Impact of urbanization on the stream water quality in the Lesser Carpathian region

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Abstract— The paper deals with the following subjects: Statistical analysis of the selected pollution determinands in two sampling sites of the Gidra River (above and below Pila village); 2. Assessment of relation between discharge and concentrations of selected water quality parameters for the Gidra stream; and 3. Impact of the anthropogenic activities on the water quality in the Gidra stream. The analysis was based on the water quality time series, monitored by the Institute of Hydrology of the Slovak Academy of Sciences (IH SAS) weekly (fortnightly) during the period 1991–1993 and 2004–2006. In the samples of surface water, the chemical pollution determinands were analysed, e.g.: nitrate, nitrite, ammonium, sulphate, chloride, phosphate, pH.

Keywords—water quality, backward pollution, stream water, headwater.

I. Introduction

HIGH concentration of inhabitants in the Trnava's lowland region belongs to its characteristic features (density of the population is about 170 inhabitants per 1 km^2). Both, the intensive industry, and agriculture have a negative influence on water quality in this region. Most of local settlements (incl. Trnava city) are exclusively supported by drinking water from own groundwater sources. As these sources are irreplaceable, it is necessary to intensify the research of this problem.

Runoff water quality in relation to the forest ecosystem was evaluated by [1] in 12 catchments of the Lesser Carpathians. Author of [2] was interested in the impact of human activities on groundwater quality in the Lesser Carpathians headwaters. He found that chloride, sulphate, and especially nitrate concentrations permanently increase in the groundwater. Lehotsky and Toth [3] processed the water quality of 96 forest springs and wells on the ridge of the Lesser Carpathians. Evaluation of drinking water quality was made in [4]. In a study by Fottova [5], the chemical composition of precipitation, runoff water, and mass balance were evaluated based on data from the Vydrica catchment within the Czechoslovak network of small catchments, Geomon (catchments with various land uses), gathered in 1990. Slaninka et al. [6] monitored precipitation, surface runoff, and spring water runoff, for the sake of mass balance in the Vydrica catchment up to the Spariska section.

In 1991–1994 we were monitoring the selected chemical parameters in seven headwater streams in the Lesser Carpathians within the project on Impact of the anthropogenic activities on stream water quality. In study [7] authors studied the chemical regime and interaction of surface and groundwater in this region (from Bratislava city to Trstin village). They focused on the analysis of the chemical regime of the rain-, surface-, and groundwater in this region. From this study it follows, that in groundwater, the occurrence of local maxima and minima was delayed by 120–150 days in a dry year, and 30–60 days in a wet year, respectively. Thus, in a dry year, nitrogen penetrates into groundwater slower than in a wet year. Generally, stream load and specific yield of nitrogen and phosphates from territory of Slovakia were studied in [8] and [9].

Ten years later in 2004–2006 we repeated the monitoring of selected chemical determinands in seven headwater streams in the Lesser Carpathians. In [10], monthly and yearly runoffs of total nitrogen for the period 1991–2002 were modelled in the Vydrica stream (the Lesser Carpathians region) based on the empirical relationships. Nitrate wash off from the Bratislava Forest Park basin Vydrica in years 1986–2005 was presented in [11].

Based on these works we focused on the evaluation of the impact of settlements on surface water quality in the Gidra stream in this study. The aims of this study are:

i) Statistical analysis of the selected pollution determinands in two sampling sites of the Gidra river;
ii) Assessment of relation between discharge and concentrations of selected water quality parameters for the Gidra stream;
ii) Impact of the anthropogenic activities on the water quality in the Gidra stream.

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II. Materials

A. *Water quality data*

As it was mentioned above, in 1991–1994 and 2004–2006 we monitored selected water quality parameters in seven headwater basins in the Lesser Carpathians. Water samples were picked up in two weeks intervals in eight sampling sites (Fig. 1a). Water temperature and pH were measured in situ. Nitrate, nitrite, ammonium, sulphate, phosphate, and chloride were analysed in the chemical laboratory of IH SAS during 1991–1994 period. During 2004–2006 the samples were analysed in laboratory of SVP in Bratislava.

In this study we used data measured during two hydrological years 1991/92–1992/93, and after ten years during 2004/05–2005/06 from two sampling sites (Fig. 1a-b):

i) – Gidra: Pila – above the village (5);

ii) – Gidra: Pila – below the village (4).

The selected catchments represent a forested area, and urban area. The sampling site above the village is identical with the discharge gauge of the Slovak Hydrometeorological Institute.

Fig. 1a. Location of surface water quality sampling sites in the Lesser Carpathians region.

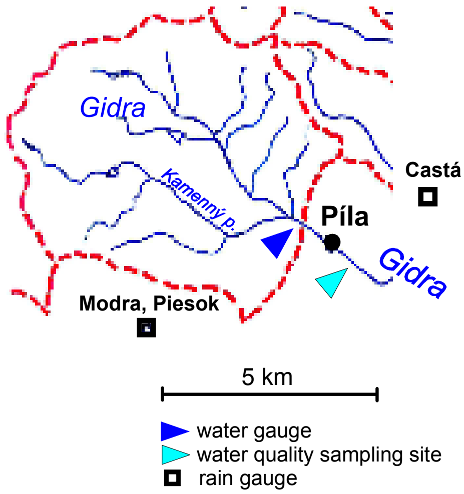


Fig. 1b. Gidra stream basin up to water gauge station above Pila village. Location of the sampling sites.

III. Results

A. *Analysis of the hydrological regime of the Gidra River*

The Slovak Hydrometeorological Institute (SHMI) established water level gauging station on the Gidra stream in 1956. Its basic geographic characteristics and water balance are presented in Tables 1a-b. Discharge characteristics were evaluated from the SHMI daily discharge data for the period 1961–2010. Selected discharge characteristics are given in Table 2.

Table 1a) Basic physiographic characteristics of the Gidra basin; A – catchment area, L – valley length, A/L^2 – basin shape characteristic according to [12].

Gidra: Pila		
A	[km^2]	32.95
L	[km]	7.9
A/L^2		0.5
River km	[km]	33.3
Elevation zero water level	[m a.s.l.]-	270.04
Forestation	[%]	95

Table 1b) Basic water balance characteristics of the selected basin, P – basin mean annual precipitation 1931–1980 [13], R – runoff, Kr – runoff coefficient, qa – mean specific runoff, Qa – mean annual discharge in 1961–1980 according [14].

Gidra: Pila		
P	[mm]	1024
R	[mm]	294
Kr		0.29
qa	[l s^{-1} m^{-2}]	9.32
Qa	[m^3 s^{-1}]	0.294

Table 2 Basic characteristics of the 1961–2010 mean daily discharges *Qd* and *qd*, Gidra River.

Gidra: Pila	Qd [m^3 s^{-1}]	qd [l s^{-1} km^{-2}]
mean	0.285	8.6
min	0.02	0.6
max	6.473	196.4
330-day	0.068	2.1
30-day	0.674	20.4
cs	5.2	
cv	1.3	

Since 1960, mean annual flows in the station have slowly decreased. The discharge rise during recent years still has not outbalanced the long-term decrease (Fig. 2). In most rivers of Slovakia, decrease of runoff has been observed within the 1961–2010 years. This runoff decrease will probably cease after year 2010 when high precipitation was observed.

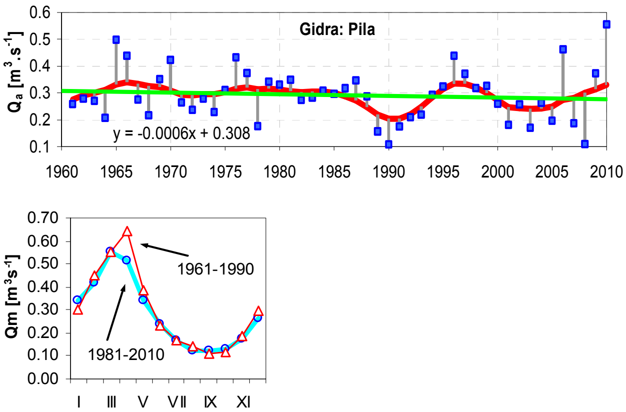


Fig. 2 Mean annual discharges, multiannual variability, and a long-term linear trend (up). Long-term mean monthly discharges for the two periods: 1961–1990 and 1981–2010 (down). Gidra river.

Fig. 3a Water gauge and water quality sampling site, the Gidra River (Photo Pekarova, 2011).

Fig. 3b The Pila village after catastrophic flood event on 7 June 2011 on the Gidra stream. Photo Pekarova, 2011).

On the 7th June 2011, in the afternoon, on the southeastern slopes of the Lesser Carpathian range, a catastrophic flood situation developed, hitting headwater of the Gidra creek. Resulting flood wave caused heavy damage of the Píla village (Fig. 3b). Calculated Gidra peak during this flash flood was estimated on more than 44 m^{3}s^{-1} (Fig 4)

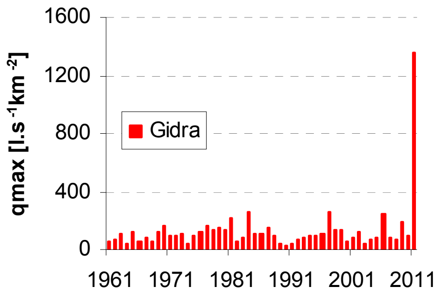


Fig. 4 Maximum annual Gidra specific runoff time series within the period 1961–June 2011.

B. Precipitation pollution

Acidification and eutrophication damage aquatic and terrestrial ecosystems, not only in the vicinity of the sources, but also in sensitive background regions. Precipitation is an important source of pollutants to forested ecosystems [15]. There is no rainfall gauge situated directly in the upper Gidra basin [16]. The closest station is at the Astronomic and geophysical observatory of FMFI UK Modra-Piesok on the Tisove rocks at 531 m a.s.l., which is operated since 1988. In Fig. 5 there are mean daily precipitation depth at station Modra-Piesok, and discharge of Gidra at Pila.

The daily rainfall depth and rain water quality were processed by IH SAS from samples manually collected by observer in the Smolenice village 100 m below the forest line during 4 water years 1991/92–1994/95. In Fig. 6 there is the relation between measured nitrate concentrations and measured rainfall depths measured at station Smolenice - Zalazne.

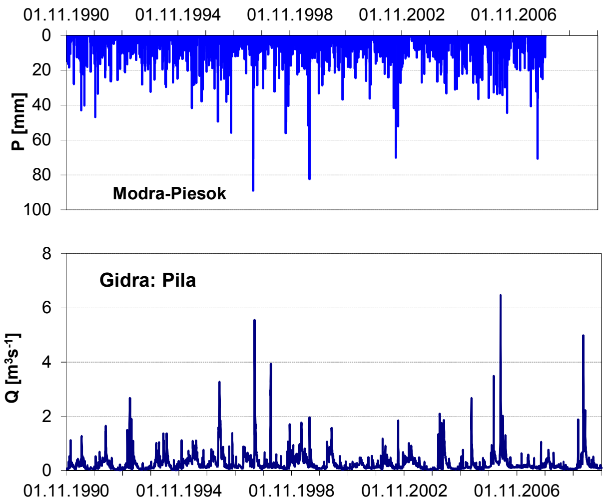


Fig. 5. Daily precipitation depths P in 1990–2007 and mean daily discharge Q at Gidra: Pila gauge in 1990–2009.

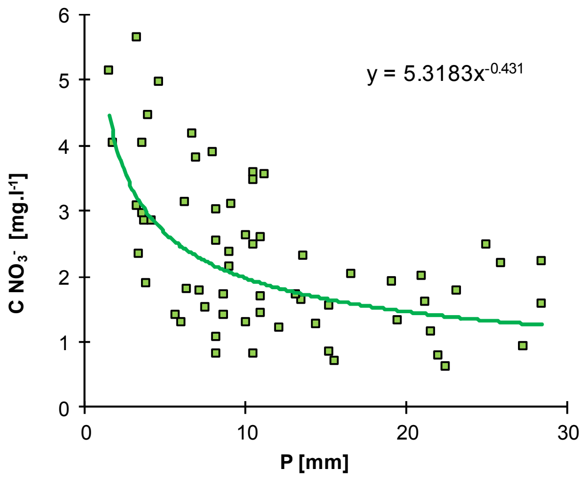


Fig 6. Relation between measured nitrate concentrations and measured rainfall depths of the water sample, station Smolenice-Zalazne, 1992-1995.

C. *Statistical analysis of the Gidra River pollution*

Compounds of nitrogen mainly issue from industrial and natural fertilizers, industrial and waste water, and NOx emissions from combustion engines and traffic. Nitrates are of significant seasonal variability. Higher values of them occur during snow-melting in spring [17]-[19]. Incorrect application of fertilizers during the vegetation period leads to rapid increase of nitrate concentration in stream waters.

Both nitrate and nitrite concentrations reach their maximum values during the wet periods, first of all during the spring snow melting. Nitrates are washed off by rain water from the surface into a river. Generally, in the rivers of this region the discharge increase leads to the total nitrate concentration growth. On the other hand, phosphate concentrations and pH in settlement basins increase while the discharge is low. Both sulphates and chlorides behave similarly.

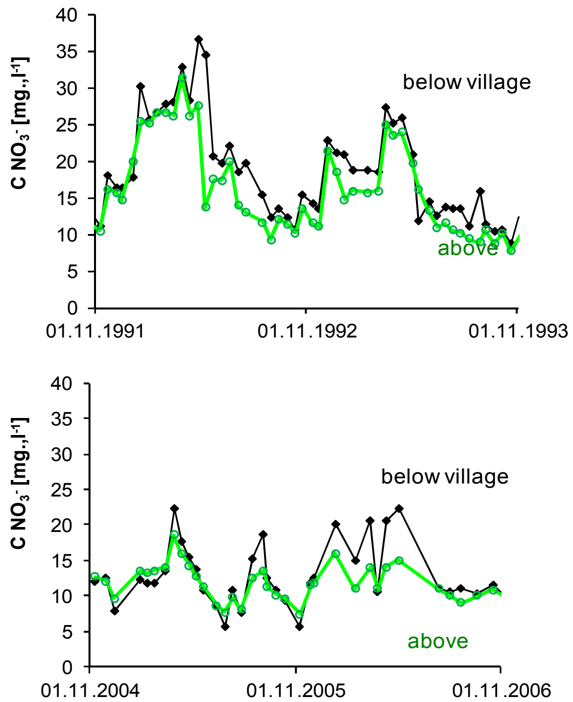


Fig. 7. The time courses of the observed nitrate (up) and phosphate (down) concentrations in the Gidra stream water, above/below Pila village, Nov, 1991–Oct, 1993, and Nov, 2004–Oct, 2006.

In Fig. 7, the time courses of measured nitrate and phosphate concentrations are presented, for two periods 1991/91–1992/93, and 2004/05–2005/06. The basic statistical characteristics of the nitrate and phosphate concentrations are given in the Table 3a-b.

Table 3. Basic statistical characteristics of the nitrate and phosphate concentrations in Gidra river above and below Pila village, period a) 1991–1993; and b) 2004–2006

a)	1991-1993			
	below	above	below	above
	NO_3^-	NO_3^-	PO_4^{3-}	PO_4^{3-}
average	18.02	14.99	0.06	0.04
st. dev	6.55	5.28	0.06	0.04
min	10.40	8.84	0.00	0.00
max	36.60	27.60	0.23	0.16
P10	11.28	9.79	0.01	0.01
P90	26.50	23.70	0.17	0.08

b)	2004-2006			
	below	above	below	above
	NO_3^-	NO_3^-	PO_4^{3-}	PO_4^{3-}
average	12.99	11.27	0.05	0.03
st. dev	4.89	2.29	0.03	0.02
min	5.70	7.40	0.02	0.01
max	22.30	16.00	0.12	0.08
P10	9.04	9.06	0.03	0.01
P90	20.54	14.40	0.10	0.05

The highest nitrate pollution was found at Gidra river below Pila village, where the average nitrate concentrations reached 36.6 $mg.l^{-1}$ on 27.04.1992 (Table 3). Value c90 with the probability of being exceeded in 90% of cases reached 23.7 $mg.l^{-1}$ for nitrates. In the case of the phosphates, the situation was similar.

The most pronounced difference in the pollution above and below the village was observed for electrical conductivity. In the rain water the observed mean conductivity was about 16 µS/cm. In the profile above the village the mean value was 124 µS/cm during the two water years 2004/04–2005/06. Almost twice higher values were observed below the village – 242 µS/cm.

Table 4. Basic statistical characteristics of the selected pollutants in the Gidra river above and below Pila village

	below	above	below	above
	pH	pH	EC	EC
			µS/cm	µS/cm
average	6.81	6.86	242.3	123.9
st. dev	0.65	0.43	40.59	40.52
min	5.2	5.8	151	69
max	7.8	7.37	301	194
P10	5.95	6.3	195	83
P90	7.32	7.23	282.5	180

	below	above	below	above
	NH_4^+	NH_4^+	NO_2^-	NO_2^-
	mg/l	mg/l	mg/l	mg/l
average	0.74	0.73	0.057	0.033
st. dev	0.36	0.33	0.130	0.022
min	0.01	0.1	0.01	0.01
max	1.6	1.45	0.81	0.106
P10	0.242	0.246	0.0126	0.012
P90	1.138	1.058	0.0658	0.06

	below	above	below	above
	SO_4^{2-}	SO_4^{2-}	Cl^-	Cl^-
	mg/l	mg/l	mg/l	mg/l
average	82.76	76.96	7.10	6.45
st. dev	15.46	13.39	5.53	5.69
min	48.90	57.01	1.74	0.87
max	126.00	110.60	27.10	27.50
P10	65.80	61.37	3.47	1.74
P90	100.20	90.06	13.66	13.22

D. Relation between discharge and selected determinand concentration

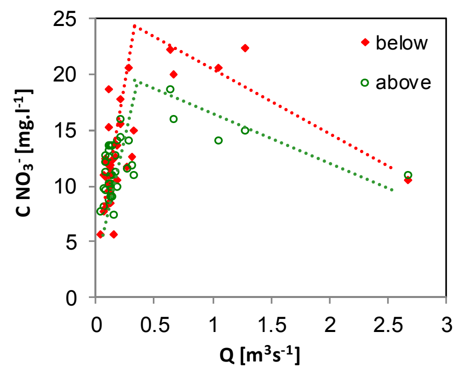
River water quality is typically characterized by significant diurnal, seasonal, and event-driven variations [20]-[23]. There is a variety of the stream pollutant concentration models known from the literature, which are based on empirical relationships [11], time series analysis [24] or hydrological models [25]. These relate concentration C of the polluting substance to a variety of its affecting factors, as e.g.:

$$C = f(Q, T, P, Agr, Veg, F, CP, Cg) \quad (1)$$

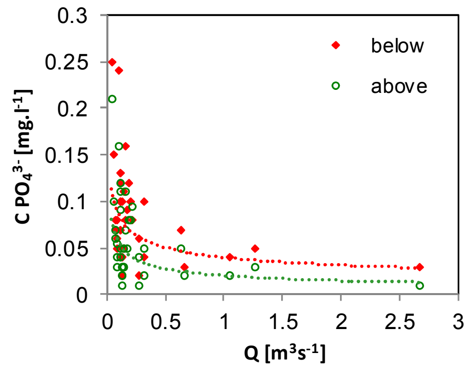
where:
Q - discharge;
T - water temperature;
P - effective precipitation;
Agr - percentage of the land used for agriculture;
Veg - type of vegetation;
F - consumption of the industrial fertilizers;
CP - concentration of substances in precipitation;
Cg - concentration of substances in groundwater.

The main factor influencing the pollutant concentrations in the stream water is discharge – volume of water in the stream. On Fig. 8, there are presented the relationships between mean daily discharge and nitrate (phosphate) concentration in the Gidra stream during 2004–2006 period.

During the increase of discharge up to do 0.5 m^3s^{-1} nitrite concentrations are rapidly increasing, but during the continuing discharge increase the concentrations are diluting. The phosphate concentrations are decreasing with increasing discharge. Figs. 7-8 show that both nitrate and phosphate concentrations are higher below the Pila village. The relations can be used to specify the annual pollutant loads in the stream.



a)



b)

Fig. 8. Relationship between discharge and nitrate concentration (a) and discharge and phosphate concentration (b), the Gidra river, 2004–2006 period.

IV. Conclusions

The Water Framework Directive (WFD) 2000/60/EC of the European Parliament and the Council [26] entered into force in December 2000. The directive gives the framework for the harmonization of the water quality assessment and protection policy. One of the WFD requirements is to evaluate the long-term development of anthropogenic impacts on surface- and groundwater.

The paper presents complex information about field experiments done by IH SAS in the Lesser Carpathians in the Gidra basin. According the expectations, the concentrations of pollutants above the village were lower compared to values below the village. The stream basin above the Pila village can be considered as unpolluted by anthropogenic influences – as the background basin, not only for the Gidra stream, but for all the streams in the region, as well. Also the decrease is interesting of concentrations of selected pollutants during the 10 years. It is necessary to evaluate the annual transport of pollutants in the stream because year 2006 was wet, and years 1992 and 1993 were dry, in opposite. Only on the base of these calculations it will be possible to assess, if the pollution of the stream did reduce.

From the statistical analysis of the selected chemical matters it follows that the pollution of surface water slowly decreases. The high values were found above all for nitrate nitrogen in stream water in 1991–1993.

The most pronounced difference in the pollution above and below the village was observed for electrical conductivity. In the rain water the observed mean conductivity was about 16 μS/cm. In the profile above the village the mean value was 124 μS/cm during the two water years 2004/04–2005/06. Almost twice higher values were observed below the village – 242 μS/cm.

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