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Seasonal Characterisation and Trends Study of Nutrient Concentrations in Surface Water from Catchments with Intensive Livestock Farming

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***Abstract* – Temporal changes in observed nitrogen and phosphorus losses to surface water were studied in 3 agricultural catchments in order to evaluate the achievement of water protection targets in Latvia. The aim of this study is to investigate the water quality measures in high density livestock farming catchments. Long-term monitoring data (years 1996–2008) of water quality used in the analysis show a high annual and monthly variability of nutrients. The results demonstrate little or no reduction of nutrient concentrations in surface water. The results suggest that water protection measures for agricultural production need to be further intensified.**

***Keywords* – Livestock farming, nutrients, point source surface water pollution, seasonality, trends.**

I. Introduction

Farming with high livestock density can lead to local manure surpluses, which can result in surface water pollution problems in rural regions. During the last years there is a tendency in Latvia to increase the number of big animal farms, thereby livestock concentration in specific areas can cause nutrient pollution from point sources and subsequently prevent the fulfillment of objectives of the Water Framework Directive (WFD, 2000/60/EC) and the Nitrates Directive (91/676/EEC). According to the assumption that point source pollution is usually concentrated, it is considered as the most significant contamination source [1]. Generally, the origin of point source pollution is from one location, and thereby runoff from a feedlot or overflows from hog lagoons and slurry deposition on fields near streams, are examples of agricultural point sources of contamination. However, possible source of such types of pollution in agriculture can also be associated with a high number of livestock units or with high animal density (livestock units (LU) per ha) in a farm. According to HELCOM (Helsinki Commission - Baltic Marine Environment Protection Commission) guidelines, the agricultural area or farm should be considered as a hot spot, if it is a watershed with an animal density higher than 1.5 LU per ha or an area with large animal farms with more than 250 LU that cannot demonstrate appropriate fertilizers and manure storage or application [2].

The aim of the study is to estimate surface water quality in the territories with a high number of livestock unit farms by describing water quality parameters (total nitrogen, total phosphorus, nitrates) variation with regard to time and season. In addition, nutrient concentrations variation in agricultural catchments surface water is examined and a trend analysis is carried out in order to investigate whether the proposed changes in agricultural practices have affected nutrient concentrations in the surface water. The study consists of comparing seasonal nutrient concentrations in surface waters and the detection and quantification of the water quality trends in surface water nutrient concentrations by the Mann–Kendall Seasonal Test and the Sens Slope Estimator. Understanding the status of surface water and nutrient trends in streams and conditions that affect them was possible thanks to the agriculture run-off monitoring project provided by the Department of Environmental Engineering and Water Management, Latvia University of Agriculture.

II. Material and Methods

The study is based on the long-term (1996-2008) nutrient concentration in surface water observation data from three catchments (Bauska, Ogre, Auce) included in the national network for the agriculture run-off monitoring programme designed to cover point source agriculture pollutant investigation. In all agricultural catchments, the amount of livestock is remarkable (more than 250 LU) and most of the cultivated land is under cereal crop cultivation, which is common in southern and central Latvia. The main characteristics of all catchments are presented in Table 1. Results are compared with the diffuse source agricultural pollution monitoring results to provide an overall view of the major water quality characteristics occurring in surface waters. The long term point source and diffuse source database is maintained by the Latvia University of Agriculture (LLU).

TABLE 1
CHARASTERISTICS OF CACHMENTS

Catchment	Area, ha	Soils	Land use	Farm type	Known point sorce inputs
Auce	60	sandy loam	grain farming	pig farm, established in 1990	slurry application on 30 ha
Bauska	800	silt, loam	grain farming	pig farm, established in 1970	slurry application on 50 ha
Ogre	300	silty clay loam	moderate farming	pig farm closed in 1992	runoff from old slurry lagoons

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The grab water samples from draining ditches were analyzed for total phosphorus ($P_{tot.}$), total nitrogen ($N_{tot.}$) and nitrate nitrogen (NO_3-N). Water quality parameters are tested in accordance with standard methods LVS EN ISO 11905-1, LVS EN ISO 13395 ($N_{tot.}$) and LVS EN ISO 15681-1 ($P_{tot.}$).

A seasonal analysis including an evaluation of seasonal patterns of nutrients in surface water are conducted for two seasons (summer and winter) by Mann–Whitney U test and for twelve season (monthly data) by Kruskal-Wallis. The seasonal patterns are also evaluated using box plots to provide a general overview of the trends and calculating seasonal indices. The statistical significance of nutrient trends are determined by a Seasonal Kendall test**.** This test is suitable for water quality data because it requires no assumption of normality that is very important to investigate point source pollution [4]. It consists of the sum of the individual MKs values for each cyclic period, thereby removing the seasonal component. The magnitude of statistically significant trends was estimated according to the Seasonal Kendall slope estimator.

III. RESULTS AND DISSCUSION

The basic descriptive statistics of nutrient concentrations in surface water regularly conducted over a period (1996–2008) at 3 catchments are summarized in Table 2. The results demonstrate that nutrients in surface water tend to be highly variable. The highest values as well as the high variability for all nutrients are observed in the Bauska catchment which is characterized by high animal density and the application (utilization) of manure. Despite the high manure rates applied on the fields, the median nitrate concentrations in all catchments are below the threshold value 11.3 mg L^{-1} of NO_3-N established by the Nitrate Directive. However, high concentration of total nitrogen ($N_{tot.}$) and total phosphorus ($P_{tot.}$) are documented. $P_{tot.}$ is the parameter that shows the greatest degree of variation throughout the studied period in all catchments except Ogre where farming activities are abolished. The median values $P_{tot.}$ in the Bauska and Ogre catchments are higher than the critical value of 0.15 mg L^{-1} which is considered a minimum requirement for the avoidance of eutrofication effects [11].

The analyzed water quality parameters show striking seasonal variations for different reasons. According to the research [3, 5, 7, 8, 10], nutrient concentrations vary throughout the year, largely due to the response to changes in precipitation, ground water levels and flow rates. Some of them depend on discharge and seasonality; but same are magnified by agricultural activities. The Mann-Whitney U test used to compare nutrient concentrations in the summer and winter months according to the Nitrate Directive (winter period: October – March, summer or vegetative period: April – September) also affirms statistically significant nutrient concentrations differences (all p-values less that 0.02) between these two periods in all catchments. However, on the practical level, the $P_{tot.}$ median values in the summer and winter are very close in the Auce catchment. Figure 1 displays the median values of nutrient concentrations for the summer and winter months separately and compares results with long term (1996-2008) diffuse pollution monitoring data. This examination of data shows that $N_{tot.}$ values tend to be higher in the winter while $P_{tot.}$ values are higher in the summer months. Nitrogen concentrations in agricultural streams can be high during the winter in connection with high water flows and the low intensity of biological processes, however more phosphorus are transported during storms. Exploration of data also includes comparison of observed values with long term agricultural diffuse pollution monitoring results. Observed $N_{tot.}$ values in the Bauska and Auce catchments are clearly higher than the $N_{tot.}$ concentrations (median 7.2 $N_{tot.}$ mg L^{-1}) recorded in the high input agriculture run-off monitoring database. However, the median values of $N_{tot.}$ in Ogre decrease down to the level of medium input agriculture run-off long term median value (3.3 $N_{tot.}$ mg L^{-1}) in the winter, but in the summer $N_{tot.}$ concentration in the Ogre catchment reach the value (1.4 $N_{tot.}$ mg L^{-1}) typical for the low input agriculture conditions in Latvia. Median values of $P_{tot.}$ are two and more times higher as the observed phosphorus concentration in high input agriculture farming conditions (0.12 $P_{tot.}$ mg L^{-1}). However, $P_{tot.}$ in the Auce catchment are close to the values typical for low input farming.

TABLE 2

STATISTICAL PARAMETERS OF THE NUTRIENT MONTHLY VALUES (MG L^{-1}) IN SURFACE WATER

Catchment	Nutrient	Mean	Median	Std. Deviation	Coeficient of variation	Skewness	Kurtosis	Minimum	Maximum	Percentiles	
										25	75
Bauska	NO_3-N	6.953	6.000	5.768	83%	0.585	-0.491	0.010	26.000	1.500	10.800
	$N_{tot.}$	16.793	11.260	26.976	161%	7.740	77.307	1.100	298.000	5.700	17.700
	$P_{tot.}$	1.814	0.437	2.785	153%	3.338	17.865	0.010	22.000	0.178	2.800
Ogre	NO_3-N	2.267	1.200	6.472	285%	10.715	120.364	0.000	74.700	0.808	2.300
	$N_{tot.}$	3.914	2.600	7.421	190%	9.409	98.091	0.300	82.800	1.900	3.650
	$P_{tot.}$	0.570	0.518	0.376	66%	3.621	19.881	0.001	3.102	0.369	0.674
Auce	NO_3-N	6.911	5.670	5.211	75%	1.014	0.711	0.100	24.500	2.700	9.900
	$N_{tot.}$	7.877	6.510	6.042	77%	1.853	5.758	0.600	39.300	3.450	11.100
	$P_{tot.}$	0.025	0.018	0.029	115%	5.309	34.726	0.002	0.262	0.013	0.026

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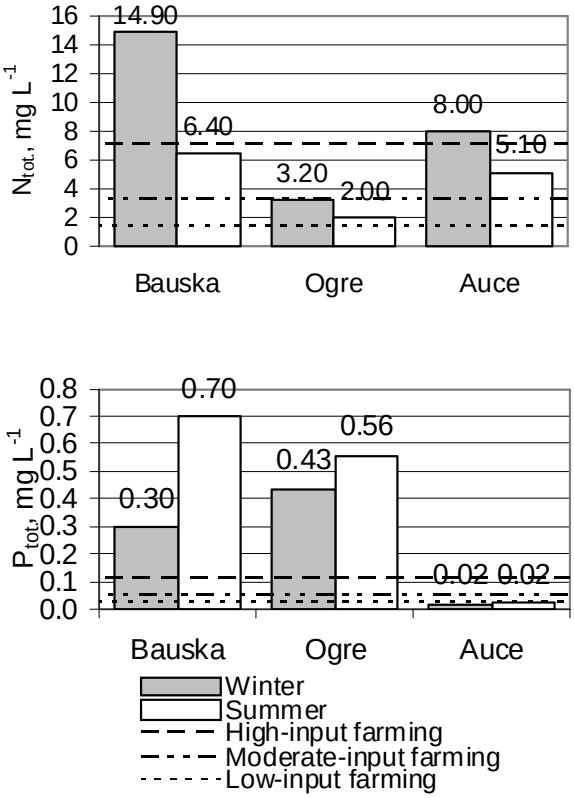


Fig.1. Median values of nutrient concentrations in point source pollution monitoring catchments comparing with agricultural diffuse pollution levels.

Table 3 represents all observed results according to the research of the Latvia University of Agriculture [6] on the status estimation of surface water chemical quality in small agricultural streams. It is observed that in agriculture areas with small catchments, high water quality corresponds to <1.5 mg L^{-1} of $N_{tot.}$ and <0.025 mg L^{-1} $P_{tot.}$, good quality to 1.5-2.5 mg L^{-1} $N_{tot.}$ and 0.025-0.050 mg L^{-1} $P_{tot.}$, moderate quality to 2.5-7.5 mg L^{-1} $N_{tot.}$ and 0.050-0.150 mg L^{-1} $P_{tot.}$, poor quality to 7.5-10.5 mg L^{-1} $N_{tot.}$ and 0.150-0.250 mg L^{-1} $P_{tot.}$. Higher values are assigned to bad surface water quality.

Long term monitoring data show that more than 50% of the samples taken in the observation period in Bauska have links to bad water quality measured in both ways by $N_{tot.}$ and $P_{tot.}$. Water quality in the Ogre and Auce catchments in relation to observed $N_{tot.}$ concentrations mostly relate to moderate quality, while water quality in the Ogre catchment are greatly affected by phosphorus. $P_{tot.}$ concentrations in Ogre mostly fall in the bad water quality class. Contrary to the Ogre catchment, water quality associated with phosphorus in the Auce catchment is acceptable. The threshold value of 11.3 mg L^{-1} NO_3-N is exeeded in 23% of all monthly observations in Bauska, 18% and 0.6%, accordingly in the Auce and Ogre catchments due to the study period.

Another important application of statistics in relation to water pollution control, is the understanding of the extremes of water quality conditions; because some water quality variables may change dramatically. Nutrient concentrations vary throughout the year not only through the seasons mentioned above, largely in response to changes in precipitation and streamflow and in relation to the time elapsed since fertilizer or manure application. Therefore the next analyze of seasonal patterns in nutrients concentrations are done based on monthly data defined by the frequency with which data are collected.

TABLE 3

SURFACE WATER CHEMICAL QUALITY STATUS IN OBSERVRD CATCMENTS DUE TO STADY PERIOD

Nutrient	Catchment	Season	Water quality class					Total
			high	good	moderate	Poor	bad	
			% of cases within season					
$N_{tot.}$	Bauska	winter	1.3	2.6	11.7	10.4	74.0	100
		summer	5.1	11.5	37.2	11.5	34.6	100
		total	3.2	7.1	24.5	11.0	54.2	100
	Ogre	winter	0.0	23.9	67.2	3.0	6.0	100
		summer	13.6	59.1	25.8	0.0	1.5	100
		total	6.8	41.4	46.6	1.5	3.8	100
	Auce	winter	1.3	3.9	40.3	14.3	40.3	100
		summer	13.2	13.2	42.1	15.8	15.8	100
		Total	7.2	8.5	41.2	15.0	28.1	100
$P_{tot.}$	Bauska	winter	0	0	19.5	19.5	61.0	100
		summer	2.6	1.3	12.8	10.3	73.1	100
		total	1.3	0.6	16.1	14.8	67.1	100
	Ogre	winter	1.5	0.0	2.9	2.9	92.6	100
		summer	1.5	0.0	1.5	4.5	92.4	100
		total	1.5	0.0	2.2	3.7	92.5	100
	Auce	winter	83.1	15.6	1.3	0.0	0.0	100
		summer	66.7	23.1	6.4	2.6	1.3	100
		total	74.8	19.4	3.9	1.3	0.6	100

Displaying data in box-whisker graphs allows for a more effective visualization of seasonal nutrient variation and changes over time and potential trends. The box-whisker plot (Figure 2) illustrate both the distribution and summary statistics (median, interquartile range (the box are the 25th and 75th percentiles), outliers and extremes) for monthly observations, showing that nutrient concentrations are extremely variably between catchments and seasons. Outliers or extreme values show observations that do not conform to the rest of the data in a particular database and indicates a possible presence of accidental nutrient release. Therefore the presence of point source pollution influence comes more evident because there are a large number of extremely high nutrient concentration values that occur under specific conditions. The unexpected extreme values of nutrients are typical for all catchments and may indicate accidental loss of nutrients. Nutrient concentrations in streams typically are

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elevated during high spring stream flows; also the nutrient compounds tend to increase in the autumn (September to October) following manure application. Relatively large interquartile ranges for $N_{tot.}$ in the Auce and Bauska catchments indicate that these sampling sources are highly variable, while limited farming activities in the Ogre catchment result in comparatively stable concentrations of $N_{tot.}$ throughout the year. A high variation of $P_{tot.}$ in the vegetative period is typical for the Bauska catchment, while at other times the $P_{tot.}$ variation is relatively small. Similar results came from the Auce catchment.

The seasonal pattern of data is verified by the Kruskal–Wallis test. However, statistically significant differences are not found for $P_{tot.}$ monthly variations in the Ogre catchment. It is important to note that phosphorus concentrations are still comparatively high in the Ogre catchment.

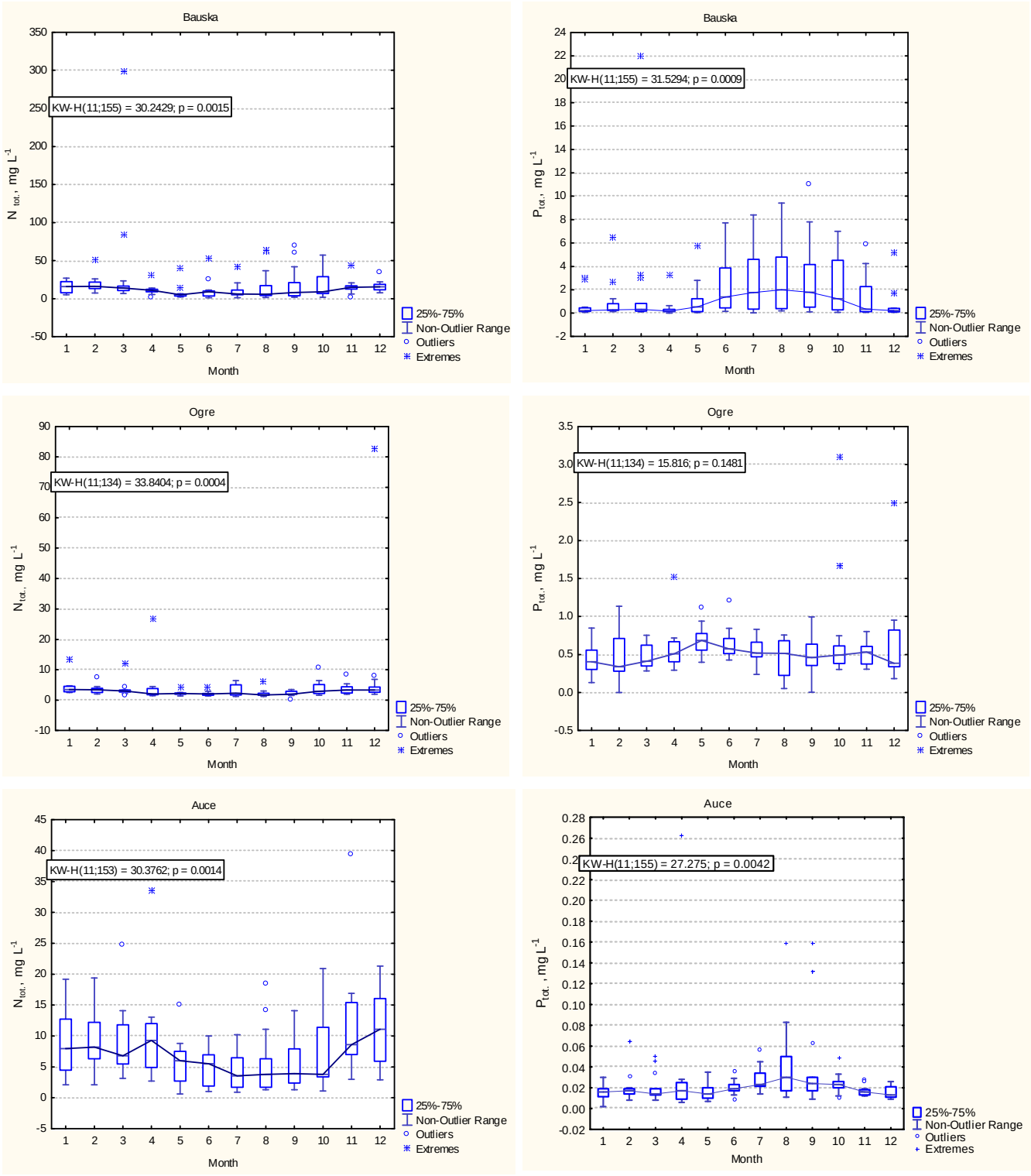


Fig. 2. Box-plots of nutrient monthly variations.

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components: trend-cycle (T, C), seasonal (S) and irregular (R)

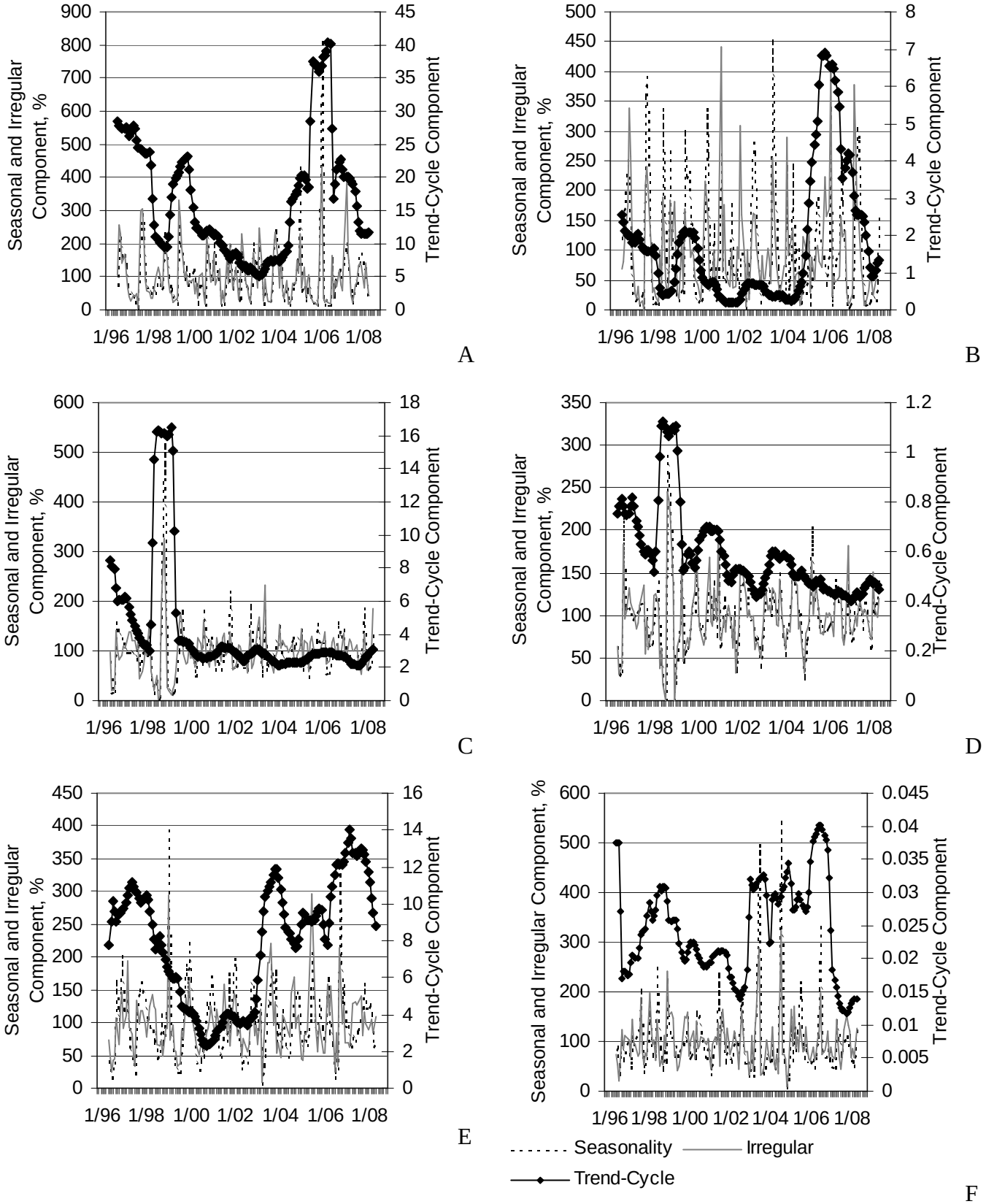


Fig.3. Seasonal decomposition results of $N_{tot.}$ and $P_{tot.}$: A-Bauska, $N_{tot.}$; B-Bauska, $P_{tot.}$; C-Ogre, $N_{tot.}$; D-Ogre, $P_{tot.}$; E-Auce $N_{tot.}$; F-Auce $P_{tot.}$.

The results of the seasonal decomposition (using the multiplicative model) procedure to divide time series into three results are displayed in Figure 3. The trend-cycle component is

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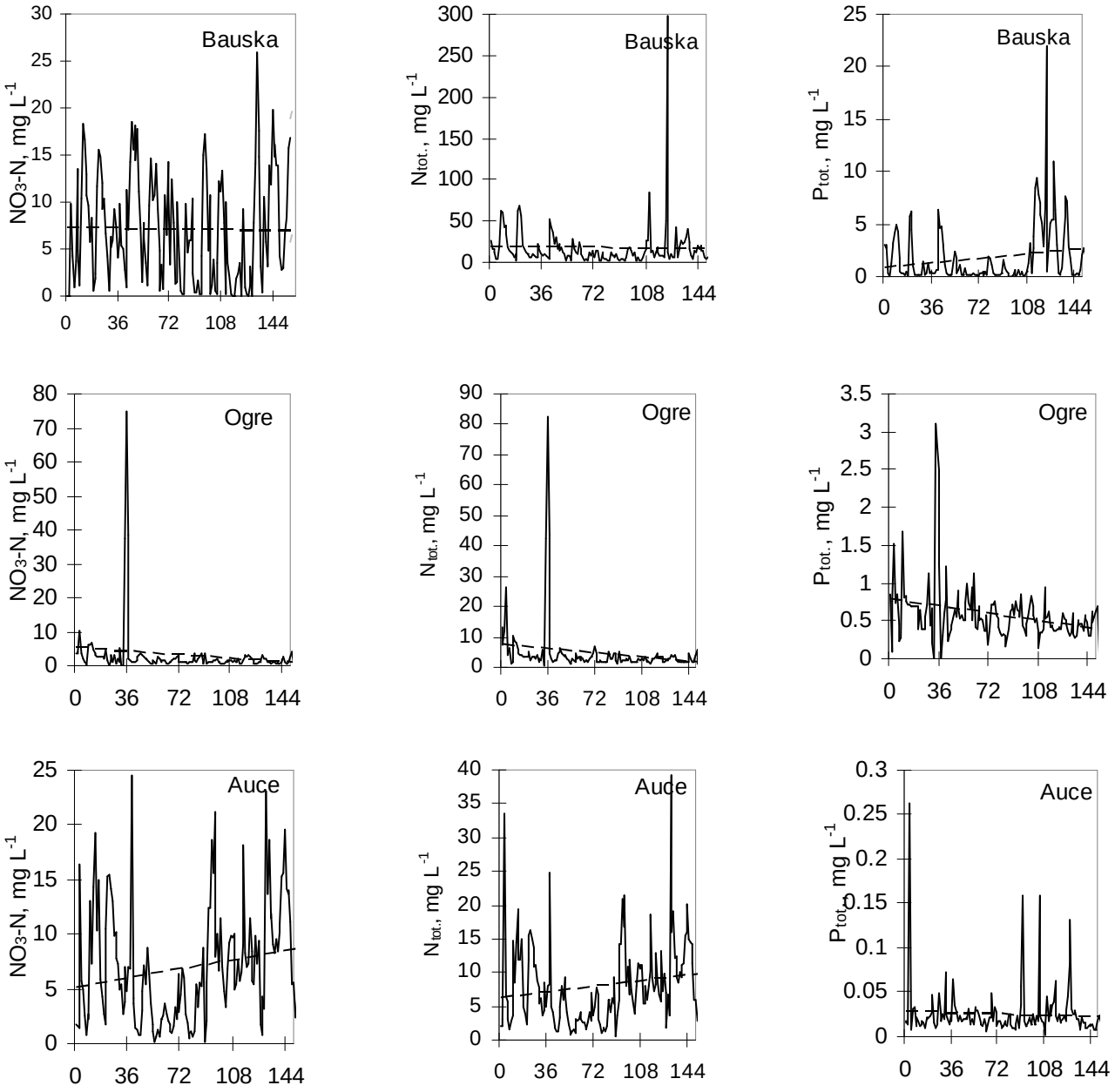


Fig. 4. Original data time series and trends, independent variable in all graphs: time step.

estimated by smoothing the time series data using a simple moving average with span *k* equal to the length of seasonality *s*.

Once the trend-cycle has been estimated, it can be removed from the data. For a multiplicative model, this is done by dividing the original data by the estimated component:

$$\hat{S}_t\hat{R} = \frac{Y_t}{\hat{T}\hat{C}_t}. \quad (1)$$

The resulting estimates of the seasonal-irregular component are then averaged across all observations within each season to remove the irregular component, resulting in an estimate of the seasonal component. The seasonal components are then adjusted so that an average season has a value of 1.0. For a multiplicative model, the estimated irregular component is obtained by dividing the observations by the estimated trend-cycle and seasonal components:

$$\hat{R}_t = \frac{Y_t}{\hat{T}\hat{C}_t\hat{S}_t} \quad (2)$$

and then normalized so that the average residual equals 1.0 (corresponding to an index of 100).

The seasonal indices for $N_{tot.}$ data range from a low of 51 in May to a high of 187 in March for the Bauska catchment. This indicates that there is a seasonal swing from 51% of the average to 187% of the average $N_{tot.}$ concentration throughout the course of one complete cycle. $N_{tot.}$ concentrations above

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long term average value are estimated in December, January, February and March. In the Ogre catchment, seasonal indices for $N_{tot.}$ sway from 69% in June to 158% in December from the average $N_{tot.}$ value throughout the course. Similarly the highest seasonal indices in Ogre are estimated for October-February. N_{tot} seasonal indices in the Auce catchment sway from 54% in July to 152% in November of average $N_{tot.}$ value throughout the course. High values are also typical for the winter and spring periods in the Auce catchment. Seasonal indices for $P_{tot.}$ data range from a low of 27 in January to a high of 177 in June for the Bauska catchment, from a low of 81 in January to a high of 122 in May for the Ogre catchment and from a low of 69 in January to a high of 170 in August for the Auce catchment. High $P_{tot.}$ indices are typical for June-October in the Bauska and Auce catchments and May-June, October-December in the Ogre catchment. The highest $N_{tot.}$ and $P_{tot.}$ irregular indices are typical for the Bauska catchment. For example, in the sample data, the large residual in March of 2006 in the Bauska catchment, equaling to 432 indicates that $N_{tot.}$ concentration in that month was 332% above what would have been expected, given the estimated trend-cycle and seasonal effects. It is necessary to admit that high irregular indices are very typical for July, August and November for the Bauska and Auce catchments and July and August for the Ogre catchment. High irregular indices appear 2-3 months after the spring and autumn slurry deposition.

The next part of the study assesses trends for nutrient time series. According to the previous data analysis results, most concentrations in surface waters show strong seasonal patterns. Some possible causes of seasonal patterns include both natural and agricultural activities. Therefore the seasonal Kendall test is used to determine trends in the observed nutrient time series. The seasonal Kendall test is a non-parametric test that accounts for seasonality by calculating the Mann-Kendall test on each of *m* seasons separately, and then combining the results. The Sen slope is estimated as the median annual slope of all possible pairs of values representing the magnitude of the trend. Results of the trend analysis are summarized in Figure 3 and Table 4. None of the studied catchments with intensive farming activities show a clear decrease in $N_{tot.}$ and $P_{tot.}$ during 1996–2008. By contrast, a slight increase of $N_{tot.}$ is detected in the Auce catchment. Statistically significant decreasing trends of nutrients in monthly concentrations are only observed in the Ogre catchment where active farming activities are interrupted. The strong nutrient concentration reduction at the Ogre catchment can be reasoned by the reduction of agricultural activities. However, observed concentrations of P_{tot}. in the Ogre catchment still stay comparatively high.

The study results indicate that the impacts of emissions of nutrients on water quality show wide variations and weak responses to surface water quality increase can be reported in the catchments observed. The findings of the study confirm that a decrease in nutrient concentrations and the water quality response to reduced manure application may be slow and limited. From the 2004 concentration of $N_{tot.}$, as well as $P_{tot.}$ dropped below long term mean value after which the amplitude and variability of nutrient concentrations becomes rather stable in the Ogre catchment. According to the positive $N_{tot.}$ concentration trends there is a risk of exceeding the threshold value of 11.3 mg L^{-1} of NO_3-N more often in the future at the Auce catchment. In addition, concentrations of $N_{tot.}$ and $P_{tot.}$ tend to increase in the last years of the observation period in the Bauska catchment. Studies about the trends in nutrient concentrations in Latvian rivers response to change in agriculture similarly highlight little evidence that this change in agricultural practices has immediate influence on decreases in nutrient concentrations [9].

TABLE 4
RESULTS OF SEASONAL KENDALL TEST

Catchment	Nutrient	Seasonal Kendall Test Statistic	p-value	Slope Estimate
Bauska	NO_3-N	-63	0.267	-0.064
	$N_{tot.}$	-15	0.792	-0.033
	$P_{tot.}$	66	0.245	0.011
Ogre	NO_3-N	-78	0.168	-0.042
	$N_{tot.}$	-205	0.000	-0.1
	$P_{tot.}$	-160	0.005	-0.019
Auce	NO_3-N	167	0.003	0.269
	$N_{tot.}$	169	0.003	0.3
	$P_{tot.}$	-67	0.236	0.000

IV. CONCLUSIONS

The paper summarizes and examines some of the major issues and choices involved in detecting and estimating the magnitude of temporal trends in measures of stream-water quality in agricultural catcments influenced by point source of pollution. An analysis of long-term records of the concentrations of major nutrients for high intensive animal agriculture sites in Latvia is reported. The results of the present study show that, despite legislative efforts to restrict nutrient loading, little or no reduction of loads has been achieved during the study period (1996–2008). The water quality observations in the agricultural catchments with intensive livestock farming show no significant downward trends in the concentrations of nutrients. Significant downward trends are revealed for $N_{tot.}$ and $P_{tot.}$ in the catchment where the farm is closed since 1992. Whereas, upward trends revealed for NO_3-N and for $N_{tot.}$ are recorded in the catcment with high-input agricultural activities. There is a strong seasonal structure in time series analysis results, however also high values of irregular variation of nutrient concentrations are detected and can be linked with farming activities. Nutrient concentrations in catchments influenced of point source pollutin increases as much as 2-5 times that of diffuse pollution values detected. Especially high concentrations of $P_{tot.}$ are recorded a long period after the closure of a farm.

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Laima Bērziņa, Ritvars Sudārs. Biogēno elementu koncentrācijas virszemes ūdeņos sezonālo svārstību un trendu analīze intensīvas lopkopības apstākļos Latvijā
Pētījumā analizētas biogēno elementu koncentrācija virszemes ūdens objektos lopkopības saimniecībās ar augstu dzīvnieku blīvumu, lai novērtētu lauksaimnieciskās ražošanas radītā koncentrētā piesārņojuma ietekmi uz ūdens kvalitātes izmaiņām. Ūdens kvalitātes novērojumi hidrogrāfiskā tīkla sākuma posmā dod iespēju vistiešāk novērtēt piesārņojuma ar biogēnajiem elementiem (slāpeklis un fosfors) slodzi un raksturu. Kopumā biogēno elementu koncentrāciju izmaiņas ūdeņos raksturo liela mainība, ko nosaka dabisko un antropogēno faktoru mijiedarbība. Rakstā detalizēti apskatītas biogēno elementu koncentrāciju sezonālās svārstības, kas dod priekšstatu par lauksaimnieciskās ražošanas slodžu ietekmes intensitāti gada griezumā. Novērojumu rezultāti trijās saimniecībās, kas izvietotas nitrātu jutīgajā teritorijā Latvijā, tikai atsevišķos gadījumos norāda uz augstu un labu virszemes ūdeņu kvalitāti. Sezonālā Manna-Kendala testa rezultāti neapstiprina būtiskas biogēno elementu koncentrāciju samazinājuma tendences aktīvas lauksaimnieciskās darbības apstākļos laika periodā no 1996. līdz 2006. gadam. Novērojumu postenī Auce konstatēts statistiski būtisks pozitīvs nitrātu un kopējā slāpekļa koncentrāciju trends, turklāt piesārņojuma vērtībām ir tendence pieaugt tieši pēdējos gados. Ja augsnes ir pārsātinātas ar biogēnajiem elementiem mēslošanas rezultātā, tad to izskalošanās no lauksaimniecības teritorijām var turpināties vairākus gadu desmitus pēc organiskā mēslojuma lietošanas pārtraukšanas.

Лайма Берзиня, Ритварс Сударс. Анализ сезонных колебаний и трендов концентрации биогенных элементов в поверхностных водах в условиях интенсивного животноводства в Латвии
В исследовании проанализирована концентрация биогенных элементов на объектах поверхностных вод в животноводческих хозяйствах с большой плотностью животных, с целью оценки влияния концентрированного загрязнения, образовавшегося в процессе сельскохозяйственного производства, на изменение качества воды. Наблюдения за качеством воды в начальной стадии гидрографической сети позволяет наиболее точно определить объём и характер загрязнения биогенными элементами (азот и фосфор). В целом изменениям концентрации биогенных элементов в воде характерно высокое непостоянство, что обусловлено взаимосвязью природных и анторпогенных факторов. В публикации детально рассмотрены сезонные колебания концентрации биогенных элементов, что дает представление о влянии интенсивности нагрузки сельскохозяйственного производства в течении года. Результаты наблюдений в трёх хозяйствах, которые расположены в Латвии на территории чувствительной к нитратам, только в некоторых случаях указывают на высокое и хорошее качество поверхностных вод. Результаты сезонного теста Манна-Кендала не подтверждают существенную тенденцию снижения концентрации биогенных элементов во время активной сельскохозяйственной деятельности в период с 1996 по 2006 год. В месте наблюдений в Ауце обнаружен статистически существенно положительный тренд концентраций нитратов и общего азота, причём наблюдается тенденция увеличения объёмов загрязнений именно в последнии три года. Если почва пресыщенна биогенными элементами в результате удобрения, тогда их вымывание с сельскохозяйственных территорий может продолжатся несколько десятилетий после прекращения использования органического удобрения.