Inorganic Constituents in Snow and Surface Runoff from Urbanized Areas in Winter: the Case Study of the City Of Brest, Belarus

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Abstract
Urban surface runoff can carry significant amount of pollutants. Various factors influence surface runoff quality during snow melting periods of winter season (from November to March) in countries with moderately continental climate. In the city of Brest, surface runoff from majority of drainage collectors is emitted directly to the river Muhavets. The aim of this paper is to study snow and snowmelt runoff inorganic constituents on the urbanized territories and to point out components that can present a potential environmental threat on the example of the city of Brest, Belarus.

Keywords
Snowmelt, surface runoff, pollution.

INTRODUCTION

Urban environment is characterized by significant present of impervious surfaces (such as road and pavement covers and roofs), decreased natural sinks and a large number of sources of pollution (Parikh et al., 2005; Carter, 2008). Impervious surfaces alter natural hydrology because they do not permit rain and snowmelt infiltrate into the soil, and thus form significant amount of surface runoff. While the rain surface runoff is a common subject of investigation in many countries, the snowmelt urban runoff has been paid little attention (Buttle et all., 1988). Various factors influence surface runoff quality during snow melting periods of winter season (from November to March) in countries with moderately continental climate: litter and rubbish from streets, soil and pavement erosion, vehicle emissions, aerosols and emissions from industry, winter weather characteristics (periods of snow fall and snow melt, intensity of snow fall, duration of dry periods), road de-icing composites constituents, pattern of street cleaning, salting and snow removal etc. (Суйкова, 2012; Щукин, 2012).

In cities where surface runoff drainage system was designed in the middle of XX century refusing runoff directly to the water streams is a common practice, as for a long time it was considered quite pure. In the city of Brest, surface runoff from majority of drainage collectors is emitted directly to the river Muhavets. Urban surface runoff can carry significant amount of impurities, sometimes comparable to that one of municipal wastewaters (Chouli, 2007), so in modern cities an approach of wasting surface runoff directly to the water streams is not suitable.

The aim of this paper is to study snow and snowmelt runoff inorganic constituents on the urbanized territories and to point out components that can present a potential environmental threat. According to this, concentrations of inorganic ions such as chlorides, phosphates, nitrates and ammonium, some heavy metals (HM) as well as suspended solids (SS) and pH were measured in samples of snow, snow layer along the roadsides, snowmelt runoff and snow from snow landfill sites.

MATERIALS AND METHODS

Three sample points typical for urbanized territories were chosen in the city of Brest for evaluation of inorganic pollutants in snow and snowmelt. Sample point 1 was a street in the downtown area of the city with intensive traffic, a large number of public transport and public institutions. Sample point 2 was the street with mainly residential development and no public transport. Sample point 3 was the street with road junction and a big parking lot in front of supermarket, with less intense public transport then at point 1, and with mainly residential development.

Samples of snow were taken during the snowfall periods in clean plastic vessels; snow was melted and analysed during 24 hours. Samples of snow layer were taken at the same points in clean plastic vessels, discarding the very top of snow layer, melted and analysed the same way that the snow samples. The samples of snowmelt surface runoff were taken in the ends of drainage pipes that carry effluent from target points to the river Muhavets. Samples of snow from snow landfills we taken at two sites where the snow from the city streets is stored. These samples were taken by the same method and analysed the same way as snow layer samples within 24 hours. Sample period was from December 2012 to April 2013.

SS were measured by gravimetric method. Paper filters were weighted in weighing bottles. Then 100 mL of sample (or a less volume diluted to 100 mL) was filtered through the paper filter, filter in the same weighing bottle was dried at 110 °C, cooled to room temperature and weighted again. The contentment of SS was calculated as a difference between two weighings.

Chlorides were measured by titrimetric method with silver nitrate and potassium chromate as an indicator. Heavy metals (Mn, Zn, Fe, Co, Cr) were measured by AAS.

Nitrates, phosphates and ammonium were measured by photometric method. Determination of phosphates is based on the reaction of phosphate-ion with partly reduced hexavalent molybdenum resulting in formation of blue colored complex. Determination of ammonium ions is based on their ability to form yellow-brownish compound with Nessler reagent. Determination of nitrates is based on the reaction of nitrate-ions with sodium salicylate in presence of sulphuric acid, which result in formation of mixture of salts of 3-nitrosalicilyc and 5-nitrosalicilyc acids that have yellow colour in alkali media.

RESULTS AND DISCUSSION

According to the primary results obtained in our study, several components can cause a potential environmental impact. To evaluate the impact for the surface waters all results were compared to the strictest national regulation - maximum permissible concentration (MPC) for the fish breeding waters (Постановление No. 43/42). SS concentrations were compared to the national regulation for urban surface runoff discharges (Технический кодекс 17.06-08-2012 (02120)), because regulation for the fish breeding waters does not limit concentration of SS, but only its maximum permissible increase after waste water discharges.

All tested pollutants were indicated in samples of snow (see Table 1.). Impurities in the precipitation in Belarus have mainly transboundary origin, although reduced nitrogen has basically local origin (Струк, 2002). pH is slightly acidic (average value is 6,57). Phosphates, Zn, Fe and Co concentrations overcome MPC in all tested samples.

In samples of snow cover from the roadsides all tested pollutants (except nitrate ions) overcome MPC, pH is slightly alkaline (see Table 2.). Concentrations of all pollutants were also high in samples of snowmelt runoff (see Table 3.)

Table 1. Results of snow samples analusis.

Sample point	Mean concentrations				MPC
	1	2	3	Overal mean	
SS, mg/L	0	0	0	0	20
pH	6,67	6,3	6,8	6,57	6,5-8,5
Cl^{-}, mg/L	1,93	4,61	23,67	8,83	300
NO_3^{-}, mg/L	0,39	0,48	0,1	0,37	40
PO_4^{3-}, mg/L	1,07	1,26	1,8	1,37	0,2023
NH_4^{+}, mg/L	0,2	0,31	0,27	0,26	0,4736
Mn, mg/L	0,0027	0,0035	0,0054	0,0035	0,01
Zn, mg/L	0,2559	0,9739	0,2955	0,5510	0,01
Fe, mg/L	0,1117	0,1500	0,1243	0,1295	0,1
Co, mg/L	0,027	0,2533	0,0204	0,066	0,01
Cr, mg/L	0,0055	0	0	0,0022	0,005

Table 2. Results of snow layer samples analysis.

Sample point	Mean concentrations				MPC
	1	2	3	Overal mean	
SS, mg/L	8874	8923	3058	6948	20
pH	7,41	7,48	7,35	7,41	6,5-8,5
Cl^{-}, mg/L	2453,68	4416,52	2671,87	2992,53	300
NO_3^{-}, mg/L	0,44	0,51	0,47	0,47	40
PO_4^{3-}, mg/L	2,24	1,68	1,75	1,92	0,2023
NH_4^{+}, mg/L	0,91	1,15	0,83	0,93	0,4736
Mn, mg/L	0,046	0,1068	0,0703	0,0744	0,01
Zn, mg/L	0,3310	0,813	0,1998	0,4479	0,01
Fe, mg/L	0,1309	0,1773	0,1253	0,1445	0,1
Co, mg/L	0,1307	0,02	0,0308	0,0603	0,01
Cr, mg/L	0,0305	0,0327	0,0103	0,0245	0,005

Table 3. Results of snowmelt runoff analysis.

Sample point	Mean concentrations				MPC
	1	2	3	Overal mean	
SS, mg/L	2860	348	140	1266	20
pH	7,9	7,68	7,57	7,73	6,5-8,5
Cl^-, mg/L	4379,72	2741,55	504,17	2881,42	300
NO_3^-, mg/L	1,58	2,89	1,26	2,07	40
PO_4^{3-}, mg/L	2,02	3,25	2,78	2,68	0,2023
NH_4^+, mg/L	1,14	1,07	1,09	1,1	0,4736
Mn, mg/L	0,2092	0,1861	0,1572	0,1919	0,01
Zn, mg/L	0,2905	0,3024	0,3418	0,3029	0,01
Fe, mg/L	0,2194	0,485	0,2742	0,3410	0,1
Co, mg/L	0,0262	0,0103	0,0283	0,0197	0,01
Cr, mg/L	0,0383	0,0005	0	0,0147	0,005

Analysis of samples of snow from the snow landfills sites showed that it has lower content of pollutants than snow layer from roadsides and snowmelt runoff (except SS concentrations). This can be explained by the climate characteristics: in Brest typical winter weather is presented by successive periods of cold (below zero) and warm (above zero) periods, thus snow at landfill sites undergoes continuous periods of melting and freezing. During such periods of melting and freezing self-purification process in the landfill snowdrifts takes place, and the burden of pollutants is washed with melted water. SS are not soluble and on the contrary are accumulated in snowdrifts, because SS particles most probably are to coarse to penetrate inside snow pores, so the content of SS is much higher then in roadsides snow layer or runoff. Snow landfill sites have significant potential for ground water contamination. Kinetics of the process and impact on ground waters of each site should be further studied.

SS and chloride ions are the prior pollutants both in snow from the snow layer and snowmelt runoff. This is due to the de-icing of streets and roads, which is accomplished with reagents containing sand and sodium chloride mixture. Average concentrations of SS and chlorides are several times bigger than MPC values. Concentrations of SS and chlorides most probably depend on the street cleaning and icing pattern and snow removal frequency. Highest concentrations of SS and chlorides in samples of snowmelt runoff were obtained from sample point 1, with most intensive traffic and public transport and most intensive solting and snow removal, because all applied reagents are readily washed by the snowmelt under such conditions. Highest concentrations of SS and chlorides in samples of snow layer were obtained from sample point 2 with most rare snow removal schedule. SS concentration in snowmelt runoff is lower than in snow layer samples, because substantial percent of SS (with more coarse particles) retain on the roads and pavements during the snow melting periods (see Figure 1.). The same explanation should be probably used for the small decrease in chloride ions concentration in runoff comparing to snow layer, which are apparently absorbed by SS. Remained SS present potential contamination threat for the river waters, as they can be washed to the receiving waters by surface runoff during later storm events. Moreover, suspended solids can absorb pollutants on their surface and then release them after getting to receiving water stream and cause long-term pollution effects. Elevated SS levels alter natural sedimentation processes in water streams, and can result in depletion of dissolved oxygen and bental aerobic microorganisms inhibition (Суйкова, 2012). Chloride ions are natural components of surface waters, but continuous discharge of wastes with high chloride concentrations can increase the total water salinity, thus making it not suitable environment for many limnetic organisms and not usable for potable supply.

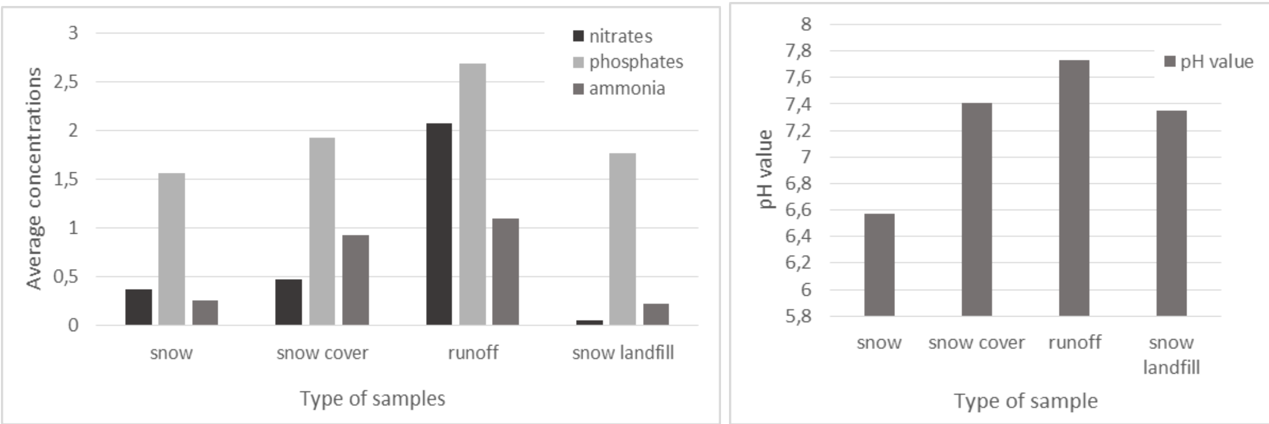
Figure 1. Retained solids on roads and pavements after snow melting, Brest, Belarus.

pH values do not cross any national regulation values (except snow at sample point 2) and change from slightly acidic in precipitation to slightly alkaline in snowmelt runoff, which can be due to contact with concrete pavement covers, buildings and road constructions and solubilisation of alkaline components.

Ammonium and phosphate ions average concentration in snow layer and snowmelt runoff also exceed MPC values. Discharge of the effluent with elevated level of nutrients (e.g. ammonium and phosphates) can contribute to eutrophication effects in r. Muhavets. According to the long-term observation data, water in r. Muhavets is characterised by continuous contamination with phosphates, nitrites and ammonia, and thus surface runoff contributes to the total pollution with the components of main concern (Логинов, 2009, 2010, 2011, 2012).

Concentration of several components follow similar variation increasing from snow to snow layer and to snowmelt runoff samples and decreasing in samples of snow from snow landfill sites (see Figure 2.). As concentrations of nitrate, phosphate and ammonium ions constantly increase from snow to snow layer and snowmelt runoff samples, this impurities are not only washed from atmosphere with precipitation, but accumulated in snow layer and snowmelt surface runoff during its formation.

The main sources of HM pollution in Brest are vehicle emissions, abrasion and corrosion of vehicle parts (Mn, Zn, Co and Cr are often used as alloying elements to steel, Mn and Fe can be used as fuel additives), as the city of Brest has no big industries that can emit heavy metals (Щукин,2012). The capability of HM ions to absorb readily on SS particles can very likely explain the decrease in concentrations of some metals (Zn, Co) in runoff samples comparing to snow layer, as they are absorbed and retained on the roads with coarse SS particles. The distribution and fate of HM in snow and snowmelt runoff should be further studied.



A B

Figure 2. Variation of concentrations of some pollutants (A) and pH values (B) with type of sample.

CONCLUSIONS

The surface runoff formed during snow melting periods carries a significant burden of pollutants which excide national regulation levels and thus can cause long-term environmental effects on water streams, if the runoff is drained into the water body without treatment. In Brest a significant percent of surface runoff is drained to the r. Muhavets with ought treatment and falls with river waters into Western Bug, which is a transboundary river and thus surface runoff from Brest city territory can contribute to transboundary element transport. The pollutants of the primary concern during winter period are SS, chloride ions, phosphates and ammonium.

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