the agro-landscape in the range 0.35-0.5 entered. At the same time, the lands of these regions are ecologically stably unstable. The *third level* covers the land districts mostly stably unstable, since they have a high land use intensity. The value of the coefficient of ecological stability of the agro-landscape is less than 0.35; the anthropogenic load factor is over 3.4 points; the rate of plowing of the territory is over 70%; ratio of agricultural land is over 90%; coefficient of agricultural development of the territory is over 80%, recreational capacity is less than 0.25; it characterizes the extremely complex state of land use. The districts with a high land use intensity occupy 43.9% of the area that is fairly large part of the territory of the Cherkasy region. Thus, lands of Cherkasy region have intensive natural and economic use. The most vulnerable were the lands that have a third level.

Results of assessment

Based on the assessment of intensive natural and economic use of lands in the Cherkasy region, indicators for 20 regions were determined. Taking into account the value of the coefficient of ecological stability of the agro-landscape, three levels of intensity of natural and economic land use were identified: moderate, medium and high. The boundaries of indicators values are defined. The lands of Cherkasy, Kaniv and Chyhyryn districts are ecologically medium stable and refer to a moderate level. To the medium level of land use intensity, we defined the lands of 7 regions, which are ecologically stably unstable, to the high we defined the lands of 10 districts, which are environmentally stably unstable. The lowest rates had the lands of Khrystynivka, Zhashkiv and Drabiv districts. At the same time, coefficient of ecological stability of the agro-landscape is less than 0.26. These lands have a complex state of land use. Therefore, special attention should be paid to the land use in these districts.

Conclusions

In order to improve land use, it is necessary to define a strategy for optimizing the land use of districts at certain levels and to develop a balanced land use structure at the regional level. Prospects for further research are to conduct an assessment of the intensity of natural and economic land use at the national level that will allow defining a strategy of rational land use and land protection in Ukraine and form directions for the development of land use in the regions of Ukraine.

5.2 MODELLING PROSPECTS OF GLOBAL FOOD PROBLEM SOLUTION WITHIN THE CONTEXT OF ASYMMETRIC WORLD DEVELOPMENT

Introduction

Solution of the food problem is the most topical issue of the current stage world economic system development. In accordance with the *FAO* estimates, the global famine scale has been decreasing for two previous decades. Malnourished population share has been reduced to a much larger extent than an absolute quantity of the malnourished people, but in the developing countries a substantial share of the population still fails to consume the amount of food products necessary for active and health life.

Literature Review

Considerable attention is paid to the research of the global food problem by national researchers. Fundamental works of the scientists working in this area, viz. Berehovyi (2011), Bilorus (2003), Luzan (2011), Paskhaver (2006), Sabluk (2008), Vlasov (2006) et al have developed principal evaluation methods and methodology of registration of various factors' influence forming country's food security and agro development, but the question related to the causes forecasting, mechanisms of the global food issue development, its tendencies by means of mathematical models are covered insufficiently. At the same time, existing scientific approaches to the food problem evaluation on a global scale described in the works of Uusitalo (2015), Lehikoinen (2015), Helle (2015), Myrberg (2015), Pianosi (2015), Sarrazin (2015), Wagener (2015) practiced Global Sensitivity Analysis (*GSA*), that is increasingly being used in the development and evaluation of environmental models. They have presented Matlab/Octave toolkit for *GSA* application. In the works of Lokers (2016), Knapen (2016), Janssen (2016), Yke van Randen (2016), Jansen (2016) has been suggested to use data processing technologies based on highly productive computations, to create new opportunities for intensive data processing in a diverse agro-ecological sector. In the works of Eerens (2014), Haesen (2014), Rembold (2014), Urbano (2014), Tote (2014), Bydekerke (2014) it is emphasized that monitoring of the global food problem is vital taking into consideration strong year-to-year variability, growing competition for natural resource sand effects of climate change on agriculture. They suggest to apply software *SPIRITS* for the global food problem evaluation, but the proposed autonomous toolkit is developed for the environmental monitoring in order to receive accurate and evidence-based information for crop production; so, it is impossible to get a clear understanding of the global food problem by means of the mentioned toolkit. Mason-D'Croz (2016), Vervoort (2016), Palazzo (2016), Islam (2016), Lord (2016), Helfgott (2016), Havlík (2016), Peou (2016), Sassen (2016), Veeger (2016), Arnout van Oesbergen (2016), Arnell (2016), Stuch (2016), Arslan (2016), Lipper (2016) in their works developed methods for the application of scripts that provide alternative futures to inform food policy makers. The implementation process of the proposed regional scripts for South-East Asia is described in their scientific work. Regardless of a great number of scientific works in this area, the issues on prospects for the global food problem solution with the help of mathematical models remain under-researched.

The *aim of the article* is to study the prospects of the global food problem solution by means of mathematical models built on the basis of biological neural networks operation.

Empirical results and discussion: Analysis of target indicators of the global food problem solution provided in the Millennium Development Goals inspires optimism and hope for solution of the tasks set. Thus, the malnourished population share is annually reduced by 0.5%. If this tendency persists, then malnourished population share will amount to 12.8%, which is just 1.1% higher than the target indicator of the Millennium Development Goals. Forecasting of indicators of the absolute quantity of malnourished people in the world is of equal importance. If relative future stability of absolute values of the malnourished people, average level of the series, average absolute increment and average growth rate are assumed, a conclusion can be made that in time this indicator will tend toward zero or that complete solution of the global food problem may be reached (*Figure 5.2.1*).

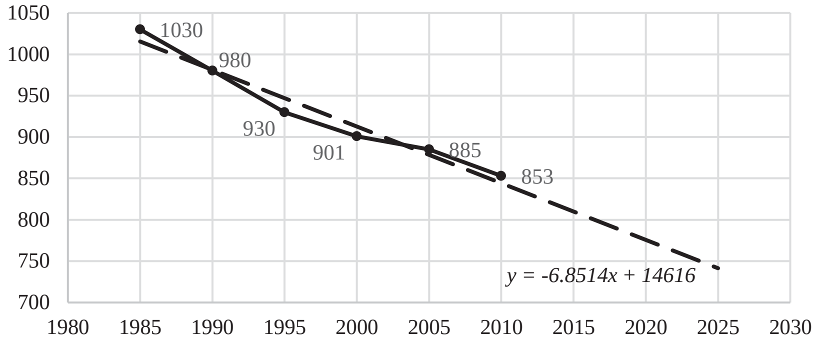

Figure 5.2.1: Forecast of solution of the global food problem on the basis of the regressive model, mln malnourished people

Source: calculated by author

In general, this forecast for the period ($n + t$) can be presented as a function (5.2.1), where Y_{n+t} is a forecast value of the level of the time series; l is a period of advance; Y_n is a level of the series taken as an extrapolation base; a_i are trend equation parameters.

$$Y_{n+t} = f(Y_n, l, a_i) \tag{5.2.1}$$

The malnourished people shall include the persons, who consume less than 1,700 calories per day. However, application of this approach, when the forecast level is equal to the average value of the series levels in the past provides a predictive point estimate. Exact match of these estimates to the actual data is unlikely. Therefore, this forecast should not be perceived as an authentic one unequivocally in the long term period, although for one or two-year forecast these approaches enable gaining results with a high authenticity level.

Forecasting of the process of the food problem solution is rather complicated task, which requires attention of considerable number of factors including asymmetric information. That is why the US Department of Agriculture has involved mathematical modelling tools, which consist of 76 partial equilibrium models in order to assess prospects of solution of the global food problem. These models are mainly focused on assessment of the prospects of the poorest world regions (African and Asian countries). Forecast of food problem solution has been carried out by means of assessment of the food products consumption level by different population groups. For this purpose, the population has been divided into five groups subject to the scope of food consumption (from the lowest to the highest scope) in each country. Herewith, the scope of food consumption has been assessed for three product groups only: cereals, edible roots and other. This complicated modelling procedure required several powerful computers simultaneously.

Naturally, several powerful computers with the cutting-edge mathematical modelling kit cannot be used within the framework of our research. Therefore, the mathematical model of the National Scientific Centre "Institute of Agrarian Economy" based on the neural networks combining autoregressive models with neural components of various complexity levels, has been used to model prospects of the global food problem solution. This combination improves quality of the forecast in the context of the asymmetric information on the present and future of the world economy and its food system. Mathematical models built on the principle of operation of biological neural networks (neural networks) have been widely used in forecasting recently. As opposed to regressive models, they are enable taking into account asymmetry of information, non-linear connections, uncertainty of economic development, unpredictable quick changes in subjective factors.

To determine the current neuron status (S), the weighted total of indicators at the entry point is calculated by formula (5.2.2), where x_i and w_i are the indicators processed by the neuron.

$$S = \sum_{i=0}^{n} x_i \times w_i \qquad (5.2.2)$$

The outgoing result of the neuron is characterized by the functions of its state. It may be presented in different ways. Mainly, it is a non-linear function, which is called the activation function. One of the most common ones is a non-linear function with saturation, so-called logistical function or sigmoid function (i.e. S-shaped function).

Neural networks are used to solve complicated non-formalized tasks without established analytical solution algorithms, incomplete or controversial incoming data, which correspond to the forecast on the global food problem to a certain extent. Principal spheres of neural networks application include recognition of target attributes of the researched objects, dynamic forecasting of numeric values of the object in time and automatic grouping of objects.

When world economy development processes and the food problem are modelled, in particular, neural networks enable determining the most influential ones, which are most likely to define changes in food provision and the global food problem due to group recording of a large number of independent variables. The modelling process is presented in *Figure 5.2.2* in the simplified form.

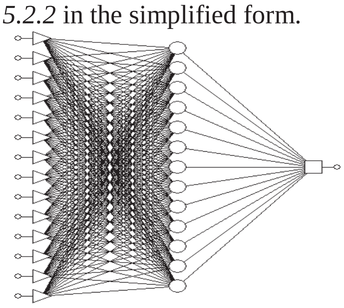

Figure 5.2.2: Functional diagram of food problem development modelling on the basis of neural networks

Source: adapted by author according to Matviichuk (2011)

Due to uncertainty increase in economic development, unpredictable changes in the food problem and asymmetry of information, establishment of interconnections among principal macroeconomic indicators by means of mathematical tools is very complicated. Therefore, hybrid models combining regressive and autoregressive components and artificial neural networks have been used in our research. This combination is quite efficient, as it is able to reproduce complicated non-linear processes by means of the econometric tools. In particular, autoregressive neural networks (*AR-NN*) enable exercising behavior of linear oscillations around the average the level of which can change in time on a non-linear basis. More complicated case is smooth transition regressive hybrid models (*ST(A)R*) and smooth transition multi-regime hybrid models in which the behavioral structure not only of the mean value (intersection), but also the rest of beta coefficients are non-linear. By contrast with the regressive models, when preconditions for improvement or deterioration of the global food problem state, which are restricted to the continued development assumption the main past tendencies in the future are formalized and identified, neural networks take into consideration asymmetry of information, growing uncertainty and impact of subjective factors in the context of economic instability and crises, unpredictable changes in tendencies and identify non-linear interconnections.

To determine preconditions of changes in the state of the food problem, correlation and regression analysis has been conducted; comparative analysis of its deliverables with the ones received from application of neural networks both to the internal and external factors has been performed. The conclusion has been made that synthesized feed-forward back propagation (*FFBP*) neural networks are most flexible and efficient when working with economic data. They are the structures, which approximate any continuous multivariable function with sufficient precision. The *FFBP* architecture includes two or three levels: input, hidden and output. The input and output levels perform linear transformations and aggregation of input data; hidden level determines the main attributes of the neural network, which perform logical "switch", i.e. "if…, then…" rather than linear ones. They can be presented mathematically in the form of the logic sigmoid function (5.2.3), where $\psi(s)$, $\psi(s) \in R$ is a value of the neuron activation function; s, $s \in R$ is a weighted total of input values (artificial neuron entry); k, $k > 0$ is a parameter, which defines curvature of the function, speed of its transition from zero-close values to the values close to one:

$$\psi(s) = \frac{1}{1+e^{-ks}} \tag{5.2.3}$$

In practice, the most common autoregressive model with the neural feed-forward back propagation component with one output is neural network *AR-NN(p, q)* in the following form (5.2.4), where y_t is a dependent variable in the current period; w_t is a vector of order $(1 \times p)$ regressors (lag values of dependent variables); β_0' is a vector of linear parameters of the order autoregression $(1 \times p)$; q is a hidden layer neuron quantity; β_j is a vector of weight coefficients of the output layer of the neural network of the order $(1 \times p)$; γ_j' is a weight coefficient vector of the hidden layer of the order $(1 \times p)$; $G(\gamma_j' w_t)$ is a hidden neurons activation function; ε_t is a vector of independent identically distributed remains.

$$y_t = \beta_o^{'} w_t + \sum_{j=1}^{q} \beta_j G(\gamma_j^{'} w_t) + \varepsilon_t, \tag{5.2.4}$$

In the model the forecasting object is an absolute value of the quantity of malnourished people in the world. This indicator is most representative to assess the state of the global food problem. Modelling has been performed on the basis of assessment of two factor groups, which have internal and external impact on a provisional basis. The data have been taken for the period from 1980 until 2015. The source data on the state of the food problem have been taken from the indicators of socioeconomic development of Oxford Economics, the British analytical service.

This analytical service was founded in 1981 as a commercial enterprise in the business college of Oxford University in order to provide an economic forecasting and modelling for British companies and financial institutions. Throughout the period of its existence, Oxford Economics has turned into one of the leading global independent advisory centers for the development of reports, forecasts and provision of analytical tools for 200 countries, 100 industrial sectors and over 3,000 cities. Global economic and industrial models and analytical tools, which are the best in their class give an unprecedented opportunity to forecast world market tendencies, perform econometric modelling, scenario planning and analysis of economic impact on markets, research into and assess socioeconomic processes and their impact on business. Empiric data for modelling have been gained on the basis of a set of 14 factors, which have been selected from among 238 indicators of the general global socioeconomic development of Oxford Economics, the British Analytical Service. All data available have been collected as to each measurement of the food problem, and changes have been analyzed within the framework of the forecast. The indicators within 4 measurements, which are determined on the scale from 1 to 5 have been aggregated into consolidated indicators for each measurement for 1980-1995 and 2000-2015 by means of weight coefficients calculated on the basis of principal component analysis. The radial basis function (*RBF*) has been used for this purpose (5.2.5):

$$f(x) = \sum_{j=1}^{m} w_j h_j(x) \tag{5.2.5}$$

The functional diagram of the radial basis function is presented in *Figure 5.2.3*.

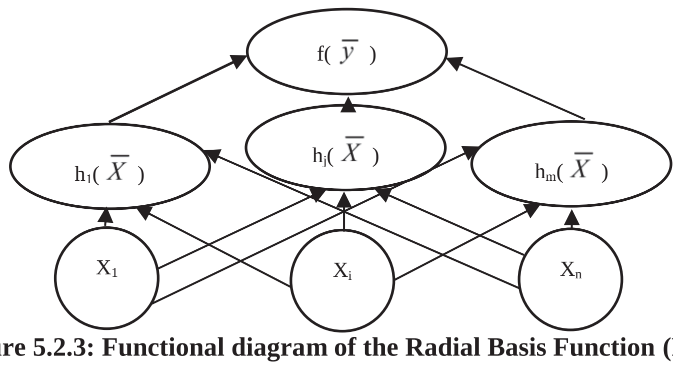

Figure 5.2.3: Functional diagram of the Radial Basis Function (RBF)

Source: created by author according to Matviichuk (2011)

The process of predictive modelling and analysis of factor impact has been performed and divided into 3 networks: (1) training, (2) verification, (3) modelling for network testing, for the use of 33 quantities of data, 17 of which were used for network training, 8 for verification and 8 for network testing. As a result of self-education by the feed-forward back propagation neural network, the following most significant factors have been selected from modelling of the state of the food problem: (1) customer price index; (2) total world population; (3) reference values of per capita GDP (mln USD) and GDP deflator; (4) amount of agricultural investments and total amount of investments into fixed assets (at constant prices and at the current USD exchange rate); (5) global grain production scope; (6) global food price index; (7) current payment balance; (8) current world prices of agricultural raw materials and world food prices as of the end of the period. These factors have been selected upon identification of the internal impact on the state of the food problem.

Ten models with the lowest absolute error were selected in the course of analysis. The program tested models and result of their ranging on the basis of the error size. The model without the hidden (internal) layer presented in *Figure 5.2.4* was selected from among them at the initial stage.

The multi-perceptive model with the hidden internal series, which included the following indicators from the internal factors group was selected in the course of modelling of prospects of solution of the global food problem: global grain production scope; agricultural investments; global food price index; current world prices of agricultural raw materials and world food prices as of the end of period (*Figure 5.2.5*).

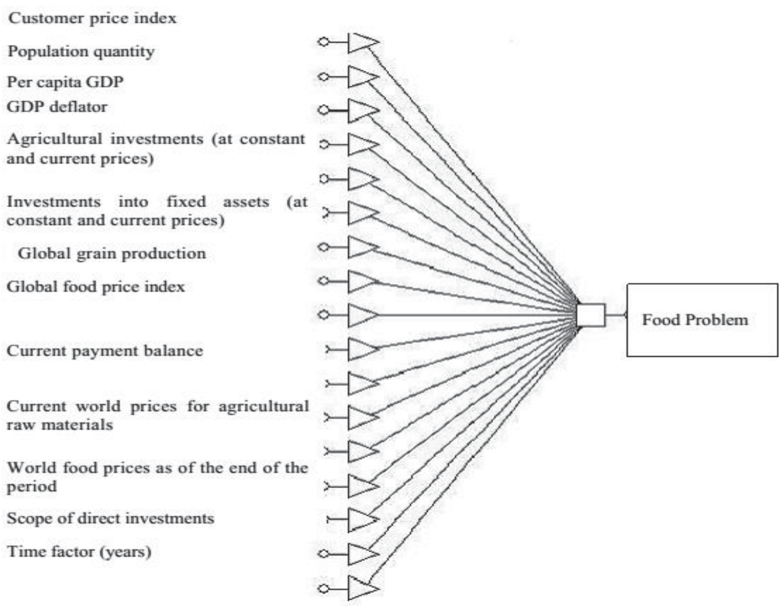

Figure 4: Structure of the model with the neural component with one output for modelling of prospects of solution of the global food problem on the basis of the Internal Indicators Group

Source: developed by author

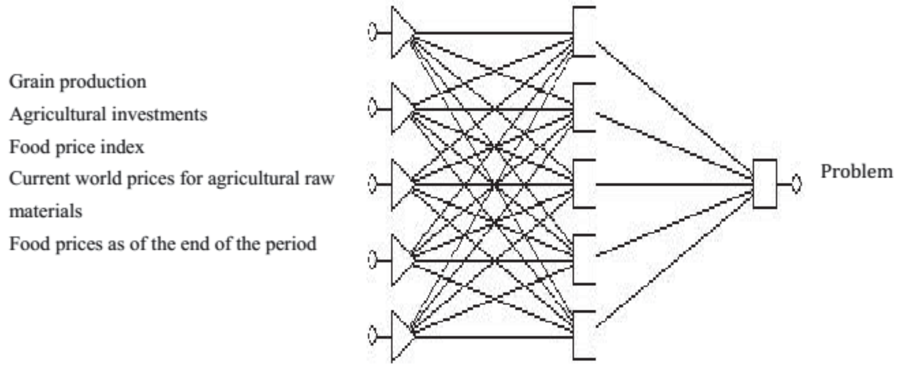

Figure 5.2.5: Structure of the model with the neural component with one output for modelling of prospects of solution of the global food problem on the basis of the Internal Indicators Group

Source: developed by author

As a result of predictive modelling of the global food problem solution prospects by means of the feed-forward back propagation neural network, the following most significant factors have been selected from the group of external impact factors: world oil demand, mln tones (annualized, i.e. estimated on a year-to-year basis); cost expression of the world oil demand (annualized); world oil supply, mln tones (annualized); cost expression of the world oil supply (annualized). Absence of the forecast on the grain production both in general and its estimate per capita has preconditioned its modified exponent (5.2.6), where: $A = -4{,}129.307306$; $B = 5{,}684.033942$; $C = 1.004832$.

$$Y = A + B \times C^n \tag{5.2.6}$$

The forecast data gained by means of the neural network has enabled modelling prospects of the global food problem. Modelling deliverables are shown in *Figure 5.2.6.*

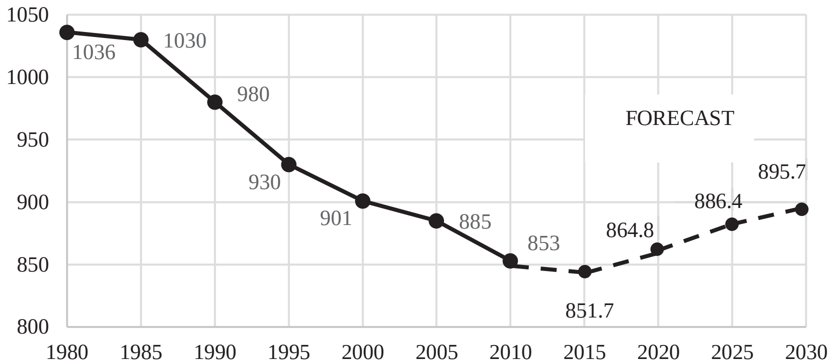

Figure 5.2.6: Forecast of the global food problem solution by means of the neural network, mln malnourished people (consuming less than 1,700 calories per day)

Source: calculated by author

Conclusions

Modelling deliverables demonstrate that the world economy is at the critical stage of the global food problem solution. If the relative indicator of the share of the malnourished planet population is stabilized at the level of 12-13%, in the short term there may be an increase in the number of people, who have been consuming less than 1,700 calories per day. According to our forecast, the malnourished people quantity in the world may increase by 12-13 mln by 2020 as opposed to the current state, and it may increase by 34-35 mln by 2025. The important forecasting deliverable is that if no effective measures are taken to solve the food problem, the situation with the malnourished people will deteriorate, and their quantity will keep growing. The example given is a neural forecasting model, which has been developed and assessed on the actual information and takes into account impact of internal and external changes on solution of the global food problem, confirms capabilities for their application for systemic analysis, forecasting and quantitative assessment of influence on principal macroeconomic indicators in the context of uncertainty, asymmetric information and possible changes in economic development tendencies.

The existing mathematical models built on the basis of neural networks enable forecasting with the high authenticity level. In forecasting of the malnourished people quantity in the world, the absolute average error is 7.31. It has been defined on the basis of *MAE* (mean absolute error) criteria (5.2.7). The correlation index is 0.96.

$$MAE = \frac{1}{n}\sum_{k=1}^{n}\left|Y_{t+k} - F_{t+k}\right| \tag{5.2.7}$$

Solution of the global food problem is mainly decelerated by low rates of world economy development and resulting potential reduction in the scope of agricultural investments. For instance, according to the forecast, reduction in agricultural investments scope by USD 10 bln during three years brings decrease in agricultural production by USD 2.1 bln. It will mostly affect animal industries, fodder and vegetable production. Approximately 0.5 mln employees will be fired from the agricultural industry. Having no respective qualifications, most of them will stay unemployed.

The model takes into consideration effect of the existing economic indicators and makes a forecast thereon in the future, also it takes into account the risks caused by deterioration of the socioeconomic situation in the world. Therefore, stabilization of the political situation in the most problematic regions of the planet and engagement of the population into efficient labor for economy development and human well-being are getting currently central. Involvement of economically developed countries into assistance provision to develop economies of the poorest world countries is equally important. This assistance must be first and foremost associated with development of agriculture and rural areas.

Impact of the oil market on the global food problem solution is ambiguous. On the one hand, decrease in the world oil prices promotes reduction of expenses for production and carriage of agricultural products, thus, increasing the supply level of agricultural products. On the other hand, decrease in the oil prices in the context of the persistently low demand for these commodities hinder development of the world economy and growth of the population's well-being and have negative impact on the consumer demand. A fall in the oil prices brings about impoverishment of population in the oil countries of Latin America and deteriorates the food problem in this region.

The following factors promote the food problem solution: international economic integration and foreign trade development; foreign trade liberalization in agricultural products; activation of scientific research in the agricultural area, viz. plant breeding and protection, distribution of highly-efficient seeds and animals. Taking into consideration high potential of the national agriculture and agrarian science, Ukraine's important task is to take up a decent position on the world agricultural markets.

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