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The Influence of the Transition to Ecological Farming on the Quality of Runoff Water

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Abstract: The aim of the paper is to analyze and evaluate the long-term impacts of the transition from agricultural production to ecological farming on the quality of runoff water in small catchments based on the analysis of water samples in the period 1986–2022. A total of 111 samples were analyzed. The following parameters were determined: nitrites, nitrates, chlorides, sulphates, phosphates, iron, coliform bacteria, and pH. Until 2006, the catchment was intensively managed by using artificial fertilizers and chemical preservatives. Since 2006, the catchment has been managed exclusively in an ecological way without the use of fertilizers and chemicals. The results of the analysis confirmed the positive impact of the transition of agricultural production to ecological farming, especially in the parameters of nitrates and chlorides. The greater use of organic fertilizers has caused an increase in coliform bacteria in the runoff water. The long period of the research also caused it to be possible to assess the impact of other potential factors. Changes in pH parameters and sulphates indicate an improvement in air quality. Changes in nitrite and iron parameters may indicate climate change associated with more intense precipitation activity.

Keywords: water quality; ecological farming; agriculture

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1. Introduction

Water is a basic commodity and a condition of life. The importance of water as a raw material is growing because of increasing water scarcity and decreasing water quality. In the Slovak Republic, underground sources (82.2%) and surface sources (17.8%) are used for drinking water abstraction. In the literature [1,2], a term "water quality" defines the combination of physical, chemical, and biological properties of water.

Although, a number of key drivers, such as geological weathering, hydrologic and geomorphic processes, climate conditions, plant and environmental factors, and physio-chemical and biological processes influence water quality [3,4], it can be stated that, within the regulating stream water quality, land use and the composition of land cover (LULC) within a watershed plays a significant role [5–9]. Landscape elements have been identified as the most important parameter affecting water quality through their impact on non-point source pollution resulting from complex run-off and landscape interactions [10–14].

Considering runoff from catchment areas into water bodies as the main source of nutrients and pollutants [15], the attention to the relationship between water quality and changes of land use has raised [16]. The conversion of native vegetation to agriculture and human settlements has significantly increased the human well-being at the expense of the degradation of many ecosystem services and biodiversity [17,18]. Agriculture and urbanization degrade the quality of water in water bodies through the production of damaging nutrients and xenobiotics. On the other hand, woodlands and wetlands work as sinks of non-point-source pollution [19]. Johnson et al. (1997) [20] pointed out that nutrient and sediment inputs to a basin are positively correlated with the percentage of agriculture and urban cover types. On the contrary, for example, forests generate lower runoff coefficients [21,22] and contribute to protecting the land, tending to favor infiltration and reducing rapid flow at the surface.

The aim of this study is to analyze and evaluate the long-term impacts of the transition of agricultural production to ecological farming on the quality of runoff water in a small catchment based on the analysis of water samples in the period 1986–2022.

Ecological farming is an environmentally friendly system that aims at a sustainable agro-ecosystem that uses primarily local and renewable resources and environmentally friendly technologies and practices that minimize environmental damage. It uses fertilizers of organic origin such as compost manure, green manure, and bone meal and places emphasis on techniques such as crop rotation and companion planting. By respecting the natural possibilities of plants, animals, and ecosystems, the conditions for quality in all aspects of agriculture and the environment are optimized. Ecological farming dramatically reduces the residual load coming from the use of chemical-synthetic fertilizers, pesticides, and pharmaceuticals. In addition, in cooperation with natural laws, it makes it possible to simultaneously increase soil fertility and resistance to diseases and pests.

The work follows the long-term research carried out in the years 1986–1994 [23] and in the years 2009–2012 [24]. This is a total period of 36 years. During this time, there was a change in the way how agricultural production is managed in the analyzed catchment. Until 2006, the catchment was intensively managed by using artificial fertilizers and chemical preservatives. Since 2006, the catchment has been managed exclusively in a way of ecological farming without the use of fertilizers and chemicals (internal materials of the "Látky" agricultural farm, annual reports of used fertilizers, and chemical preservatives). At the same time, in the 1990s, agricultural production was reduced by approximately half (Internal materials of the "Látky" agricultural farm, annual reports–indicators of animal and plant production) and the catchment was overgrown with trees and shrubs. The length of the analyzed period also allows for the assessment, based on the change in the quality parameters of the runoff water, of the modification related to the change in air quality, as well as the possible consequences of climate change. Taking this into consideration, three research questions were defined:

- RQ1: Which qualitative parameters of water were affected after the transition to ecological farming in the catchment?
- RQ2: Which qualitative parameters were affected by other ongoing changes during the analyzed period?
- RQ3: How is the quantitative extent that the qualitative parameters of water have been affected by these changes?

The basic structure of the paper includes Introduction, Methods, Results, Discussion, and Conclusion. The introduction deals with the issue of the water quality and ecological farming. Methodologically, it is based on the "Mann–Kendall trend test" and "Mann–Whitney U test" to analyze the influence of land use on the content of individual water parameters. According to the statistical analysis, the Section 3 defines water parameters that have been affected by the transition to ecological farming, parameters affected by other factors, and those without changes. Subsequently, the paper discusses the results achieved with similar scientific works. The conclusion part states if the transition to ecological farming improves water quality indicators.

2. Materials and Methods

2.1. Study Site

The authors examined the chemical characteristics of surface runoff in a small catchment in Central Slovakia in the mountains Slovenské rudohorie. The catchment has an area 1.44 km^2 and consisted of meadow (70%) and arable land (30%). The catchments is located at an average elevation of 850 m above sea level; the average annual rainfall is 920 mm and average annual temperature 5 °C. The geological subsoil of the catchment consists of granodiorites and the soil is unsaturated brown soil. The total humus levels reach from

225 to 250 t·ha^{-1}; the humus form is moderate. The total nitrogen supply in upper soil horizon is from 6.0 to 6.5 t·ha^{-1}. Most parts of the catchment have a slope of up to 30%. The average annual water flow was 31 l·s^{-1}.

The sampling plot for the catchment is marked with a red point in Figure 1.

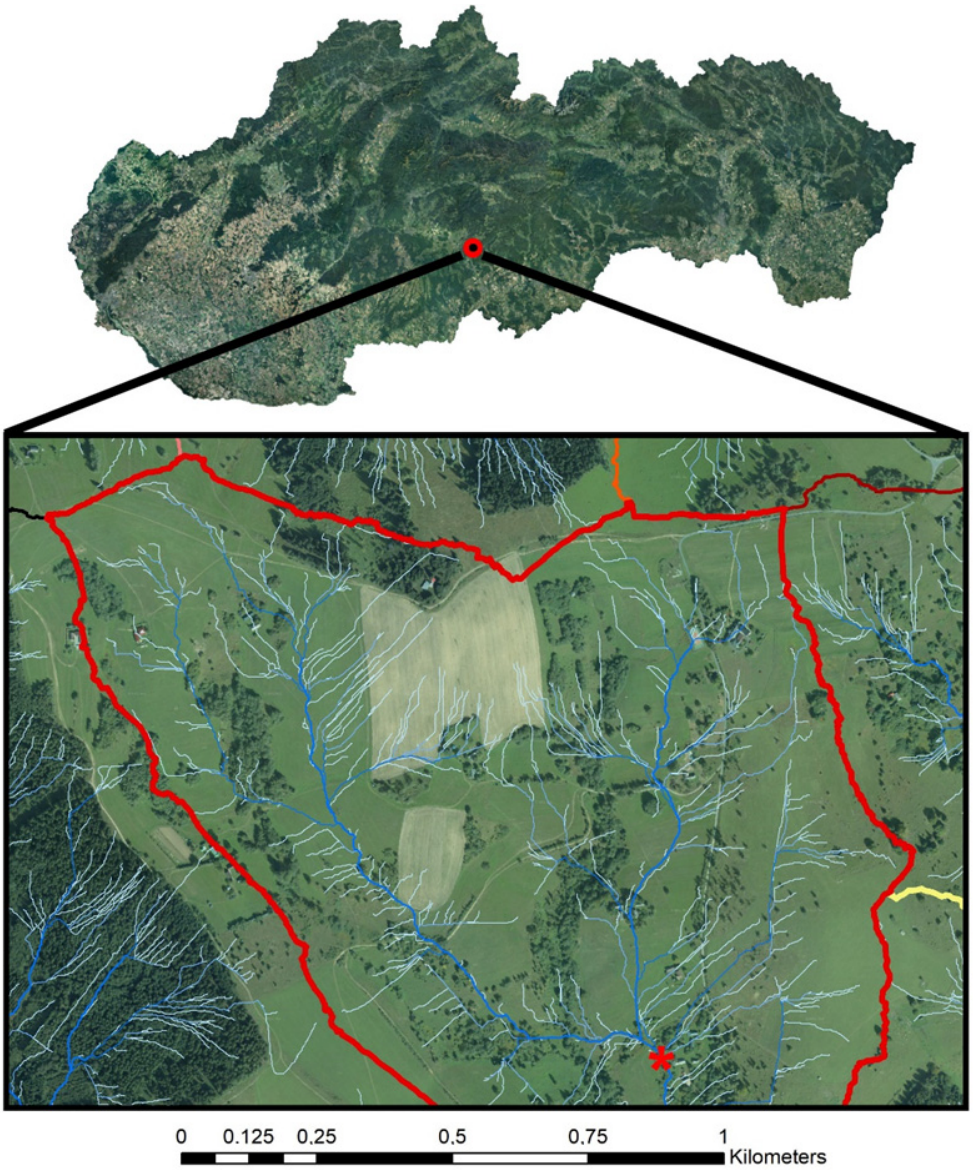

Figure 1. Aerial photograph of the study site. The red point represents study area, the red asterisk represents the sampling plot for the analyzed catchment (own study).

Most of the catchment area is managed by the Farm Cooperative, Látky. It currently manages about 1500 ha of land, of which about 100 ha are arable land. The predominant part of the cultivated area is meadows and pastures. The cooperative is focused on animal production and the production of bulk feed. Rye, wheat, oats, and potatoes are grown on arable land. The catchment area falls under a third degree protection zone of water source because of the Málinec Reservoir. For this reason, since 2006, the cooperative has moved to ecological farming with a total ban on the use of fertilizers and chemicals (internal materials of the “Látky” agricultural farm). At the beginning of the experiment, in 1986, this catchment was used for intensive animal and crop production, with the use of fertilizers and chemical preservatives (internal materials of the “Látky” agricultural farm, annual reports of used fertilizers and chemical preservatives). At that time, the cooperative managed twice as much area (approximately 3000 ha) as it does nowadays. In the 1990s, there was a gradual decrease in agricultural production. The number of farmed animals decreased (sheep from 3000 to 1800, cattle from 3000 to 150) and some unused arable land was turned into meadows and some parts became overgrown with shrub species (internal materials of the "Látky" agricultural farm, annual reports—indicators of animal and plant production). Until 2006, the quality of runoff water was affected by the use of artificial fertilizers as well as chemical preservatives. In our case, in the 1980s, an agricultural land manager used an average of 500 tons of fertilizer per year, which is almost 0.2 tons per ha. The proportion of nitrogen in fertilizers was almost 90 kg·ha^{-1}, the proportion of phosporus 70 kg·ha^{-1}, and the proportion of potassium 40 kg·ha^{-1}. The following types of fertilizers were most often used: NPK-gold, ammonium sulphate, potassium sulphate, superphosphate, saltpetre, and ammonium nitrate (internal materials of the "Látky" agricultural farm, annual reports of used fertilizers). In addition to artificial fertilizers, the spraying with herbicides, fungicides, and insecticides was carried out every year in an average volume of about 10 L·ha^{-1}. These were the following preparations: Aminex, Retacel, Gramaxone, Topogard, Vaztak, Ridomil, Ladob, Decention, Santofan, Cymbush, Basagran, Metaxyl, and Harmavid (internal materials of the "Látky" agricultural farm, annual reports of used and chemical preservatives). With the decrease in cultivated land in the 1990s, the volume of used fertilizers and protective chemical preparations decreased continuously until 2006. At present, manure is used for fertilization in the volume of about 20 t·ha^{-1}·year^{-1}. Chemical preservatives are not used at all (internal materials of the "Látky" agricultural farm, annual reports of used fertilizers and chemical preservatives).

2.2. Sample Collection

The water samples were collected in the following periods: 1986–1990, 1992–1994, 2009–2012, and 2019–2022. We analyze the analyzed samples in time into two groups. The first group represent samples extracted before the transition to ecological farming (53 samples analyzed in 1986–1994) and the second group constitutes samples extracted after the transition to ecological farming (59 samples analyzed in 2009–2022). A total of 112 samples were analyzed. The following parameters were determined: nitrites, nitrates, chlorides, sulphates, phosphates, iron (all in mg·L^{-1}), coliform bacteria (CFU·100 mL^{-1}, CFU–Colony Forming Units), and pH. The numbers of samples extracted in each year are shown in Table 1. The samples were always extracted once a month from the exact same place at approximately 1.5 km from the source of the streams. For the purposes of sampling, a dam was built in catchment in 1986. The samples were extracted into sterilized containers—sample boxes according to the instructions of the laboratory from a depth of 5 to 10 cm below the surface of the stream. After sampling, the sample boxes were transported in the refrigerator to the laboratory. The water analyses from the first group (1986–1994) were carried out by the Technical University in Zvolen, while the water analyses from the second group (2009–2022) were performed by Stredoslovenská vodárenská spoločnosť (Central Slovak Water Company).

Table 1. Number of samples extracted each year for water analysis.

Year	**1986**	**1987**	**1988**	**1989**	**1990**	**1992**
Number of samples	8	9	11	9	4	1
Year	**1993**	**1994**	**2009**	**2010**	**2011**	**2012**
Number of samples	9	2	7	9	12	12
Year	**2019**	**2020**	**2021**	**2022**		
Number of samples	2	11	5	1		

2.3. Statistical Analysis

From the point of view of processing statistical analyses, the authors divided the analyzed period into the first (1986–1994) and second (2009–2022) experimental period.

All statistical analyses were conducted in accordance with statistical methods in water resources [25]. We tested the influence of land use on the content of individual elements using the Mann–Whitney U test. To test the development of the content of elements in water at time we used Mann–Kendall Trend Test.

3. Results

Based on the results of the statistical analysis (Tables 1 and 2), the monitored characteristics were divided into three groups in the long run: parameters affected by the transition to ecological farming, parameters affected by other factors and parameters without changes.

Table 2. Average values of parameters and Mann–Kendall trend test in the period before and after the transition to ecological farming.

	Parameter	Average ($mg \cdot L^{-1}$, $CFU \cdot 100\ mL^{-1}$)	MK-Stat	s.e.	z-Stat	*p*-Value	Trend
Before the transition to ecological farming	pH	6.729	−30	125.0253	−0.232	0.817	no
	phosphate	0.076	400	129.430	3.083	0.002	yes
	sulphate	12.750	113	123.054	0.910	0.363	no
	nitrates	11.418	401	130.319	3.069	0.002	yes
	chlorides	15.318	15	112.450	0.125	0.901	no
	iron	0.062	−226	129.980	−1.731	0.083	no
	nitrite	0.010	328	82.531	3.962	0.000	yes
	coliform	92	−61	86.393	−0.695	0.487	no
After the transition to ecological farming	pH	7.328	−39	148.964	−0.255	0.799	no
	phosphate	0.083	223	134.792	1.647	0.100	no
	sulphate	13.747	−497	149.040	−3.328	0.001	yes
	nitrates	3.862	329	149.040	2.201	0.028	yes
	chlorides	2.416	−342	148.829	−2.291	0.022	yes
	iron	0.220	−344	148.912	−2.303	0.021	yes
	nitrite	0.016	627	148.816	4.207	0.000	yes
	coliform	837	845	148.949	5.666	0.000	yes

3.1. Parameters Influenced by the Transition to Ecological Farming

A significant change in the average values of the parameters between the two analyzed periods, a change in the trend and the potential influence of fertilizers and pesticides indicate three parameters that were affected by the transition to ecological farming. From the analyzed parameters, they are: nitrates, chlorides, and coliform bacteria (Table 2, Figure 2). The differences in the data before and after transition to ecological farming are also confirmed by the results of the Mann–Whitney U test (Table 3).

Table 3. Mann–Whitney U test results.

Parameter	*p* Value
pH	0.000
phosphate	0.516
sulphate	0.205
nitrates	0.000
chlorides	0.000
iron	0.000
nitrite	0.001
coliform	0.000

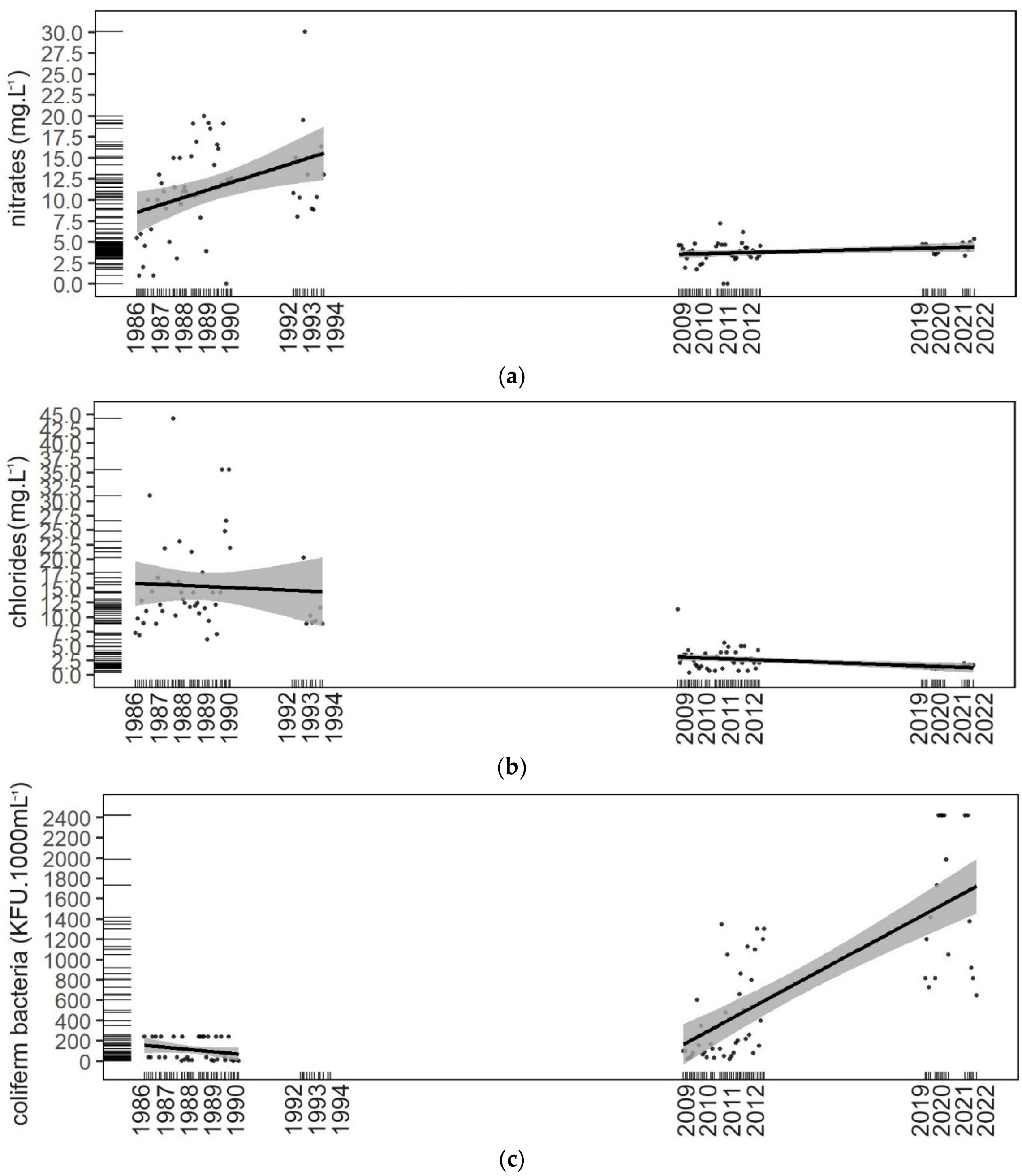

Figure 2. Linear regression analysis for water parameters influenced by the transition to ecological farming. The contents of water parameters of the surface runoff (**a**) Nitrates, (**b**) Chlorides, (**c**) Coliform Bacteria.

3.2. Parameters Influenced by Other Potential Factors

The parameters that are influenced by other potential factors include the pH of the runoff water and the content of sulphates, nitrites, and iron (Figure 3).

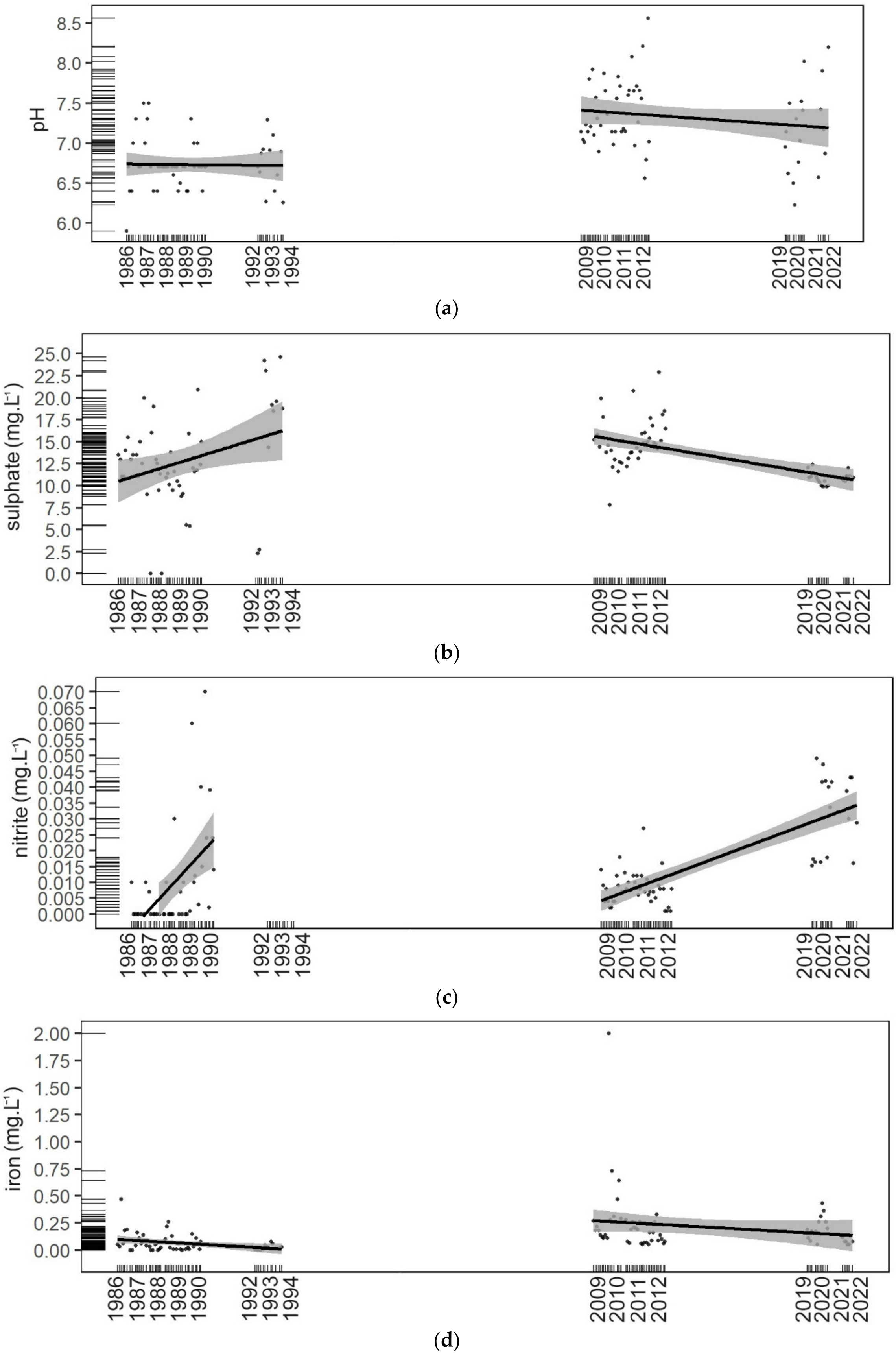

Figure 3. Linear regression analysis for water parameters influenced by other potential factors. The contents of water parameters of the surface runoff (**a**) pH, (**b**) Sulphate, (**c**) Nitrite, (**d**) Iron.

The pH parameters of the runoff water and the sulphate content indicate trends in the impact of air pollution by sulphur oxides. The changes in the parameters of nitrates and iron point to climate change (washout with more frequent occurrence of intense precipitation).

3.3. Parameters without Changes

Among the parameters that are without confirmed statistical changes (Tables 2 and 3) are phosphates (Figure 4).

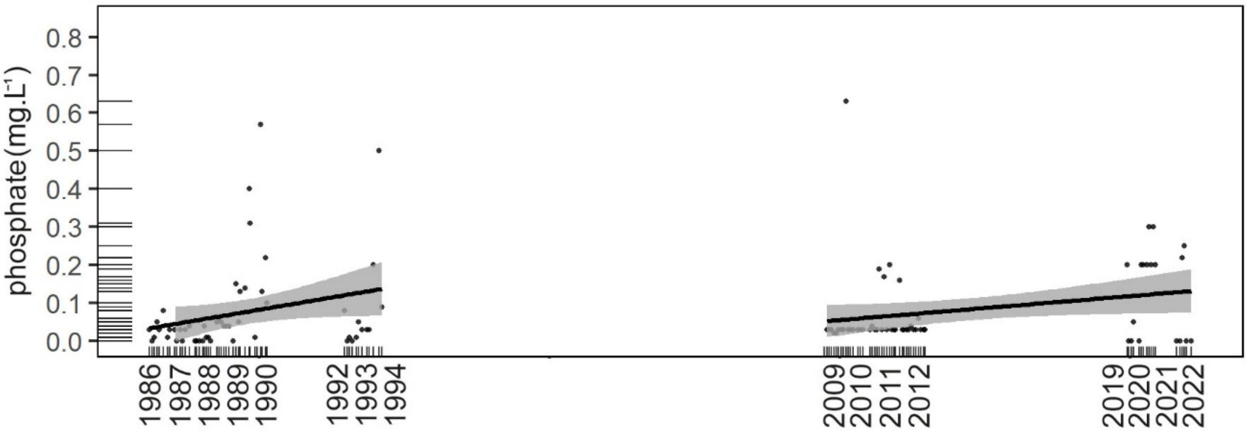

Figure 4. Linear regression analysis for water parameters without changes. The contents of water parameters of the surface runoff—Phosphate.

4. Discussion

Before the transition to ecological farming, the average value of nitrates in the runoff water in the catchment reached 11.4 mg·L^{-1}, after the transition to ecological farming there was a marked almost threefold decrease. For example, China [26], Brazil [27], and Spain [28] also report a high influence of agricultural land on nitrogen. For chlorides, the decrease in the average value is more than sixfold (before: 15.32 mg·L^{-1}, after: 2.42 mg·L^{-1}). Before the transition to ecological farming, a significant upward trend was confirmed for nitrates, after the transition to ecological farming, a slightly upward trend for nitrates and a slightly declining trend for chlorides was confirmed (Figure 2, Table 2). The significant difference in values and the change in the trend for nitrates and chlorides was caused by the ban on artificial fertilizer and pesticide use in the agricultural management of the catchment. The use of pesticides has been found to be a greater danger to the environment than any other pollution of soil, air, and water by industrial civilization. This means that current forms of agricultural intensification are potentially the greatest danger for the future healthy development of humankind [29]. Artificial fertilizers were replaced by organic fertilizers, which was reflected in the increased content of coliform bacteria (average value before: 92 CFU·100 mL^{-1}, after: 837 CFU·100 mL^{-1}) and also on the change of the trend; where the trend was not confirmed before and after the transition to ecological farming, we can talk about the rising trend (Figure 2, Table 2). The increased proportion of coliform bacteria may also be associated with the use of several buildings for seasonal housing in the catchment in connection with the discharge of wastewater. Another possible cause is the growth and decomposition of the organic matter of the riparian vegetation, which arose after the transition to ecological farming around the stream.

The long-term effect of the acidic disposition caused by industrial emissions, especially in the 1980s, resulted in a "limit load on land" [23]. This load increased the acidity of the run-off water during the first period (from 1986 to 1994). In the 1990s, industrial production was reduced, which significantly reduced sulphur oxides in the atmosphere. In the 1990s, annual SO_2 emissions in the Slovak Republic exceeded 500,000 tons. In the 1990s, a gradual decline began, and in the second period (from 2009 to 2022), SO_2 emissions were at the average level of 50,000 tons per year, representing a 10-fold decrease [30,31]. While the average pH value of the runoff water in the period before the transition to ecological farming was 6.7 and no trend was statistically confirmed at the sulphate content (1986–1994), in the years 2009–2022 the average pH value of the runoff water is at the level of 7.3 and the sulphate content has a decreasing trend (Table 2, Figure 3).

The average value of nitrite in the period before the transition to ecological farming was 0.010 mg·L^{-1}, after the transition 0.016 mg·L^{-1}. The growing trend was confirmed in both periods. The relatively high variability of this parameter indicates the leaching of nitrite into the runoff during precipitation activity. The rising trend, as well as the higher average value in the years 2009–2022, may indicate a more frequent occurrence of intense heavy rainfall in connection with climate change. Global climate change increases the rate of atmospheric precipitation [32]. At the same time, changes in this parameter in connection with the use of artificial and organic fertilizers in agriculture cannot be excluded.

The average value of iron content in runoff water in the period before the transition to ecological farming was at the level of 0.062, mg·L^{-1}, after the transition 0.22 mg·L^{-1}. Despite the higher average value, a slightly declining trend was confirmed in the period after the transition. Iron enters the surface runoff from the soil and geological bedrock or by import with a dissolved organic substance. A higher average value, similar to nitrite, may be related to more intense precipitation activity.

From the analyzed parameters, there were no changes in phosphate between the two investigated periods. The average value before the transition to ecological farming was 0.076 mg·L^{-1} and after the transition 0.083 mg·L^{-1}. In the period before the transition to ecological farming, a slight growing trend was confirmed, in the period after the transition, this trend was not confirmed.

Overall, it can be stated that the transition to ecological farming, with the exception of coliform bacteria, has improved water quality parameters. The intensive using of pesticides and fertilizers has had a significant impact on water quality. [33–36].

5. Conclusions

Based on the results of long-term research, which covers a period of 36 years, we identified and quantified the parameters of runoff water, which were affected by the transition to ecological farming. A total of eight water parameters were analyzed: pH, sulphates, nitrates, nitrites, chlorides, phosphates, iron, and coliform bacteria.

The transition to ecological farming combined with the exclusion of fertilizers and chemical preservatives has significantly affected the proportion of nitrates and chlorides in the runoff water from the catchment. The decrease was more than sixfold for chlorides and almost threefold for nitrates. Organic fertilizers have become a substitute for the use of artificial fertilizers. Their use in combination with the higher volume of decomposing mass of the riparian vegetation and possible fecal pollution from several buildings used for occasional housing caused a significant increase in coliform bacteria in the runoff.

The longevity of the research caused it to be possible to assess, in addition to the transition to ecological farming, the assessment of the impact of other factors on the quality of runoff water. The change in average values and trends in the parameters of pH and sulphates indicates an improvement in air quality in relation to sulphur oxide emissions. The higher variability, as well as a slight increase in the average values for the parameters nitrite and iron, indicate their increased leaching from organic matter caused by more abundant precipitation activity. Heavy rainfall is one of the manifestations of a climate change. Phosphates represent factors for which there were no long-term changes in the analyzed catchment.

Six from the overall eight analyzed parameters in runoff water from the catchment, met the requirements for drinking water. Overall, we can state that the transition to ecological farming has improved water quality indicators.

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