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Letter to Editor

An Impact Assessment of Built-Up Residential Areas on Selected Water Quality Indexes

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Abstract

This study determines the effect of compact built-up residential areas (with water mains but without sewage systems) on selected indices of water quality in the winter and summer half-year. The assessment was based on an analysis of the Grodna stream draining catchment with an area of 598.21 ha. Water quality measurements were conducted before and after water flowed through the built-up part of the catchment. The obtained results unanimously point to a negative impact on surface water quality from the residential built-up area, which has no regular water supply or sewage disposal system. Mean annual concentrations of the analyzed indices of the stream water (except dissolved oxygen) always increased after the water flowed through the built-up area. The concentration increases were sometimes very high for some indices (NH_4 over 30-fold, NO_2 and PO_4 almost 10-fold). Water quality was also assessed using a direct method.

Keywords: rural areas, residential built-up area, watercourse, water quality

Introduction

The main sources for chemical substances in waters include leaching of natural environmental chemical resources, fallout of atmospheric pollutants, agricultural area pollution (including also pollutants originating from people), municipal sewage discharges and industrial wastewater. Usually, leaching of the natural environment is not considered a source of water pollution. However, the varying chemical composition of rocks and soils, diversified contents of nutrient compounds and numerous other factors may cause surface waters to contain considerable amounts of chemical components of natural origin, whereas the chemical composition of catchment waters may greatly differ spatially. Both typical agricultural and settlement areas have an unfavourable impact on the water ecosystem. The concentration of chemical components in surface waters in rural areas are subject to large variations depending on the kind of stream, rural economy intensification, population density of the catchment area, as well as seasons of the year.

Studies conducted by many authors indicate a different impact of developed rural areas on the content of chemical compounds on surface water [1-5].

Irregular water supply and sewage disposal is considered one of the major sources of pollution in surface waters flowing through rural areas [6, 7], in addition to the lack of properly adjusted places for depositing liquid and solid organic wastes. The impact is more serious when the divergence between the outlays on water supply systems and outlays on regulation of water supply and sewage disposal systems become greater. It should be said that in most catchments interrelations between these factors are unfavourable.

The contents of some chemical components in two micro-catchments (typically agriculture and settlements) that were analyzed by Rajda and Natkaniec [5] indicate the wide range of ion components in both catchments.

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The rural settlements decidedly deteriorate surface water quality in relation to the agriculture area, particularly in view of nitrate, phosphate and ammonium concentrations. Pijanowski and Kanownik [3], on the basis of conducted studies, also have proved that the main sources of pollutants occurring in surface water are the settlement areas. In favour of the need to conduct studies in this subject, it is a necessity to control physicochemical properties of water flowing out from rural areas, and to determine the factors which decide their variability.

The aim of our study is to assess the influence of rural residential built-up areas on the concentration dynamic of selected quality indices of the surface water out-flowing, during winter and summer seasons, from agricultural lands.

Experimental Procedures

Analyses were conducted in the period from November 2005 to October 2007. They involved monthly water samplings for physicochemical analyses on precisely determined dates at two sampling points situated on the Grodno watercourse:

1) before the watercourse flowed to the built-up area,
2) after it flowed through the built-up part of the catchment.

Simultaneously, the contents of the same indices were determined in precipitation water. On-site assessments involved pH, conductance and dissolved oxygen. Laboratory analyses were aimed at determining the concentrations of nitrates, nitrites, ammonia, phosphates, sulphates,

Table 1. Significance of differences between mean water quality indices for the investigated period before the residential-farming area (1) and after the stream left the built-up area (2).

Parameters		Measurement point	Concentration range	Mean	*s*	Differences signifficant
NO_3	mg·dm^{-3}	1	0.013–5.390	1.48	1.56	*
		2	0.934–11.487	6.7	3.02	
NO_2	mg·dm^{-3}	1	0.003–0.091	0.02	0.02	*
		2	0.050–0.811	0.27	0.23	
NH_4	mg·dm^{-3}	1	0.006–0.134	0.05	0.03	*
		2	0.310–5.698	1.86	1.31	
PO_4	mg·dm^{-3}	1	0.031–0.333	0.14	0.14	*
		2	0.013–2.726	1.23	0.79	
SO_4	mg·dm^{-3}	1	27.81–59.26	44.89	7.84	*
		2	45.70–81.50	59.49	9.45	
Cl	mg·dm^{-3}	1	9.91–24.46	13.72	3.57	*
		2	22.50–33.40	27.56	2.92	
Ca	mg·dm^{-3}	1	28.00–65.90	49.40	9.96	*
		2	76.60 –119.90	97.89	11.55	
Mg	mg·dm^{-3}	1	7.7–24.2	14.67	3.41	*
		2	9.5–33.7	18.95	6.98	
K	mg·dm^{-3}	1	1.2–5.6	3.46	1.28	*
		2	4.7–16.2	9.74	3.46	
Dissolved oxygen	mg·dm^{-3}	1	7.28–9.65	8.37	0.82	
		2	6.56–9.33	7.97	0.74	
Conductivity	μS·cm^{-1}	1	245–542	426.50	66.71	*
		2	391–692	587.21	85.59	
Reaction	pH	1	7.28–8.58	7.78	0.26	*
		2	7.47–8.46	7.99	0.25	

Explanations: 1- measurement point before residential-farming area. 2- measurement point after the stream left the built-up area. *-difference in mean statistically signifficant for $\alpha=0.05$. s–standard deviation

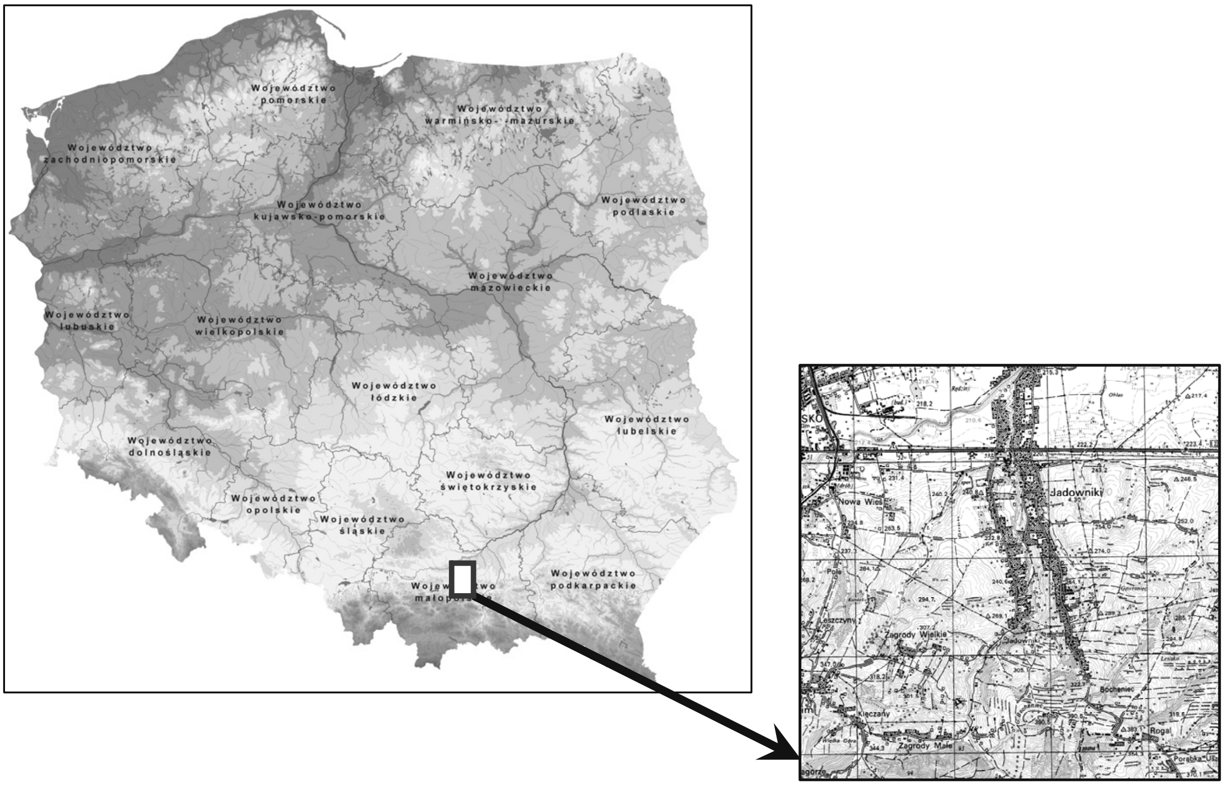

Fig. 1. Investigated localities.

chlorides, potassium, sodium, calcium and magnesium. The assessments were made by means of commonly used standard methods [8]. Water quality was determined using a direct method comparing all assessments of the analysed indices with values permissible for water purity classes I, II, III, IV and V [9].

Characteristics of the Study Area

The catchment under study has an area of 598.21ha and is situated in the Brzeski district (the Malopolska region). The land is characterised by a varied landscape and its geographical location is: 49° 58' 08" N, 20° 38' 50" E (Fig. 1). The main watercourse, the source of which is at an altitude of 320 m a.s.l., is about 8 km long. The stream has a greatly developed network of small left and right-hand tributaries, mainly in the south-western part of the catchment, in forested areas. Two water sampling points were located on the Grodna stream. The first is 1.35 km along the watercourse (280 m a.s.l) before the stream flows into the built-up terrain of the Jadowniki village residential area, and the second is 3.45 km further at an altitude of 240 m a.s.l after the stream leaves the built-up areas. There are about 320 farms in this catchment area, with a population of 1590 people, which gives an average population density of 265 people/km^2. 71% of the catchment area is used for farming. The prevailing part (59%) is covered by arable lands. Grasslands occur in the immediate vicinity of the watercourse and cover c.a. 8%; orchards occupy respectively 4% of the area. The forested areas (19%) are located in the southern part of the catchment, and the remaining areas amount to 10% (Fig. 2). The farming in the catchment area has a typical extensive character, comprising small, split-up fields, most of which at present lie fallow. The cultivated arable land is used for growing grain crops. 37.58% of the micro-catchment area has a land slope ranging from 5 to 10%. The areas located in the northern part of the catchment (22.39% of the area) mainly have a gradient between 0-5%. Land with an inclination between 10 and 15% covers 25.53% of the catchment area. On the other hand, hills with a slope of over 15% constitute 11.50% of the area.

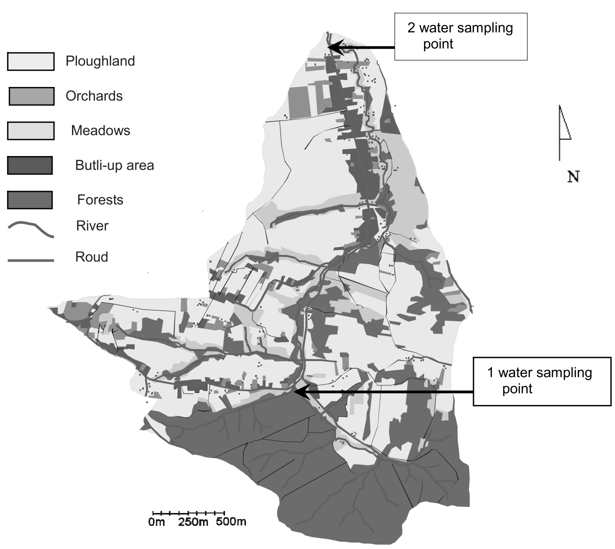

Fig. 2. Map of the Grodna stream microcatchment use.

Results

Analysis of the selected indices of watercourse water quality revealed a considerable diversification. Throughout the whole period of analyses, lower mean concentrations of nitrates, nitrites, ammonia, phosphates, sulphates, chlorides, calcium, magnesium, potassium, pH and electrolytic conductance were assessed in water flowing into the residential and farming area than in the water leaving this terrain (Table 1). Higher mean concentrations of dissolved oxygen were determined in the stream waters flowing into the residential area, but they proved statistically insignificant. The differences of mean concentrations of the other indices for the period of investigations were on a significant level: $\alpha = 0.05$ at $p<0.001$. In some cases these differences proved considerable and caused a 37-fold increase in NH4, an over 13-fold increase in NO_2, an almost 9-fold increase in PO_4 and an over 4-fold increase in NO_3.

In both winter and summer, half-year mean values of the analyzed indices were significantly lower before the watercourse flowed into the built-up area than when it left this terrain. A lower diversification of the analyzed indices was found between the summer and winter half-year values for water flowing away from the non-residential part of the micro-catchment, whereas a considerable diversification was detected after the watercourse left the built-up area. Higher values of the analyzed indices in the winter half-year were noted in six cases (nitrates, sulphates, chlorides, calcium, magnesium and dissolved oxygen). In the other cases (nitrites, ammonia, phosphates, conductance and potassium), higher values of the indices were registered in the summer half-year. No apparent differences were noted for pH (Fig. 3).

Analyses of physicochemical properties of precipitation conducted at the same time demonstrated that values of all indices of precipitation water quality, except dissolved oxygen, assumed definitely lower values than in the analyzed stream waters. Only ammonia concentration in the stream water was lower than in the precipitation. Lower values of individual indices in precipitation than in the waters flowing away from the catchment have been confirmed by the research of Ostrowski et al. [10], among others.

By comparing determined concentrations with limit values, water purity classes were determined for the waters of the analyzed watercourse in the winter and summer half-year, assuming as a reference the water purity class noted in 90% [9]. In the winter half-year, water quality in the researched stream did not change after it flowed through the built-up area only with respect to the content of sulphates, chlorides, dissolved oxygen and pH (Class I). In all other cases the content of the other indices in water flowing through the built-up area led to a worsening of water quality, i.e. in the case of nitrates from Class I to II, for nitrites from Class I to III, for ammonia from Class I to IV, phosphates from Class II to V, for calcium from Class II to III, magnesium from Class I to II and conductance from Class I to II. In the summer half-year, water quality did not change only with respect to the contents of sulphates, chlorides and pH (I purity class) and conductance (Class II). Elevated contents of the remaining indices led to a worsening of water quality after the watercourse left the built-up area in the case of nitrates from Class I to II, nitrites from Class I to III, ammonia from Class I to V, phosphates from Class II to V, calcium from Class II to III, magnesium from Class I to II and dissolved oxygen from Class I to II (Figs. 4a, 4b).

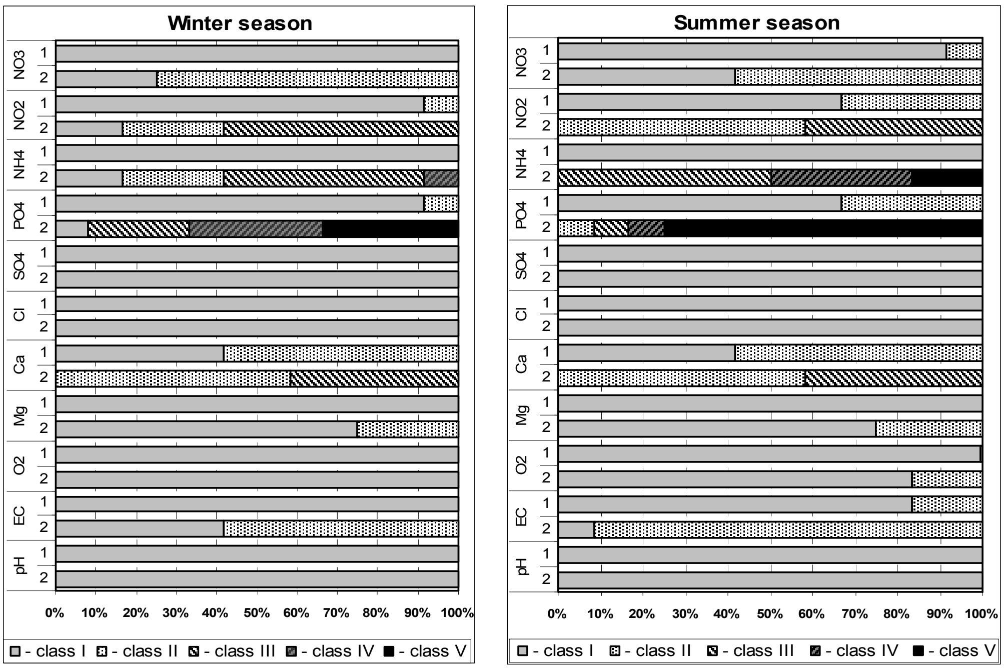

Fig. 3. Frequency [%] of occurrence of analyzed surface water quality values within individual purity classes in winter half-year (November-April) and summer half-year (May-October).

Explanations: 1- measurement point before residential-farming area, 2- measurement point after the stream left the built-up area.

Discussion of Results

Comparison of selected quality indices of water flowing through the residential-farming area demonstrated a significant increase in concentrations of all analyzed physico-chemical parameters (except dissolved oxygen), both in the winter and summer half-year. It confirms the high impact of catchment land use on the worsening of water quality [3, 11]. Other authors have also [12, 13] reported the role of rural settlements in water chemical supply. Results obtained by [1, 14] prove that the type of catchment management and use most influence surface water quality.

Higher mean values for the period of research in water flowing away from the residential-farming areas in the winter half-year (November-April) were registered for nitrates, sulphates, chlorides, calcium and magnesium. In the summer period (May-October) higher values were noted for biogens (nitrites, ammonia and phosphates), conductance and potassium.

Quality of water flowing through residential-farming areas was worsened the most by levels of phosphates (to Class V), ammonia, nitrites and calcium (to Class IV), and the least by sulphate and chloride concentrations and pH.

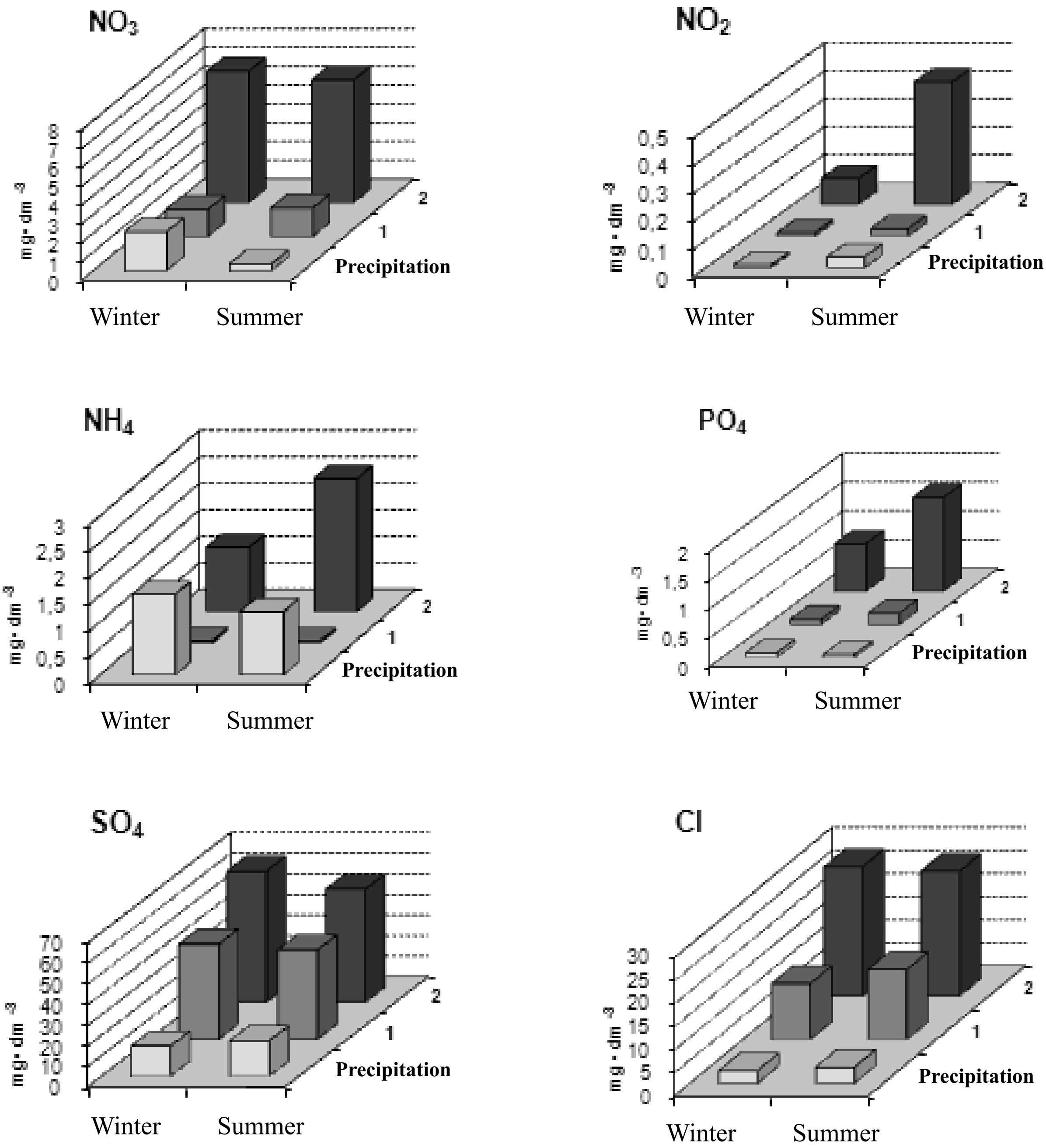

Fig. 4a. Mean values of selected water quality indices at measurement points: 1 – before residential-farming area, 2- after the stream left the built-up area and in precipitation in winter and summer half-year.

Conclusions

1. Residential areas, in comparison with typical agricultural areas, significantly deteriorate the water quality in the streams which flow through them. They cause an increase in concentrations of investigated indicators, both in averages of the study period as well as in half-year winter and summer seasons.
2. The quality of waters flowing through residential-farming areas was worsened the most by biogenic indices (nitrites, ammonia and phosphates) and calcium both in the winter and summer half-year.
3. Indices of precipitation water quality reached substantially lower values than in the surface waters. Only the ammonia concentration in the precipitation water was higher.
4. In order to secure appropriate water quality protection of an agricultural area, one should apply good agricultural practices, proper crop rotation and fertilization according to the plant requirements.
5. One of the significant pollution sources of the water flowing through rural areas is unorganized wastewater management systems as well as the lack of places for storage of liquid and solid organic wastes.

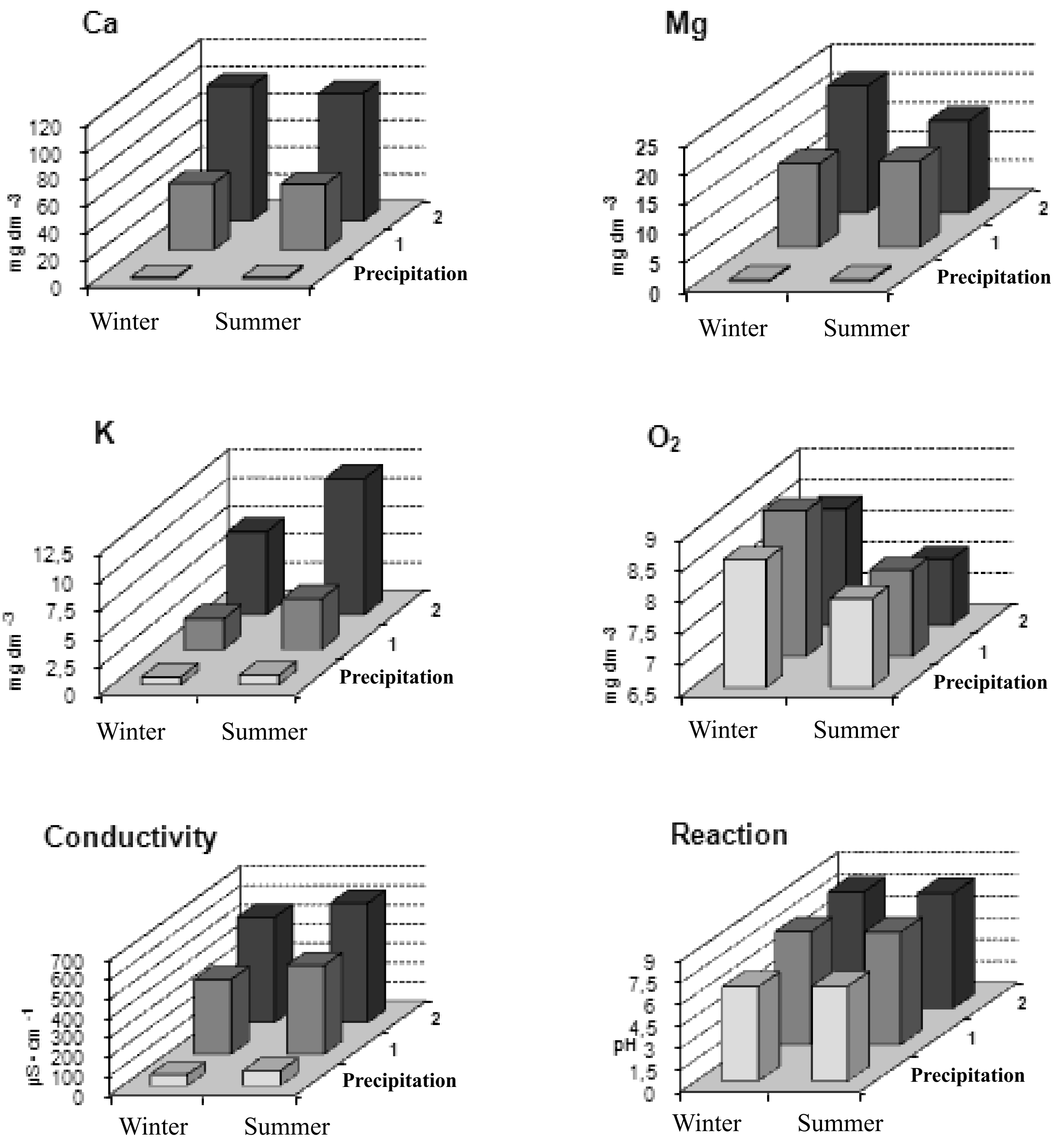

Fig. 4b. Mean values of selected water quality indices at measurement points: 1 – before residential-farming area, 2- after the stream left the built-up area and in precipitation in winter and summer half-year.

The principles for proper handling of solid wastes and sewage, including those originating from business activity, should be absolutely observed.

6. The research results concerning qualitative and quantitative changes of water in the agricultural catchment area should be, to a greater degree, applied to spatial planning, which ought to be based on the river basin's layout.

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