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The influence of structural and functional changes on N-P-K input of agricultural origin and surface water quality in the upper Dunajec River basin in the years 1980–2010

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Abstract: The aim of the study was the prediction of N-P-K inputs (hereafter referred to as NPK load) from agricultural sources. The study aimed to determine relations between the structural changes and the N-P-K load (nitrogen-phosphorus-potassium) fertilizer components in the upper Dunajec River basin (the Carpathian region in Poland). Analysis included the level and nature of agricultural production, the land use structure and non-agricultural factors. Multiple regression analysis was used for the development of the model. Relationships were determined in the form of regression models in the system of N-P-K load-structural parameters-land use-surface water quality. The quality of surface water was assessed in a range of concentrations of $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, PO_4^{3-}, Cl^-, and compared to the N-P-K load that was brought to the basin from agricultural sources. Significant structural and spatial changes took place in the upper Dunajec River basin that affected many social, economic and environmental factors. Agricultural production was reduced, resulting in a decrease of area of agricultural land between the year 1980 and 2010. The most important factors influencing the changes in biogenic load of an agricultural origin were: stocking density and mineral fertilization. Both of these parameters determined the amount of N-P-K load in approx. 80–90% (not counting the use of N-P-K components by crops). Surface water quality has generally improved, only higher concentrations of chlorides were recorded in small urbanized river basins. Therefore, the chemical composition of water plays the role of a simplified indicator of structural changes. Mathematical formulas proved changes in N-P-K load depending on variations of individual influencing factors. The development of the usable space of the investigated river basin must take into account agricultural and non-agricultural factors, as well as the proportions and relationships between them. Only then might the sustainable and multifunctional development of these areas be provided.

Keywords: structural and land use changes, agricultural production, N-P-K inputs (hereafter N-P-K load), surface water quality

INTRODUCTION

Mountain areas are characterized by their distinctness from the other, lowland parts of Poland. Their specific features include: terrain diversification, geological structure, high precipitation levels, harsh climate with high amplitudes of air temperature, high dynamics of surface water outflows (Dynowska 1995). There is a rich variety of flora, fauna and landscape (Groch & Kurek 1995).

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Demographic and cultural aspects, forms of settlement and the specific development of various economic forms, including agricultural production, determine the particular nature of the region. Also, these are areas of high environmental value where significant amounts of water resources of relatively good quality come into being (Twardy et al. 2007). Due to the abovementioned main conditions, the Carpathian areas have undergone, and continue to undergo, socio-economic and spatio-functional transformations which result from many interrelated factors of natural and anthropogenic origin (Groch & Kurek 1995).

The main objective of the study was the predicting of NPK inputs (hereafter NPK load) from agricultural sources. Also, the study aimed to determine relations between structural changes of investigated areas occurring over long time series, with a particular consideration of agricultural activities and land use structure, as well as the N-P-K load of agricultural origin in the upper Dunajec River basin. On this basis, intensity and direction of structural and environmental changes were assessed, and factors that affect the size of this load were ranked hierarchically, referring to the quality of surface water.

METHODS

Research area

The research was carried out in the upper Dunajec River basin (in the Carpathian region in Poland) as far as the cross-section in Krościenko village. This area accounts for approximately 23% of the total Dunajec River basin area and amounts to 1580 km^2 (Dynowska 1995) (Fig. 1). The following sub-basins were identified in the studied area: Biały Dunajec (224 km^2), Czarny Dunajec (456 km^2), Białka (239 km^2) and Grajcarek River basin (85 km^2). They were separately monitored, with hydrochemical monitoring carried out of the content of N-NO$_3^-$, N-NH$_4^+$-N, PO$_4^{3-}$, K$^-$, Cl$^-$. Water samples were collected once a month. The annual load of N-P-K, brought to the agricultural area, was also determined – based on the most important data on agricultural production, as discussed in detail below.

The upper Dunajec River basin is located in the mesoregions of the Tatras, Podhale and partially Beskid Sądecki. It is a typical mountain basin with its climate determined by orography, landform, environmental and hydrographic features. Average monthly temperatures range from 5.5°C to 5.8°C.

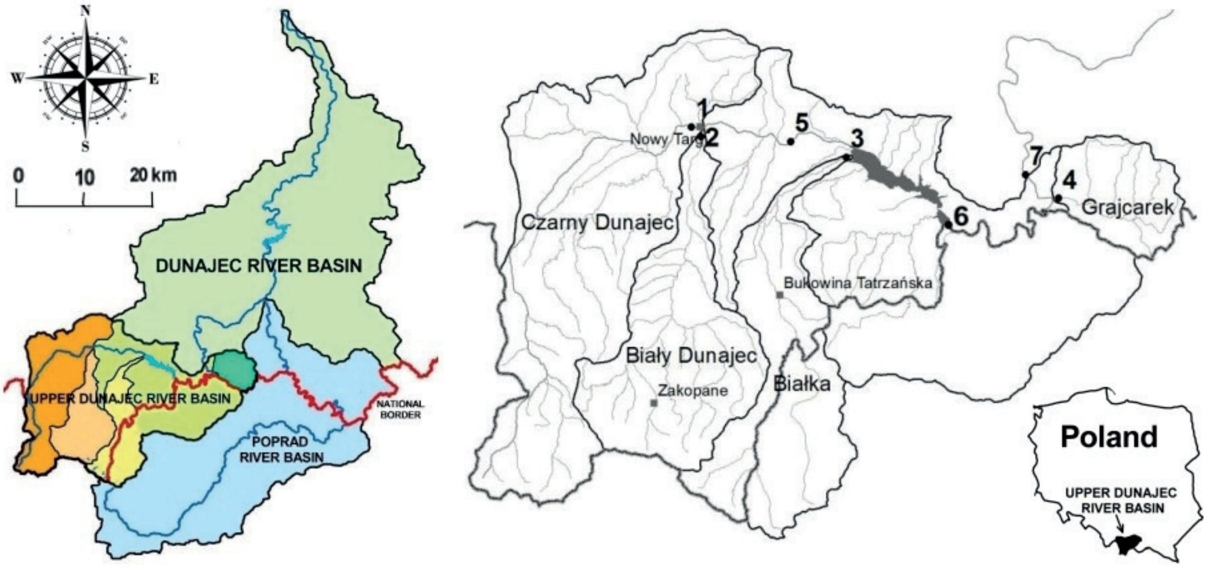

Fig. 1. *Upper Dunajec River basin against the background of the whole Dunajec and Poprad River basins and spatial distribution of measurement cross-sections in the upper Dunajec River basin. Labelling of cross-sections: 1 – Czarny Dunajec, 2– Biały Dunajec, 3 – Białka, 4 – Grajcarek, 5 – Dunajec Łopuszna, 6 – Dunajec Niedzica, 7 – Dunajec Krościenko*

There is observed an uneven distribution of precipitation across the basin with average annual values of 800–1400 mm (Kostrakiewicz 2003).

Statistical analysis was carried out for the period 1980–2010. This was a time when the most significant structural changes took place. The interpretation of the results allowed the assessment of which parameters influenced on changes of N-P-K load that was brought to the basin from agricultural sources during the investigated period, as well as their extent.

Structural data were collected for all years 1980–2010 from the Central Statistical Office of Poland, especially from the Local Data Bank. Water quality information was obtained from monitoring carried out by Voivodship Inspectorate for Environmental Protection, and supplemented with the results of water quality analyzes conducted by ITP as part of statutory research. For individual sub-basins, land use patterns were additionally quantified by the use of the utilization index (W) and the agro-forestry index (W_{rl}), which are weighted averages of five utility categories and indicate the level of retention capacity of a given area (Kopacz 2003, 2004, 2007). These data concern 13 communes that cover the entire investigated basin. Data from the "communes' system" were converted to the basin area based on the knowledge of percentage share of the area of each commune in the basin. A weighted average formula was used for conversion:

$$P_{ZL} = \frac{P_{G1} \cdot A_{G1} + P_{G2} \cdot A_{G2} + \ldots + P_{GN} \cdot A_{GN}}{A_{G1} + A_{G2} + \ldots + A_{GN}}$$

where:

P_{ZL} – value of P parameter for the basin,
$P_{G1}, \ldots, P_{GN}$ – values of P parameter for individual communes (from 1 to *n*),
$A_{G1}, \ldots, A_{GN}$ – percentage share of the commune area (from 1 to *n*) in the basin area.

Also conducted was the monitoring of surface waters in the scope of concentrations of ammonium ions $N\text{-}NH_4^+$, nitrate ions $N\text{-}NO_3^-$, phosphate ions PO_4^{3-}, potassium ions K^- and chloride ions Cl^- (Dojlido 2012) in selected seven hydrometric cross-sections (Fig. 1).

Table 1
Structural parameters used for the analysis of factors determining N-P-K load

No.	Structural parameters	Abbrev.
1	N-P-K load (input) from agricultural sources [$kg \cdot ha^{-1}$ AL] – parameter wanted	$L_{N\text{-}P\text{-}K}$
2	Stocking density [$LU^{*} \cdot ha^{-1}$ AL^{**}]	Sd
3	N-P-K balance in catchment configuration [$kg \cdot ha^{-1}$ AL]	$B_{N\text{-}P\text{-}K}$
4	N-P-K consumption from organic fertilizers [$kg \cdot ha^{-1}$ AL]	$CO_{N\text{-}P\text{-}K}$
5	N-P-K consumption from mineral fertilizers [$kg \cdot ha^{-1}$ AL]	$CM_{N\text{-}P\text{-}K}$
6	Utilization index W	W
7	Agro-forestry index W_{rl}	W_{rl}
8	Area of agricultural land [percent of total area]	AL
9	Area of arable land [percent of total area]	ALp
10	Area of grasslands [percent of total area]	Gr
11	Area of meadows [percent of total area]	Md
12	Area of pastures [percent of total area]	Ps
13	Area of forests [percent of total area]	Fs
14	Built-up area and other areas [percent of total area]	BA
15	Total crop area [ha]	CA
16	Number of cattle [heads]	Nc
17	Number of pigs [heads]	Np
18	Number of sheep [heads]	Ns
19	Number of horses [heads]	Nh
20	Number of laying hens [heads]	Nlh
21	Length of sewerage system [km]	Lss
22	Number of people using sewerage system [person]	Npss
23	Population density [$person \cdot km^{-2}$]	Pd

* LU – Livestock Unit, ** AL – Agricultural Land.

Data such as parameters for agricultural production (livestock population, area of agricultural land, sowing and yielding of crops, mineral fertilization, etc.) were entered into the MacroBil software (by IUNG Puławy) (Kopacz & Twardy 2011, Kopacz 2011) in order to calculate the N-P-K load. The analysis included 23 structural parameters, to which appropriate abbreviations were assigned (Tab. 1).

The MacroBil computer program is a tool widely used in Poland to determine the parameters of agricultural production. It calculates the nutrient balance (N, P, K) on the farm using the "soil surface nutrient balance" method. The following sources of supply components to the soil are included in the balance on the input side: mineral fertilizers, organic fertilizers, plowed by-products of crops, biological binding of nitrogen (post-harvest residues of legumes, plowed secondary crops of legumes) and precipitation. The output side of the balance includes nutrient uptake in yields. The program determines the values of balance and load of N-P-K per unit of area.

Initially, an analysis of the significance of the correlation between parameters was conducted using the so-called Spearman's correlation matrix. This is more "resistant" to deviations from the Gaussian distribution and its coefficients and also takes into account nonlinear relations. After verifying the significance of the rank correlation between structural parameters, regression relationships between N-P-K load and independent factors were determined together with water quality which, in the most appropriate way, mapped the aforementioned relations (Elandt 1964, Kowalczyk 2000, Kowalczyk et al. 2004).

A multiple regression analysis was used to prioritize the effect of these factors (Stanley 1976, Greń 1982). A simplified formula was applied assuming that there exists the impact of a set of n variables $X_1, X_2, \ldots, X_n$ on the variable Y, defined by the equation:

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n,$$

where $\hat{Y}$ is the expected value of the variable Y, and coefficients b_i for $i = 1, \ldots, n$ are estimates of the regression parameters b_i.

In addition to these factors, standardized Beta regression coefficients were also determined, as well as partial and semi-partial correlations. Beta coefficients allow the comparison of the relative contributions that each independent variable makes in the prediction of dependent variable (Stanley 1976, Stevens 1986). In turn, if semi-partial correlations are very weak and partial correlations are strong, then the given independent variable is the most important factor influencing the dependent variable (Lindeman et al 1980, Stevens 1986). Analysis of partial and semi-partial correlations allows the detection of whether the correlation between variables is only apparent or real (Stevens 1986). Calculations were carried out by means of the Statistica 7.0 software.

RESULTS

Structural changes

A noticeable reduction in the size of livestock density in the upper Dunajec River basin was observed during the period from 1980–2010. Compared with the 1980s, it decreased from around 1.4–1.6 to just 0.2–0.6 livestock units per hectare of agricultural land. Particularly noticeable is the decline of the sheep population, which in the 1980s constituted the backbone of animal production and, at the same time, a traditional way of utilizing mountain pastures in this region. The calculated (by the MicroBil computer program described above) input of nitrogen (total form) also decreased by 63%, phosphorus (total form) by 76%, and potassium (total form) by 71% (Tab. 2).

In the years 1980–2010 there were also significant changes in the structure of agricultural land, mainly due to decreasing arable land and increasing grassland area. Figures 2–4 show changes in agricultural land-use that occurred in selected parts of the upper Dunajec River basin.

The agricultural land area decreased on average by 20% (Fig. 2). The largest decreases were related to arable land (Fig. 3).

At the beginning of the 21st century, there was an increase in the area of grassland, but after 2005 a decrease was reported again (Kopacz 2011, Kopacz & Twardy 2011) (Fig. 4). The phenomenon of "converting" arable land to grassland occurred, and the decline of grassland area in recent years can be explained by self-afforestation and by the exclusion of some areas from the agricultural land category and changing their intended purpose, e.g. for housing development.

Substantial and dynamic changes have also occurred in terms of other infrastructure parameters. These included, among others, the length of the sewerage network in the upper Dunajec River basin in relation to the 1980s, which has increased several dozen times. Only in the Grajcarek River basin (Szczawnica commune), was this rise insignificant. The number of residents who at the time were connected to the sewage system varied. It grew from 28.3% to 50.0% (in the upper Dunajec River basin) over the years 1980–2010.

Table 2
Changes in N-P-K load [kg/ha of agricultural land] in the upper Dunajec River basin and its sub-basins

Hydrometric cross-section	1980	1985	1990	1995	2000	2005	2010
N load							
Upper Dunajec	136	135	112	113	88	58	50
Czarny Dunajec	136	135	112	117	88	63	53
Biały Dunajec	159	146	124	114	95	62	54
Białka Tatrzańska	136	140	129	133	112	63	51
Grajcarek	76	80	66	62	44	32	30
P load							
Upper Dunajec	27.5	24.7	15.8	15.9	12.1	7.5	6.5
Czarny Dunajec	27.2	24.2	15.9	16.3	11.9	8.1	6.8
Biały Dunajec	30.2	25.8	17.2	16.2	13.1	7.9	6.9
Białka Tatrzańska	28.8	26.3	18.5	19.0	15.3	8.1	6.7
Grajcarek	17.8	16.3	9.1	9.2	6.4	4.0	3.7
K load							
Upper Dunajec	132	121	103	89	73	45	39
Czarny Dunajec	133	122	104	95	76	51	41
Biały Dunajec	160	138	119	95	84	52	44
Białka Tatrzańska	134	126	123	111	96	52	42
Grajcarek	62	58	48	35	26	15	14

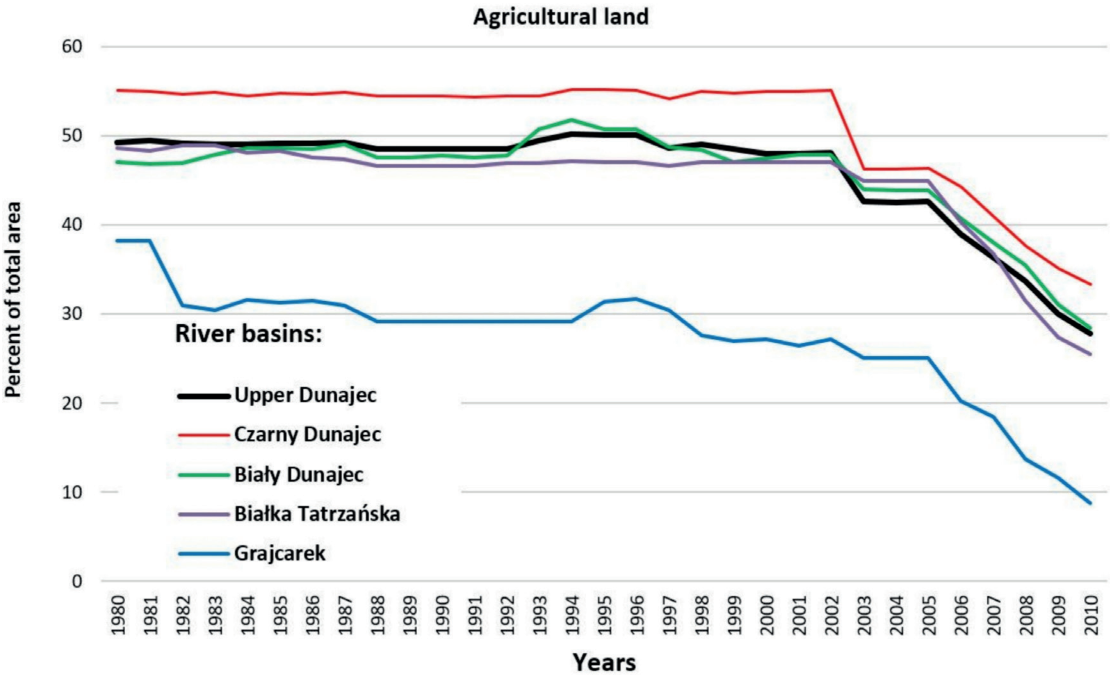

Fig. 2. *Changes in area of agricultural land in the upper Dunajec River basin*

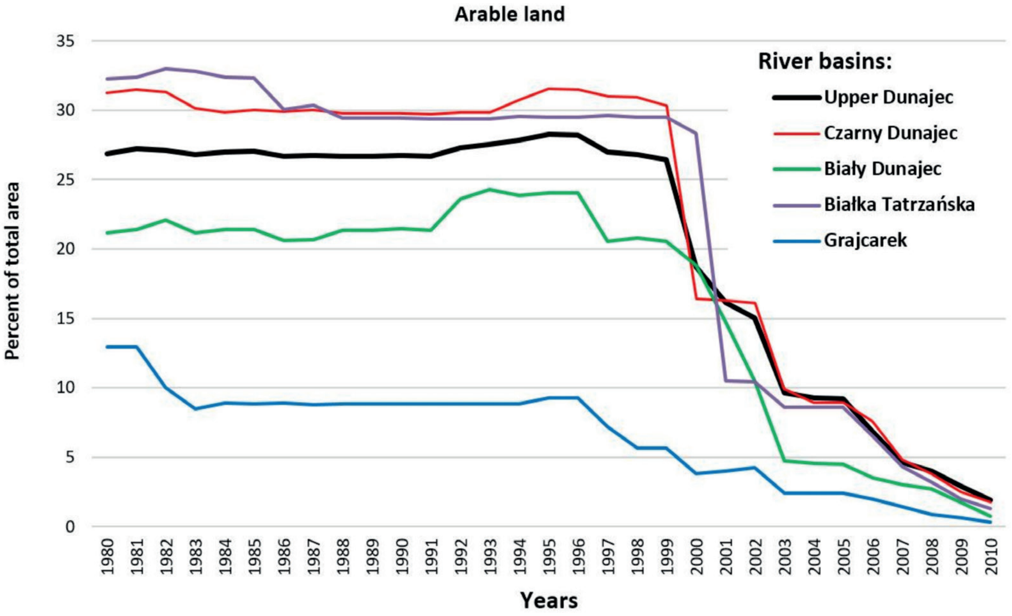

Fig. 3. *Changes in area of arable land in the upper Dunajec River basin*

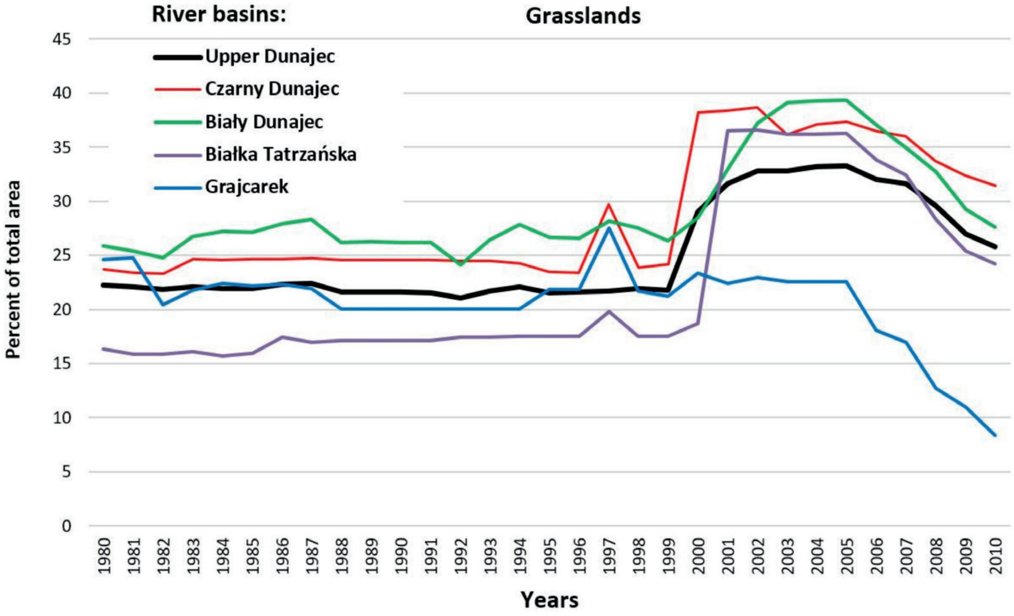

Fig. 4. *Changes in area of grassland in the upper Dunajec River basin*

The quality of surface waters

Data regarding the quality of surface water were obtained from hydrochemical monitoring carried out by the Voivodship Inspectorate for Environmental Protection in Krakow.

Water quality was analyzed for the content of nutrients (N-NH_4^+, N-NO_3^-, PO_4^{3-}, K^-) and additionally chlorides (Cl^-). Water samples were collected in designated cross-sections (Fig. 1) and analyzed according to Polish Standards in this regard.

Figures 5–9 show changes in annual average concentration of analyzed components.

During the analyzed period of 30 years, there was a slight decrease of concentration of ionic components, especially N-NH_4^+ and N-NO_3^- and K^- (Figs. 5, 6, 8). Phosphate ions showed no trends of change over time (Fig. 7). In the case of chloride ions, an ambiguous downward trend is not present. In fact, in the 2009–2010 period of research, some increase in annual average concentrations of Cl^- in surface waters of some sub-basins in the upper Dunajec River basin was even noted (Fig. 9).

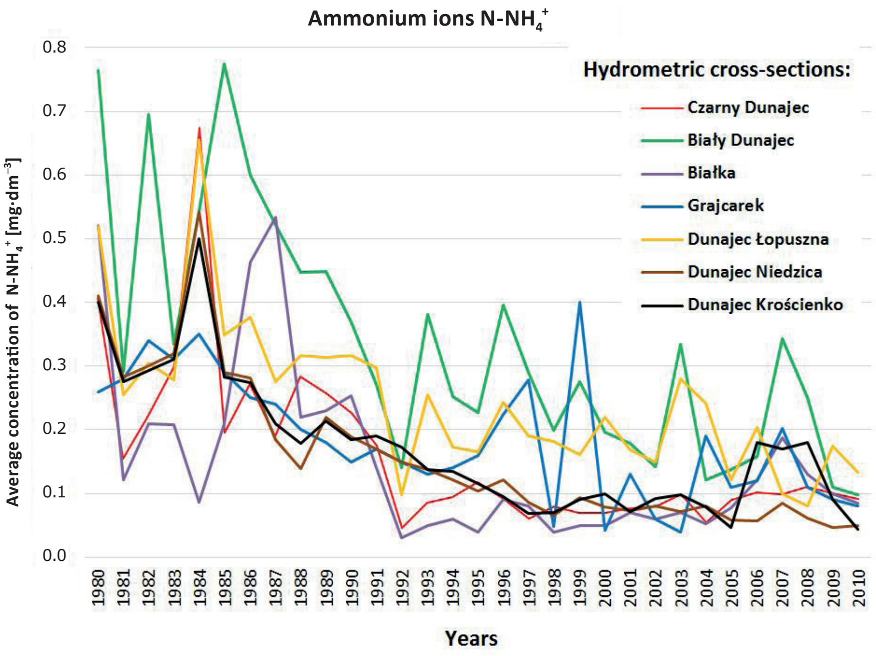

Fig. 5. *Changes in average annual concentration of N-NH_4^+ [mg·dm^{-3}] in rivers draining the upper Dunajec River basin in the years 1980–2010*

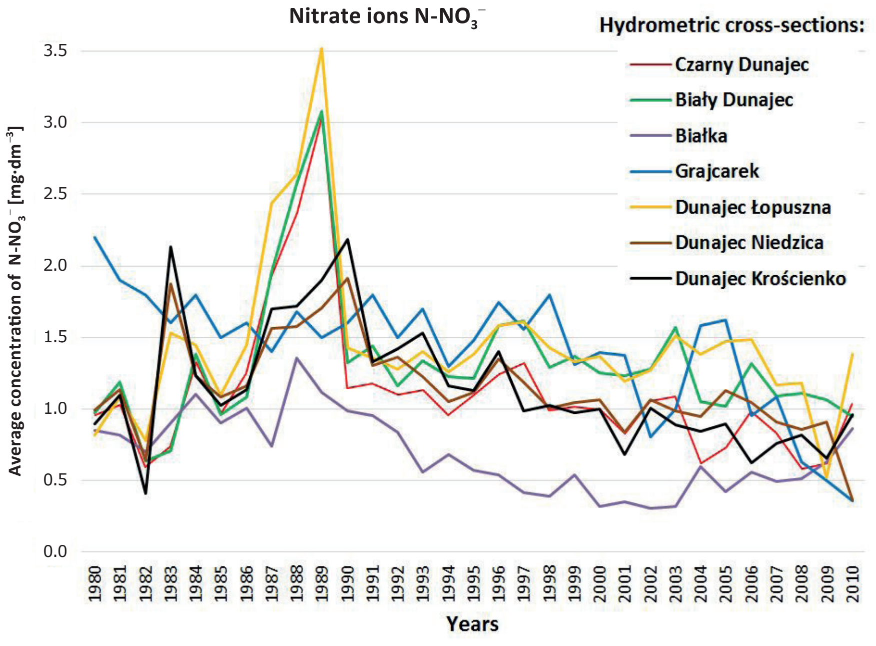

Fig. 6. *Changes in average annual concentration of N-NO_3^- [mg·dm^{-3}] in rivers draining the upper Dunajec River basin in the years 1980–2010*

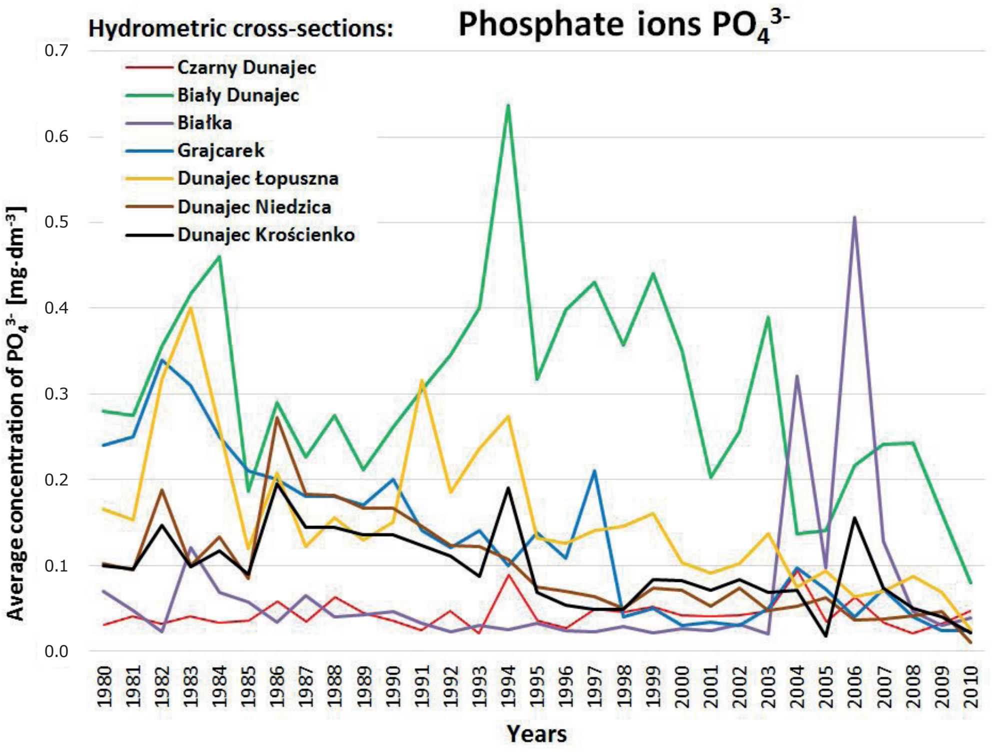

Fig. 7. *Changes in average annual concentration of* PO_4^{3-} *[mg·dm*$^{-3}$*] in rivers draining the upper Dunajec River basin in the years 1980–2010*

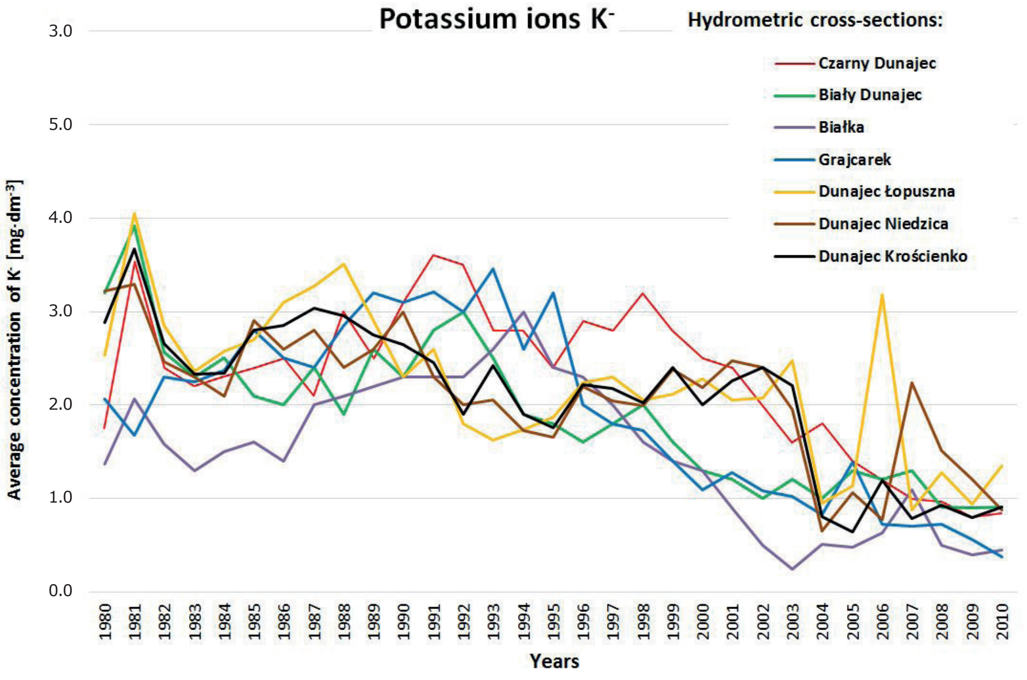

Fig. 8. *Changes in average annual concentration of* K^- *[mg·dm*$^{-3}$*] in rivers draining the upper Dunajec River basin in the years 1980–2010*

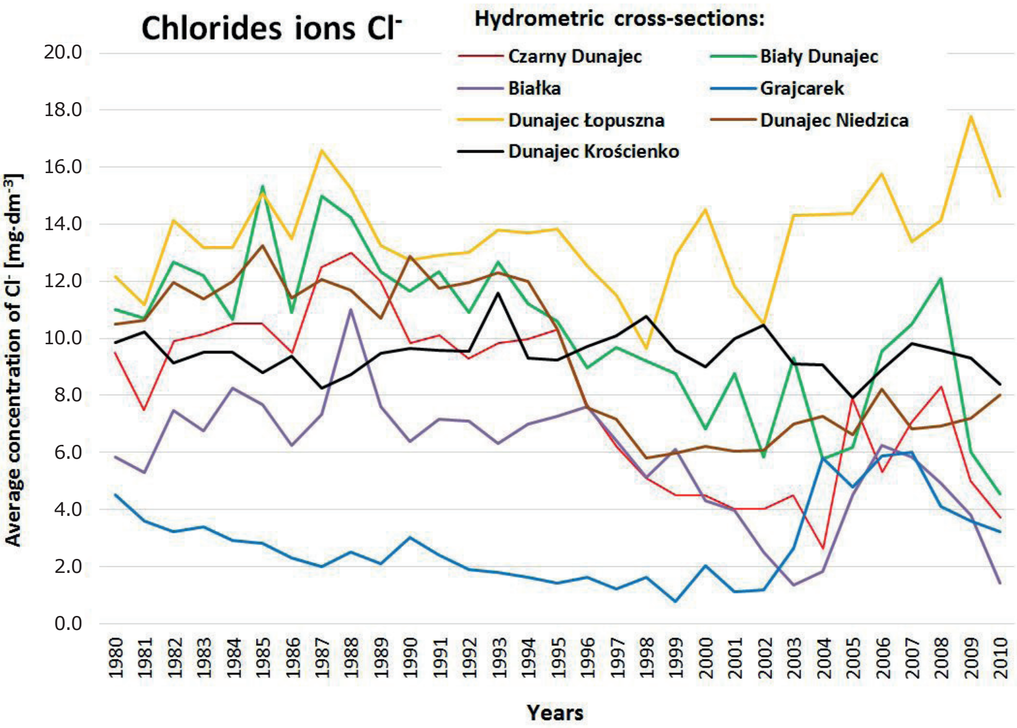

***Fig. 9.** Changes in average annual concentration of Cl^- [$mg \cdot dm^{-3}$] in rivers draining the upper Dunajec River basin in the years 1980–2010*

Relationships: agricultural production – structural changes – quality of surface water

Table 3 shows the rank correlation coefficients with respect to the dependent variable, i.e. N-P-K load, also against the background of water quality. Significant correlations (at the probability level $p < 0.05$) are indicated in bold. The smaller the area of the analysed river basin is (especially Białka and Grajcarek River basins), the stronger the correlation between N-P-K load and other factors of influence. Based on the conducted analysis of Spearman's rank correlation, independent factors were selected which in the most statistically significant way correlate with the N-P-K load in analysed river sub-basins. By linear and non-linear estimation, regression relations were determined between the N-P-K load and individual structural parameters. Functions with the highest determination coefficient were selected for the mathematical description of these relations.

Figure 10 shows an exemplary relationship between the stocking density of livestock and the N-P-K load introduced into a river basin. There is a distinct collinear correlation between the reduction of N-P-K load and the decrease in livestock population. The coefficient of determination was very high here and it clearly shows a high statistical significance of correlation.

There are also noticeable relationships between the content of nutrients in surface waters and the amount of N-P-K load (Fig. 11). In all cases, there was a collinear relation between the load of N-P-K introduced to agricultural area in the upper Dunajec River basin and the average concentrations of the examined components in surface waters. The lack of such relations concerned concentrations of potassium and chloride ions in water, hence these relations were not presented in Figure 11. The presented graphs and regression equations are not yet evidence of the unequivocal impact of a particular parameter on changes of N-P-K load. In order to hierarchize the various influencing factors, multiple regression analysis was performed.

Table 3
Spearman's rank correlation coefficients of the dependent variable N-P-K load and other parameters in the upper Dunajec River basin

Parameter	Upper Dunajec River basin	Czarny Dunajec River basin	Biały Dunajec River basin	Białka River basin	Grajcarek River basin
Sd	**0.97**	**0.96**	**0.98**	**0.87**	**0.94**
$B_{N\text{-}P\text{-}K}$	**0.97**	**0.97**	**0.97**	**0.92**	**0.96**
$CO_{N\text{-}P\text{-}K}$	**0.97**	**0.97**	**0.98**	**0.86**	**0.94**
$CM_{N\text{-}P\text{-}K}$	**0.91**	**0.92**	**0.92**	**0.83**	**0.94**
W	0.18	−0.07	**0.69**	−0.25	**0.54**
Wrl	**0.50**	**0.62**	0.33	**0.64**	**0.63**
AL	**0.62**	0.19	0.14	**0.47**	**0.76**
ALp	**0.56**	**0.59**	**0.51**	**0.67**	**0.75**
Gr	**−0.40**	**−0.51**	**−0.65**	**−0.82**	**−0.24**
Md	**−0.37**	**−0.49**	−0.09	**−0.80**	**−0.86**
Ps	−0.11	**−0.65**	**−0.65**	0.30	**0.53**
Fs	**−0.94**	**−0.43**	**−0.80**	−0.18	**−0.94**
BA	0.12	−0.08	**0.52**	**−0.41**	0.31
CA	**0.95**	**0.96**	**0.85**	**0.85**	**0.81**
Nc	**0.92**	**0.90**	**0.96**	**0.69**	**0.93**
Np	**0.95**	**0.94**	**0.98**	**0.88**	**0.91**
Ns	**0.90**	**0.89**	**0.90**	**0.93**	**0.88**
Nh	**0.98**	**0.98**	**0.98**	**0.88**	**0.95**
Nlh	**0.98**	**0.98**	**0.98**	**0.88**	**0.94**
Lss	**−0.97**	**−0.98**	**−0.97**	**−0.88**	**−0.88**
Npss	**−0.97**	**−0.98**	**−0.80**	**−0.88**	**−0.54**
Pd	**−0.97**	**−0.98**	**−0.73**	**−0.88**	**−0.83**
BOD	–	**0.53**	**0.60**	–*	–*
$N\text{-}NH_4^+$	**0.91**	**0.79**	**0.75**	–*	–*
$N\text{-}NO_3^-$	**0.42**	0.26	−0.18	–*	–*
PO_4^{3-}	**0.67**	−0.33	0.01	–*	–*
K^-	0.09	–*	–*	–*	–*
Cl^-	−0.03	**0.68**	**0.76**	**0.66**	–*

* Data not statistically significant.

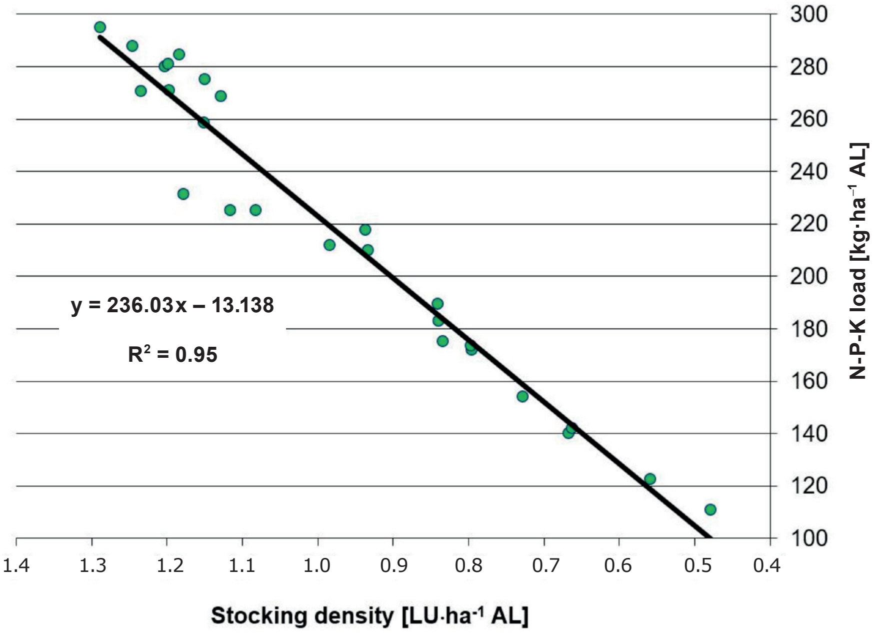

Fig. 10. *Relations between N-P-K load [kg/ha of agricultural land] and stocking density of livestock [livestock unit/ha of agricultural land] in the upper Dunajec River basin*

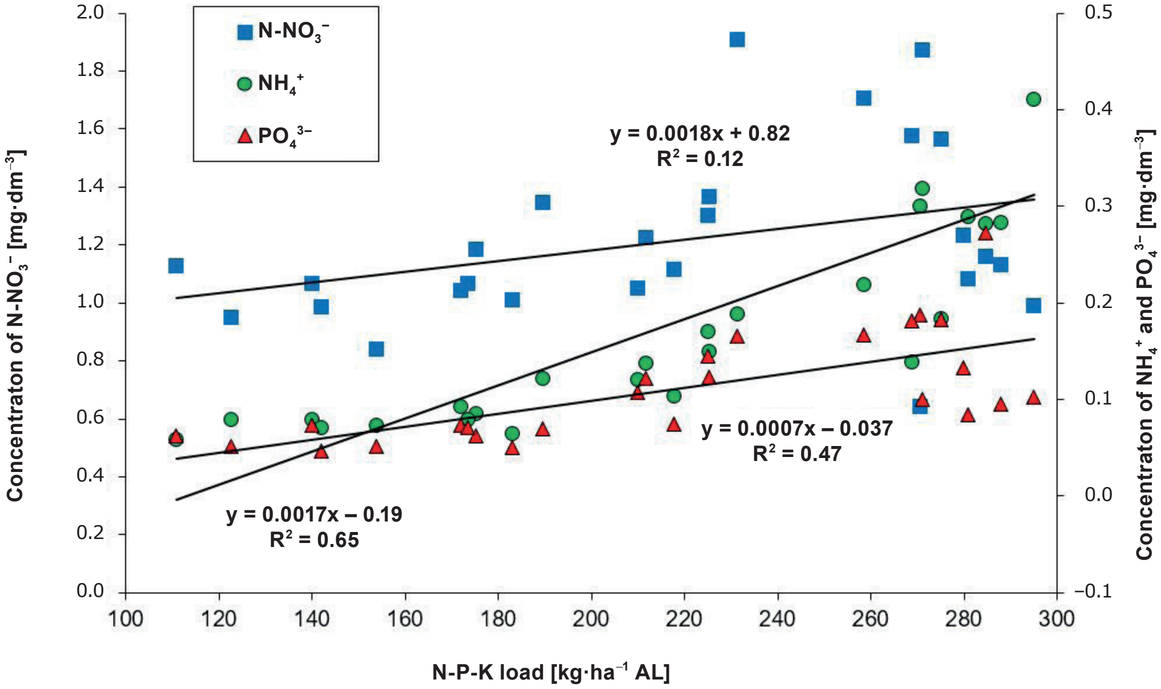

Fig. 11. *Relations between N-P-K load and average concentration of biogens in the upper Dunajec River basin*

Table 4 shows the results of this analysis for selected parameters. Those independent variables were included for which standardized Beta regression coefficients as well as partial correlation and semi-partial correlation were high (for $R^2 > 0.6$). Statistically significant values were bolded.

Normal multiple regression coefficients were also determined. These coefficients indicate which of the parameters have the strongest influence on the N-P-K load introduced into the agricultural area in the upper Dunajec River basin. Equations used for the calculation of N-P-K load (for each sub-basin) are listed below (symbols acc. to Table 1):

- Upper Dunajec River basin:

$$L_{\text{N-P-K}} = 133.76\text{Sd} + 0.84\text{CM}_{\text{N-P-K}} + \\ - 0.50\text{Gr} - 6.48\cdot\text{Fs} + 327.28 \quad (1)$$

- Czarny Dunajec River basin:

$$L_{\text{N-P-K}} = 143.06\text{Sd} + 0.95\text{CM}_{\text{N-P-K}} + \\ - 6.99\text{Fs} + 280.51 \quad (2)$$

- Biały Dunajec River basin:

$$L_{\text{N-P-K}} = 165.37\text{Sd} + 0.76\text{CM}_{\text{N-P-K}} + \\ + 0.58\text{Gr} + 0.003\text{CA} - 1.31\text{BA} + 12.54 \quad (3)$$

- Białka River basin:

$$L_{\text{N-P-K}} = 177.62\text{Sd} + 6.03\text{W} + \\ + 0.83\text{CM}_{\text{N-P-K}} - 52.84 \quad (4)$$

- Grajcarek River basin:

$$L_{\text{N-P-K}} = 169.52\text{Sd} + 0.89\text{CM}_{\text{N-P-K}} + \\ - 0.96\text{Gr} + 39.13 \quad (5)$$

In most cases, the N-P-K load prediction was determined by agricultural parameters. The most important factors determining the change of this load over time were the stocking density (Sd) and the level of mineral fertilization ($\text{CM}_{\text{N-P-K}}$). Their joint effect on N-P-K load ($L_{\text{N-P-K}}$) was 80–90% on average. The remaining 10–20% accounted for by a number of factors of varying nature.

Table 4
Multiple regression analysis in the upper Dunajec River basin (relation of N-P-K load to selected agricultural and utility factors)

Parameter	Beta*	Partial correlation	Semi-partial correlation	R^2
Upper Dunajec River basin				
Sd	**0.554**	**0.842**	**0.130**	**0.95**
$CM_{N\text{-}P\text{-}K}$	**0.342**	**0.910**	**0.182**	**0.72**
CA	0.022	0.094	0.008	0.05
AL	−0.019	−0.136	−0.011	0.05
ALp	−0.061	−0.141	−0.012	0.04
Gr	**−0.039**	**−0.258**	**−0.022**	**0.68**
BA	0.015	0.136	0.011	0.05
Fs	**−0.111**	**−0.336**	**−0.030**	**0.93**
Czarny Dunajec River basin				
Sd	**0.587**	**0.957**	**0.276**	**0.78**
$CM_{N\text{-}P\text{-}K}$	**0.418**	**0.940**	**0.231**	**0.70**
CA	0.025	0.147	0.012	0.14
AL	0.004	0.040	0.003	0.20
ALp	0.002	0.011	0.001	0.17
Gr	0.002	0.011	0.001	0.18
BA	−0.004	−0.040	−0.003	0.20
Fs	**−0.062**	**−0.490**	**−0.047**	**0.43**
Białka River basin				
Sd	**0.818**	**0.963**	**0.285**	**0.88**
$CM_{N\text{-}P\text{-}K}$	**0.549**	**0.923**	**0.191**	**0.88**
CA	0.027	0.160	0.013	0.09
AL	0.001	0.003	0.000	0.10
ALp	−0.001	−0.005	0.000	0.10
Gr	**−0.076**	**−0.514**	**−0.048**	**0.61**
BA	−0.130	−0.105	−0.008	0.00
Biały Dunajec River basin				
Sd	**0.747**	**0.928**	**0.179**	**0.94**
$CM_{N\text{-}P\text{-}K}$	**0.236**	**0.829**	**0.107**	**0.79**
CA	**0.091**	**0.400**	**0.031**	**0.88**
AL	0.064	0.080	0.006	0.01
ALp	**0.040**	**0.276**	**0.021**	**0.74**
Gr	0.020	0.079	0.006	0.05
BA	−0.016	−0.079	−0.006	0.05
Fs	−0.039	−0.341	−0.026	0.55
Grajcarek River basin				
Sd	**0.552**	**0.931**	**0.265**	**0.77**
$CM_{N\text{-}P\text{-}K}$	**0.480**	**0.918**	**0.239**	**0.75**
CA	−0.002	−0.013	−0.001	0.23
AL	−0.024	−0.113	−0.012	0.18
ALp	−0.026	−0.127	−0.013	0.18
Gr	−0.027	−0.124	−0.013	0.18
BA	−0.044	−0.340	−0.038	0.26

* Statistically significant values for $R^2 > 0.6$ are marked in bold.

DISCUSSION

The studied area of the upper Dunajec River basin is characterized by its specific geographical location, orography, climatic parameters and environmental factors. All these elements were included in the analysis and are described as agricultural and non-agricultural factors (juxtaposed in Table 1).

The structural changes that took place after 1980 were not only dynamic and intense, but also varied in time and space. The values of most parameters related to agricultural production (livestock density, fertilization level, and thus the N-P-K load) have been steadily decreasing since the 1980s. Of the livestock, the largest decrease concerned pigs, sheep, and horses, and to slightly lesser extent, cattle. However, the dynamics of these changes can be divided into two stages. In the first stage (1980–1992) it was on average twice as small as in 1993–2010.

A significant decrease in N-P-K load of agricultural origin in the upper Dunajec River basin was observed, while stocking density was reduced. In 1980, the consumption of pure N-P-K components from mineral fertilizers was on average 70.4 kg·ha^{-1} of agricultural land and it decreased to 55.4 kg·ha^{-1}. This corresponded with changes in the structure of land use. The impact of changes in agricultural production on water quality is also shown by other studies (Parris 2011, Huang et al. 2013, Ding et al. 2015, Pullanikkatil et al. 2015, Mateo-Sagasta et al. 2017) and many others. In terms of the agricultural land, the area of arable land decreased the most. In practice processes of the self-sodding of plow-areas occurred, although for some farmers it was a conscious decision to change the profile of production. Structural funds have contributed to this, including mainly agri-environmental programs of the European Union, which financially prefer pro-ecological and extensive plant production on permanent grassland.

In the upper Dunajec River basin, there has been a four percent increase in built-up areas and other areas, including those not used at all, mainly set aside lands.

During recent years, distinct positive changes related to the sanitation infrastructure have taken place. The sewerage network has expanded considerably, thus increasing the number of inhabitants who use a sewage system.

The quality of surface water has improved, especially in terms of nitrogen compounds. Only a slight increase in chloride concentrations is observed after 2004.

The most statistically significant relations referred to parameters that are directly linked to the size of agricultural production. The N-P-K load, introduced into the agricultural land of the investigated river sub-basins, was closely correlated with the stocking density of livestock, thus with the level of natural fertilization, as well as the N-P-K balance, mineral fertilization and sowing area. There was a high correlation between changes in production parameters and the structure of agricultural land use (Lubowski et al. 2006, Gutzler et al. 2015).

Inverse correlations were observed for non-agricultural factors. The expansion of the sewerage network and the increase in the number of inhabitants using a sewage system, as well as the nature of business activities were inversely proportional to changes in N-P-K load. Multiple regression analysis showed that dependencies of N-P-K load on non-agricultural parameters should be considered only as indirect. Statistically significant correlations were also noticed between the concentrations of nutrients in the surface waters of the basin and the analyzed N-P-K load (Parris 2011, Mateo-Sagasta et al. 2017).

Based on multiple regression analysis in the upper Dunajec River basin, the variability of N-P-K load was mainly influenced by the stocking density of livestock and the level of N-P-K fertilization from mineral fertilizers. The reason for this was limiting the livestock population, and as a result of economic changes, the level of mineral fertilization also decreased. Changes in the structure of agricultural land use did not have a direct impact on the N-P-K load, although there are statistically significant relations between N-P-K load and land use. This means that changes in land use structure, including the area of arable land, were only the result of changes in agricultural production and not their cause.

The impact of non-agricultural factors on N-P-K load was less significant and was inversely proportional, with the length of the sewerage network and the density of population dominating here. However, the influence of these factors should be interpreted as indirect. Restructuring and development of the upper Dunajec River basin (e.g. extension of sewerage network) is only an indicator of changes in agriculture (the reduction of agricultural production).

Based on the conducted analysis, a relational model was determined for individual parts of the analyzed basin that describe factors hierarchically affecting changes in the N-P-K load of agricultural origin. This was achieved by determining the multiple regression equations (Equations (1)–(5)) taking into account all of the most important factors of influence. They confirm hypotheses about the significant impact of agricultural factors, and the secondary importance of other non-agricultural parameters, as well as land use structure.

CONCLUSIONS

Summing up the collected material and conducted analyses, the following key findings can be drawn:

1. Significant structural and spatial changes took place in the upper Dunajec River basin affecting a number of social, economic and environmental factors. Agricultural production was reduced, which resulted in a decrease of area of agricultural land, including arable land.
2. The stocking density of livestock and the level of mineral fertilization were the most important factors influencing the changes in biogenic contamination of agricultural origin. Both of these parameters determined at 80–90% of the amount of N-P-K load introduced to the investigated area over the whole study period.
3. Surface water quality has slightly improved. There was a slight decrease in the content of some compounds (mainly ammonium, nitrate and potassium ions) and no trends in some other cases.
4. The chemical composition of water is an indirect indicator of structural and spatial changes. There has been a decreasing tendency in the concentrations of some compounds indicating that different factors contribute to formation of the water quality.

5. There have been proven indirect relationships between agricultural N-P-K loads and non-agricultural factors, which are a kind of derivative of structural changes.
6. Shaping the usable area of mountain river basins must take into consideration both agricultural and non-agricultural factors, as well as their mutual relations. Only then may the sustainable and multifunctional development of these terrains be assured.

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