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CALCULATION OF FOREST COVER CHANGE USING LANDSAT SATELLITE SERVICE AND R PROGRAMMING AND DATA ANALYSIS LANGUAGE

The problem of calculating the change in the level of forest cover in a selected forestry is considered. It is stated that the authors previously developed software for calculating forest cover and processing information on forest stands using the example of a village in the Kharkiv region. Calculations for comparing forest cover over several years using the Global Forest Watch resource, which marks in different colors the places where new stands are planted or existing ones are cut down, are also described. A number of features and shortcomings of this resource are identified. To improve the calculations, it is proposed to use satellite images of the Landsat / TimeSync project. Images of a separate forestry were taken from this resource for the period from 1984 to 2024. The resulting images were loaded into the updated application, then divided into parts (sections). The model previously created by the authors with a list of input factors containing indicators of the percentage of green color in the selected area and in neighboring areas for three years (the significant and the previous two) was chosen as the basis for the forecasting model. The predicted factor is the percentage of green color in the studied area. The formulated problem is proposed to be solved by the method of artificial neural networks in the environment of the programming and data analysis language R. A script was created in this language that not only builds an artificial neural network but also determines the best architecture and effective method of training a neural network for the selected data set. The calculation of the change in forest cover on the site is presented; a forecast is made for the last year, which provides an error of 2.3%. It is determined which architecture of the neural network provides the best result. The results of the calculations indicate high accuracy of the forecast.
Keywords: level of forest cover, deforestation, Global Forest Watch, LandSat, TymeSync, color saturation, forecasting, artificial neural networks, R- language.

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РОЗРАХУНОК ЗМІНИ РІВНЯ ЛІСИСТОСТІ ЗА ДОПОМОГОЮ СУПУТНИКОВОГО СЕРВІСУ LANDSAT І МОВИ ПРОГРАМУВАННЯ ТА АНАЛІЗУ ДАНИХ R

Розглядається задача розрахунку зміни рівня лісистості на обраному лісництві. Наведено, що авторами було раніше розроблено програмне забезпечення для розрахунку лісистості та оброблення інформації про лісові насадження на прикладі селища Харківської області. Також описано розрахунки щодо порівняння лісистості за декілька років з використанням ресурсу Global Forest Watch, який різними кольорами відзначає місця, де здійснюється висадження нових насаджень або вирубування наявних. Виявлено низку особливостей та недоліків цього ресурсу. Для покращення розрахунків запропоновано використання супутникових знімків проєкту «Landsat» / «TimeSync». З цього ресурсу були взяті зображення окремого лісництва за період з 1984 по 2024 роки. Отримані зображення завантажувалися до оновленого додатка, потім виконувався розподіл на частини (ділянці). За основу моделі прогнозування обрано раніше створена авторами модель з переліком вхідних факторів, що містять показники відсотка зеленого кольору на обраній ділянці та на сусідніх з нею за три роки (визначний та два попередні). Прогнозований фактор – значення відсотка зеленого кольору на досліджуваній ділянці. Сформульовану задачу запропоновано розв'язати методом штучних нейронних мереж у середовищі мови програмування та аналізу даних R. Створено скрипт цією мовою, що не тільки будує штучну нейронну мережу, а ще визначає найкращу архітектуру та ефективний метод навчання нейронної мережі для обраного набору даних. Наведено розрахунок зміни лісистості на ділянці, зроблено прогноз на останній рік, що забезпечує похибку у 2,3%. Визначено, яка саме архітектура нейронної мережі забезпечує найкращий результат. Результати розрахунків свідчать про високу точність прогнозування.
Ключові слова: рівень лісистості, Global Forest Watch, LandSat, TymeSync, кольорова насиченість, прогнозування, штучні нейронні мережі, мова R

Introduction

The issue of forest protection is always the most relevant [1]. Significant assistance in this can be provided by the creation and use of specialized software for calculating changes in the percentage of forest cover, processing information on forest stands and detecting illegal logging, as well as predicting changes in forest cover in individual forestry areas.

Analysis of the subject area

A number of authors, in their own works, described the application of various methods of mathematical modeling and the use of information systems and technologies for calculating the state of forest stands. For example, in work [2], in order to find ways to increase the area of the nature reserve fund of the Poltava region, the issue of the influence of reserve indicators and territorial forest cover of individual territorial units as the main indicators of environmental assessment was considered, and a comparative analysis of the indicators of environmental assessment of individual communities was carried out among themselves and with the levels of values ??of these indicators at the national and European levels. In work [3], the state of forest resources in Ukraine was investigated, a dynamic simulation model of the forest turnover system was created, the main factors influencing the development of forest funds and their economic consequences were identified, and the main indicators of forest turnover were predicted.

The authors of this article previously developed special software – an information system for calculating forest cover and processing information on forest plantations [4] using the example of the village of Spivakivka in the Izyum district of the Kharkiv region [5]. A comparison of the forest cover level over a number of years was also carried out [6], for which the World Forest Watch resource was used [7] – a specialized web application for monitoring the forest cover of the planet in real time. This site contains images from NASA satellites for 13 years (until 2013), which makes it possible to calculate the volume of lost and grown forests in different territories by year. The authors took from it images of the Pridonetsk Forestry with conventional designations: blue shows the territories where new forest plantations are being planted, and pink – where logging is taking place. To determine the percentage of logging, it was necessary to calculate the percentage of pink in relation to others. This was calculated in [8]. The disadvantage of this approach is that satellite images are only available for 13 years, up to 2013.

In [9], the degree of forest stand disturbance in the Carpathians for the period from 1984 to 2016 was investigated using time series images obtained from Landsat satellite images using the TimeSync visualization tool. The authors of [9] calculated the average forest cover of the studied area and listed the main disturbances associated with both anthropogenic and natural factors. Therefore, it was decided to use resources [10–11] to obtain images of the Pridonetsk forestry for 40 years, from 1984 to 2024 – see Fig. 1.

Fig. 1. Landsat data for the village of Spivakivka

Problem formulation and data preparation

To improve the previously created application [4] and make it possible to analyze changes in the level of forest cover using big data, the goal was to create the ability to add an image loading module with its subsequent processing. A brief description of the new functionality of the program is given - a module for predicting changes in the level of forest cover of a separate forest using the Landsat satellite service in the existing application for processing information about forest stands [12]. A new tab "Number of colors" has been added to the existing tabs (Fig. 2). Data from the site [11] was prepared and saved to a folder. Using the "Open image" button, it is possible to select the required year and image for processing from the list. Using the "Show colors" button, the user can visually see which colors prevail in this image and the number of pixels of each individual color.

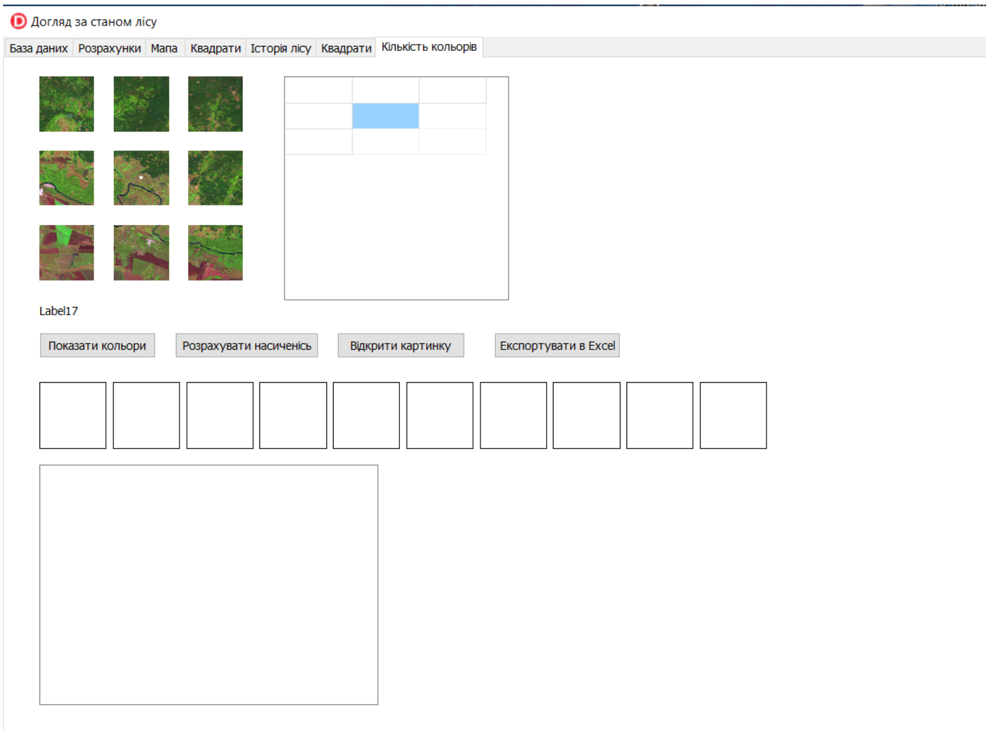

Fig. 2. "Number of Colors" tab

Since we do not need the general situation in forestry [6], but the situation in individual areas, each of the downloaded images needs to be divided into parts in the form of regular rectangles, and then analyze the data for each of these squares. The "Calculate saturation" button (Fig. 3) starts the data processing procedure for each square, calculates the percentage of green pixels to the total number of pixels in the area. This percentage is added to the corresponding cell of the table. To save the results for further processing, the user can save the data to an Excel file.

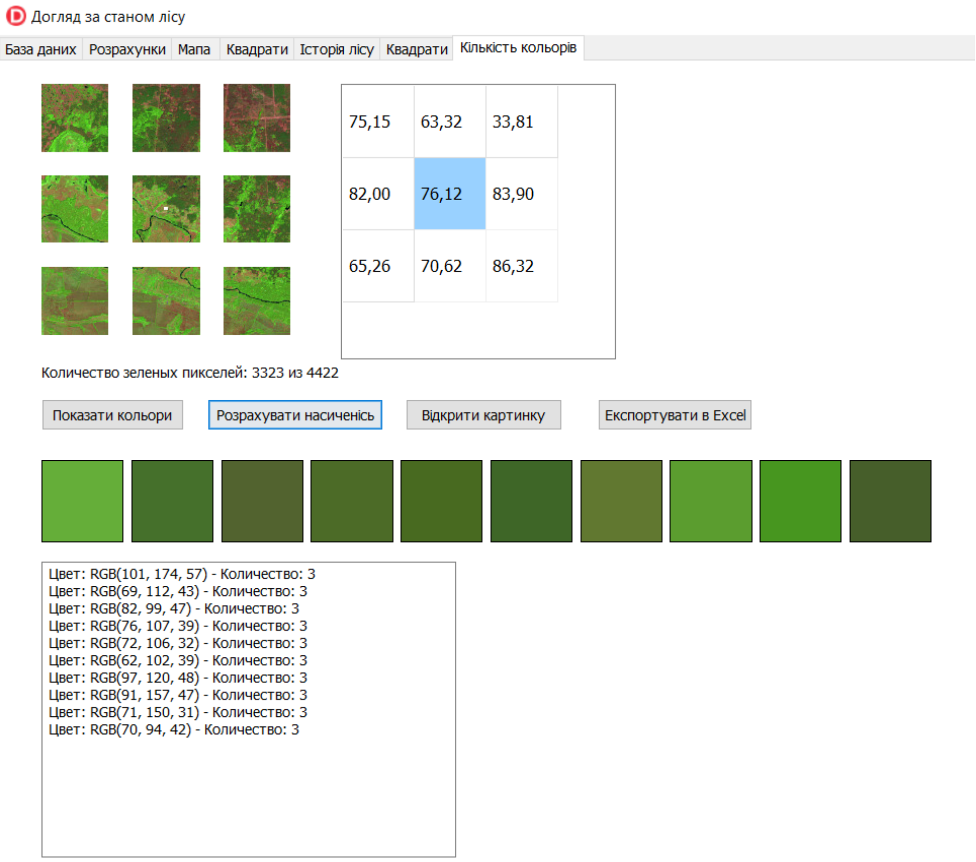

Fig. 3. Calculation of saturation

After completing the data preparation stage, we obtain data for 40 years, from 1984 to 2024 (Fig. 4).

	Квадрат	Квадрат-1рік	Квадрат-2роки	Сусід [X-1,Y-1]	Сусід [X-1,Y-1]-1рік	Сусід [X-1,Y-1]-2роки	Сусід [X,Y-1]	Сусід [X,Y-1]-1рік	Сусід [X,Y-1]-2роки	Сусід [X+1,Y-1]	Сусід [X+1,Y-1]-1рік	Сусід [X+1,Y-1]-2роки	Сусід [X-1,Y]	Сусід [X-1,Y]-1рік	Сусід [X-1,Y]-2роки	Сусід [X+1,Y]	Сусід [X+1,Y]-1рік	Сусід [X+1,Y]-2роки	Сусід [X-1,Y+1]	Сусід [X-1,Y+1]-1рік	Сусід [X-1,Y+1]-2роки	Сусід [X,Y+1]	Сусід [X,Y+1]-1рік	Сусід [X,Y+1]-2роки	Сусід [X+1,Y+1]	Сусід [X+1,Y+1]-1рік	Сусід [X+1,Y+1]-2роки
	Рез	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	Y	X0m1	X0m2	X11	X11m1	X11m2	X12	X12m1	X12m2	X13	X13m1	X13m2	X21	X21m1	X21m2	X23	X23m1	X23m2	X31	X31m1	X31m2	X32	X32m1	X32m2	X33	X33m1	X33m2
1986	54,75	77	60,74	89,24	96	91,41	98,87	100,61	99,77	91	93,69	91,14	59,02	83,31	61,1	87,36	91,99	88,49	10,9	36,3	26,91	29,38	60,74	45,41	57,42	71,98	58,8
1987	88,31	54,75	77	96,61	89,24	96	100,29	98,87	100,61	95,75	91	93,69	83,92	59,02	83,31	93,87	87,36	91,99	84,31	10,9	36,3	76,57	29,38	60,74	86,95	57,42	71,98
1988	93,22	88,31	54,75	95,84	96,61	89,24	100,72	100,29	98,87	95,91	95,75	91	89,87	83,92	59,02	96,04	93,87	87,36	70,04	84,31	10,9	92,15	76,57	29,38	94,89	86,95	57,42
1989	89,62	93,22	88,31	93,87	95,84	96,61	100,34	100,72	100,29	93,62	95,91	95,75	88,1	89,87	83,92	92,63	96,04	93,87	78,58	70,04	84,31	79,99	92,15	76,57	87	94,89	86,95
1990	85,57	89,62	93,22	95,64	93,87	95,84	100,59	100,34	100,72	95,75	93,62	95,91	78,06	88,1	89,87	92,51	92,63	96,04	67,62	78,58	70,04	69,4	79,99	92,15	77,91	87	94,89
1991	89,87	85,57	89,62	95,5	95,64	93,87	100,14	100,59	100,34	95,95	95,75	93,62	86,52	78,06	88,1	94,6	92,51	92,63	63,93	67,62	78,58	84,42	69,4	79,99	87,61	77,91	87
1992	88,24	89,87	85,57	95,75	95,5	95,64	100,02	100,14	100,59	96,25	95,95	95,75	86,07	86,52	78,06	94,87	94,6	92,51	65,85	63,93	67,62	82,79	84,42	69,4	84,55	87,61	77,91
1993	78,92	88,24	89,87	92,79	95,75	95,5	99,75	100,02	100,14	94,62	96,25	95,95	71,21	86,07	86,52	92,2	94,87	94,6	63,84	65,85	63,93	59,68	82,79	84,42	74,79	84,55	87,61
1994	61,04	78,92	88,24	88,69	92,79	95,75	99,39	99,75	100,02	91,88	94,62	96,25	60,74	71,21	86,07	87,81	92,2	94,87	31,91	63,84	65,85	44,37	59,68	82,79	65,97	74,79	84,55
1995	84,55	61,04	78,92	92,72	88,69	92,79	99,5	99,39	99,75	95,07	91,88	94,62	74,04	60,74	71,21	94,48	87,81	92,2	59,63	31,91	63,84	76,84	44,37	59,68	82,75	65,97	74,79
1996	82,34	84,55	61,04	93,33	92,72	88,69	99,25	99,5	99,39	94,91	95,07	91,88	77,79	74,04	60,74	92,27	94,48	87,81	49,19	59,63	31,91	67,03	76,84	44,37	82,02	82,75	65,97
1997	96,90	82,34	84,55	95,43	93,33	92,72	99,62	99,25	99,5	96,04	94,91	95,07	93,46	77,79	74,04	95,66	92,27	94,48	81,23	49,19	59,63	78,95	67,03	76,84	94,17	82,02	82,75
1998	74,11	96,9	82,34	90,98	95,43	93,33	98,24	99,62	99,25	92,15	96,04	94,91	69,65	93,46	77,79	93,49	95,66	92,27	40,09	81,23	49,19	43,37	78,95	67,03	76,16	94,17	82,02
1999	59,43	74,11	96,9	85,93	90,98	95,43	96,74	98,24	99,62	87,61	92,15	96,04	62,53	69,65	93,46	90,28	93,49	95,66	32,23	40,09	81,23	53,39	43,37	78,95	59,05	76,16	94,17
2000	82,50	59,43	74,11	90,43	85,93	90,98	97,76	96,74	98,24	86,88	87,61	92,15	80,35	62,53	69,65	95,55	90,28	93,49	77,84	32,23	40,09	71,17	53,39	43,37	77,34	59,05	76,16
2001	83,83	82,5	59,43	91,99	90,43	85,93	97,63	97,76	96,74	87,65	86,88	87,61	92,67	80,35	62,53	93,26	95,55	90,28	84,94	77,84	32,23	86,02	71,17	53,39	78,34	77,34	59,05
2002	62,98	83,83	82,5	87,25	91,99	90,43	96,29	97,63	97,76	85,62	87,65	86,88	63,73	92,67	80,35	92,33	93,26	95,55	54,23	84,94	77,84	57,39	86,02	71,17	72,32	78,34	77,34
2003	97,58	62,98	83,83	96,95	87,25	91,99	98,76	96,29	97,63	95,09	85,62	87,65	97,6	63,73	92,67	97,47	92,33	93,26	94,17	54,23	84,94	95,68	57,39	86,02	98,51	72,32	78,34
2004	95,64	97,58	62,98	93,58	96,95	87,25	96,81	98,76	96,29	89,42	95,09	85,62	95,12	97,6	63,73	96,56	97,47	92,33	79,83	94,17	54,23	87,18	95,68	57,39	97,72	98,51	72,32
2005	95,64	95,64	97,58	93,58	93,58	96,95	96,81	96,81	98,76	89,42	89,42	95,09	95,12	95,12	97,6	96,56	96,56	97,47	79,83	79,83	94,17	87,18	87,18	95,68	97,72	97,72	98,51
2006	93,65	95,64	95,64	92,61	93,58	93,58	95,79	96,81	96,81	87,79	89,42	89,42	95,57	95,12	95,12	96,11	96,56	96,56	63,12	79,83	79,83	86,54	87,18	87,18	95,32	97,72	97,72
2007	81,14	93,65	95,64	93,03	92,61	93,58	94,71	95,79	96,81	85,69	87,79	89,42	80,48	95,57	95,12	93,55	96,11	96,56	86,66	63,12	79,83	85,62	86,54	87,18	77,36	95,32	97,72
2008	68,72	81,14	93,65	90,05	93,03	92,61	92,94	94,71	95,79	82,61	85,69	87,79	76,28	80,48	95,57	91,29	93,55	96,11	35,39	86,66	63,12	55,27	85,62	86,54	74,97	77,36	95,32
2009	68,72	68,72	81,14	90,05	90,05	93,03	92,94	92,94	94,71	82,61	82,61	85,69	76,28	76,28	80,48	91,29	91,29	93,55	35,39	35,39	86,66	55,27	55,27	85,62	74,97	74,97	77,36
2010	68,72	68,72	68,72	90,05	90,05	90,05	92,94	92,94	92,94	82,61	82,61	82,61	76,28	76,28	76,28	91,29	91,29	91,29	35,39	35,39	35,39	55,27	55,27	55,27	74,97	74,97	74,97
2011	76,55	68,72	68,72	73,7	90,05	90,05	89,39	92,94	92,94	59,05	82,61	82,61	78,58	76,28	76,28	92,97	91,29	91,29	79,29	35,39	35,39	82,27	55,27	55,27	84,8	74,97	74,97
2012	87,16	76,55	68,72	73,72	73,7	90,05	90,66	89,39	92,94	61,17	59,05	82,61	92,81	78,58	76,28	94,05	92,97	91,29	60,29	79,29	35,39	73,47	82,27	55,27	84,46	84,8	74,97
2013	64,54	87,16	76,55	70,24	73,72	73,7	87,7	90,66	89,39	57,33	61,17	59,05	66,94	92,81	78,58	90,21	94,05	92,97	63,32	60,29	79,29	68	73,47	82,27	69,86	84,46	84,8
2014	62,66	64,54	87,16	71,55	70,24	73,72	89,03	87,7	90,66	57,58	57,33	61,17	65,85	66,94	92,81	88,83	90,21	94,05	38,44	63,32	60,29	47,65	68	73,47	65,74	69,86	84,46
2015	75,46	62,66	64,54	74,88	71,55	70,24	90,71	89,03	87,7	61,01	57,58	57,33	84,62	65,85	66,94	92,92	88,83	90,21	79,96	38,44	63,32	85,17	47,65	68	91,77	65,74	69,86
2016	67,87	75,46	62,66	74,92	74,88	71,55	90,32	90,71	89,03	60,24	61,01	57,58	72,52	84,62	65,85	91,34	92,92	88,83	36,88	79,96	38,44	61,19	85,17	47,65	68,43	91,77	65,74
2017	86,23	67,87	75,46	76,05	74,92	74,88	92,11	90,32	90,71	64,86	60,24	61,01	86,16	72,52	84,62	94,41	91,34	92,92	85,89	36,88	79,96	84,96	61,19	85,17	92,22	68,43	91,77
2018	73,50	86,23	67,87	75,6	76,05	74,92	91,45	92,11	90,32	61,58	64,86	60,24	70,94	86,16	72,52	91,11	94,41	91,34	66,15	85,89	36,88	78,11	84,96	61,19	73,52	92,22	68,43
2019	73,74	73,5	86,23	77,77	75,6	76,05	89,48	91,45	92,11	63,68	61,58	64,86	73,29	70,94	86,16	92,74	91,11	94,41	46,16	66,15	85,89	56,35	78,11	84,96	85,57	73,52	92,22
2020	68,77	73,74	73,5	76,66	77,77	75,6	91,75	89,48	91,45	65,83	63,68	61,58	76,12	73,29	70,94	90,82	92,74	91,11	44,53	46,16	66,15	73,59	56,35	78,11	70,74	85,57	73,52
2021	73,65	68,77	73,74	77,61	76,66	77,77	91,72	91,75	89,48	66,51	65,83	63,68	75,21	76,12	73,29	90,75	90,82	92,74	55,29	44,53	46,16	61,9	73,59	56,35	85,55	70,74	85,57
2022	82,59	73,65	68,77	71,82	77,61	76,66	88,85	91,72	91,75	64,04	66,51	65,83	89,96	75,21	76,12	88,63	90,75	90,82	80,69	55,29	44,53	78,49	61,9	73,59	93,42	85,55	70,74
2023	86,21	82,59	73,65	80,37	71,82	77,61	91	88,85	91,72	73,2	64,04	66,51	85,75	89,96	75,21	93,8	88,63	90,75	91,04	80,69	55,29	76,07	78,49	61,9	88,35	93,42	85,55
2024	76,12	86,21	82,59	75,15	80,37	71,82	63,32	91	88,85	33,81	73,2	64,04	82	85,75	89,96	83,9	93,8	88,63	65,26	91,04	80,69	70,62	76,07	78,49	86,32	88,35	93,42

Fig. 4. Data for 40 years

Problem solving using artificial neural networks

Next, the question arises of calculating the change in the percentage of forest stands in the selected area. This can be done in various ways. First, use regression analysis - apply a regression equation (linear, polynomial, exponential, etc.) separately to the values of each square, as well as for the entire forestry. But, as shown in Fig. 5, no single equation is suitable for predicting the percentage of deforestation in the entire forestry.

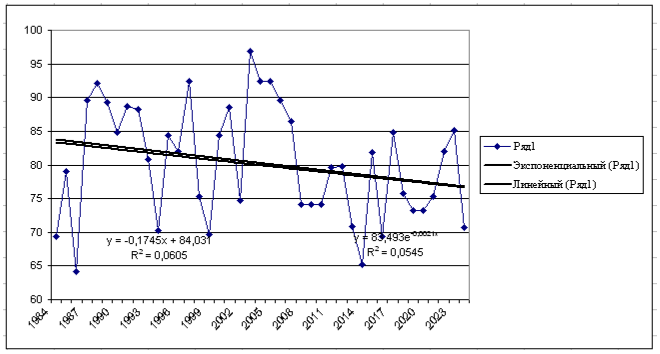

Fig. 5. Forecasting with regression equations

Another way is to use the method of artificial neural networks [13]. As input factors for this method, we can consider, firstly, the indicators of green color saturation in the studied area in the current year and for several previous years (let this value be equal to two), and secondly, the same indicators of saturation of neighboring squares from above, below and diagonally - the problem is formulated in [14–15]. Since we have values for 9 squares for three years, the number of factors will be equal to 27 - these are 26 inputs and 1 output, which contains the values in the studied area:

$$Y = F\left(X_{0m1}, X_{0m2}, X_{11}, X_{11m1}, \ldots, X_{33m2}\right) \tag{1}$$

After processing the data according to formula (1), we obtain the result already shown in Fig. 4.

The R programming and data analysis language was used to perform the calculations [16]. A script was created that performs calculations using the artificial neural network method and allows determining a more attractive network architecture and a more effective network training method for the selected data set [17].

The calculation of the change in forest cover (i.e., green color saturation) in a separate plot is given in Table 1 (test sample). It can be seen that the average error is 4.7%.

Table 1

Results of calculating the level of forest cover on a separate site

Рік	Y	Res	error
1987	88.31	85.78	0.05896
1989	89.62	91.13	0.03524
1991	89.87	91.59	0.04016
1992	88.24	88.73	0.01147
1995	84.55	82.92	0.03804
1996	82.34	86.27	0.09184
2002	62.98	64.39	0.03301
2012	87.16	89.94	0.06492
2013	64.54	65.60	0.02486
2020	68.77	71.35	0.06024
2022	82.59	85.91	0.07742

After running the script for different parameters, it was found that the best result is provided by a perceptron with an architecture containing two hidden layers with two neurons in each of them (Fig. 6). The calculation results indicate high accuracy, the use of this perceptron for forecasting for the last year showed an error of 2.3% (Table 2).

Table 2

Prediction results on the selected MLP square 26x2x2x1

N	Y	Res	error
2024	76.12	75.62	0.02335

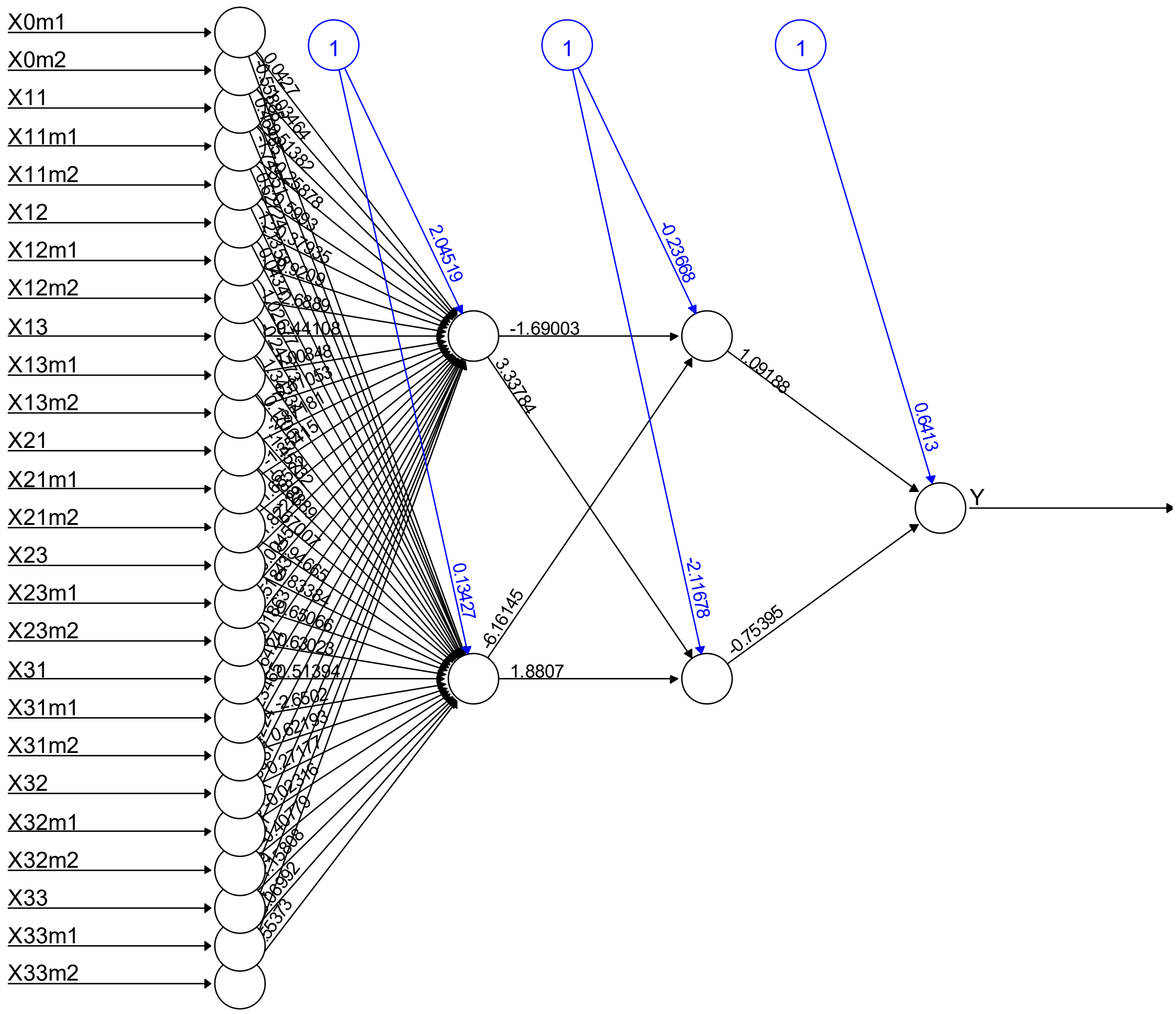

Fig. 6. Neural network architecture MLP 26x2x2x1

Conclusions

The calculation of the change in the level of forest cover was performed using the Landsat satellite service, the TimeSync visualization tool, and the R programming and data analysis language. The method of artificial neural networks was used to solve the forecasting problem. A script was created in the R language that not only performs calculations, but also allows you to determine the best architecture of the neural network and more effective ways of training it for a specific data set. It was found that for the available data, the best result is provided by a perceptron with an architecture containing two hidden layers with two neurons in each of them when using the smallest absolute gradient learning method. The dynamics of forest cover change in the selected area was calculated, the forecast error for the last year was 2.3%.

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