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THE SUSTAINABLE DEVELOPMENT ASSESSMENT OF DRINKING WATER SUPPLY SYSTEM

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Abstract. Drinking water distribution system takes a significant place in sustainable urban development. In order to solve some environmental issues it is necessary to improve the maintenance of the environmental impact of chemical compounds which can come in contact with water. The aim of the research is to complete the analysis of the sustainable development of drinking water pipelines in Lithuania as well as to structure the chemical content of pipelines for further increase of supplied water quality and simplification of maintenance. Analytical and descriptive methods were used in the research process. The investigation included 150 samples that were obtained in different water stagnation times in lab-scaled pipelines. During the research the following indicators were set: total iron, manganese, ammonium ions, nitrate and nitrite concentrations, turbidity and chemical oxygen demand (COD_{Cr}). To ensure sustainability of drinking water distribution system in the end of this research the appliance of a certain model of actions was considered. This model says that material of potable water network must be chosen depending on water chemical indicators, water reaction with pipeline material and scale formation causes. Consequently, to reduce a negative effect of chemical processes on the drinking water supply measures of sustainable ecological development have to be taken.

Keywords: sustainable development, drinking water, water supply, pipeline material, water quality indicators.

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JEL Classification: Q01, Q25, Q53.

1. Introduction

The safety and quality of drinking water standards in Lithuania are established by the Lithuanian Hygienic Norm HN24:2003 "Drinking water safety and quality requirements" and are based on European Drinking Water Directive 98/83/EB. In Lithuania all drinking water is supplied from groundwater sources, so basically it is of good quality and does not require complicated water treatment technologies. Some water quality changes may occur in water supply network. These negative changes are caused by residual concentration of disinfectant and water interaction with organic and inorganic compounds. The pipeline's scale is easily dislodged by flowing water (Tang *et al.* 2006). Scale may form because of physical, chemical and biological processes in the drinking water distribution network (Verberk *et al.* 2009). The formation of scale is strongly affected by the pipeline's material (Cerrato *et al.* 2006). Different content of relevant elements can be obtained in different pipelines (plastic, cast iron or steel) (Tang *et al.* 2006; Gerke *et al.* 2008). Water quality also has influence on scale formation (Gerke *et al.* 2008). Scale that form on inner pipeline's walls may affect the organoleptic indicators' changes (Echeverria *et al.* 2009). For example, if water stays in cast iron or steel pipelines for a definite time like 125 hours, it can reach high turbidity level (Nawrocki *et al.* 2010).

One of the main causes of scale formation is the corrosion of steel and iron pipelines (Agatemor, Okolo 2008). The most intensive corrosion of metallic pipes occurs during the first few years, later it decreases (Sarin *et al.* 2004). Corrosion activity depends on water temperature, pH, alkalinity, dissolved oxygen concentration, and water flow circulation rate (Tang *et al.* 2006; Gerke *et al.* 2008; McNeill, Edwards 2002; Nawrocki *et al.* 2010). The key factor of corrosion activity is dissolved oxygen concentration. By increasing the dissolved oxygen concentration, the corrosion rate also increases. If water pH is higher than 8, then the rate of the corrosion process will increase. The influence of water temperature on the corrosion rate is ambiguous. If the corrosion rate's limiting factor is oxygen diffusion, then in higher temperature oxygen diffusion and convection increase and this leads to an increase of corrosion rate (Gerke *et al.* 2008; McNeill, Edwards 2002; Nawrocki *et al.* 2010).

In some cases it is possible to find microorganisms in drinking water networks that stay active even after disinfection (Lehtola *et al.* 2005; Langmark *et al.* 2005). Many of these microorganisms may also become attached to inner pipe walls and form thin 10 till 30 μm biofilm (Bonadonna *et al.* 2009; Srinivasan *et al.* 2008). Biofilm is formed by heterotrophic bacteria, fungi, protozoas, threadworms and crustaceans, pathogenic bacteria and even viruses e.g. enterovirus or adenovirus may also develop in biofilm (Berry *et al.* 2006). The formation of biofilm on inner water pipeline's walls is strongly related to pipeline material physical characteristics such as surface roughness (Ramirez *et al.* 2009).

The object of this research is developed from the need to analyze the impact of materials used for pipelines on water quality in order to suggest a model that corresponds to sustainable development requirements.

The aim of the research is to complete an analysis of the sustainable development of water supply pipelines that were inappropriate because of decreased water quality in urban areas of Lithuania, as well as structuring of the chemical content of pipelines for further increase of supplied water quality.

The following tasks were set and completed during the investigation:

1. Analysis of the chemical impact of pipelines' materials on water quality;
2. Analysis of water quality changes by defining pipelines material in order to insure sustainable water supply network development.

The main hypothesis is defined as follows: materials of the drinking water supply network in urban regions do not correspond to sustainable development requirements.

Specific hypotheses are:

1. Depending on the pipeline's materials there is an occurrence of negative water quality changes in water supply networks and water users taps;
2. Pipelines made from plastic materials are more sustainable following possible impact on water quality than pipelines from metallic materials.

2. Evaluation of the existing situation in Lithuania

The main part of Lithuania's water network is based on cast iron pipelines, which compose of approximately 80% of all urban water networks. Eight different Lithuanian towns were analyzed (Fig. 1): Zarasai, Šilutė, Kupiškis, Kaunas, Druskininkai, Visaginas, Klaipėda and Nida.

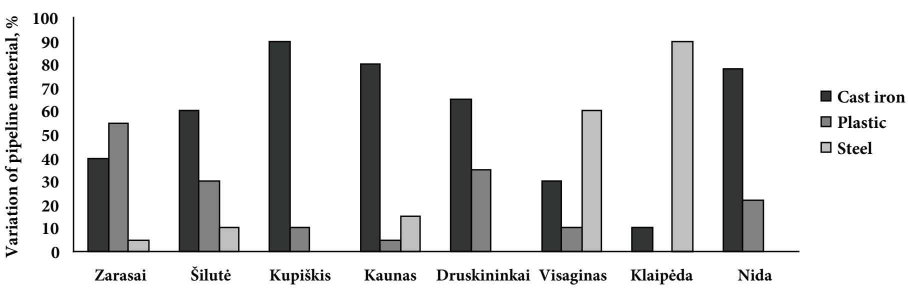

Fig. 1. Different use of pipeline materials for drinking water supply of Lithuanian towns

The dominant pipeline material is cast iron and takes approximately 56.6% of all analyzed drinking water distribution pipelines material; then twice less of steel – 22.5% and plastic – 20.7%. The same tendency is found in all Lithuanian water supply systems (Valentukeviciene *et al.* 2009).

Depending on the pipeline's material there is an occurrence of negative water quality changes in water supply networks. The main places where water changed its quality were: main water supply pipelines, "dead-end" points and user's taps. This shows that main water quality changing factors were: water interaction with the pipelines material and water stagnation time in pipelines. These factors led to increased total iron, ammonium ions and manganese concentrations. Table 1 shows existing situation of water supply distribution network in Lithuanian urban areas.

Table 1. Existing situation of water supply distribution network in different Lithuanian urban areas

Name of the town	Pipelines materials percentage of total length (%)			Negative water quality changes points	Indicators increased
	cast iron	steel	plastic (PE)		
Zarasai	40	5	55	Main water pipelines end points	Total iron
Šilutė	60	10	30	User taps	Total iron, Ammonium
Kupiškis	90	–	10	User taps	Ammonium
Kaunas	80	15	5	Main water pipelines end points	Total iron, Ammonium, Manganese
Druskininkai	65	–	35	Main water pipelines end points, User taps	Total iron
Visaginas	30	60	10	Main water pipelines end points	Turbidity
Klaipėda	10	90	–	User taps	Manganese, Nitrite
Nida	78	–	22	User taps	Total iron, Manganese

In almost all cases the water was prepared in water treatment plants, with removal of exceed total iron and manganese concentrations. Only in Šilutė water was distributed for consumers without treatment. In almost all groundwater treatment cases in Lithuania, total iron and manganese concentrations are typical components that need to be decreased (Ljung, Wahter 2007; Santamaria 2008; Tang *et al.* 2006). High nitrites concentrations can have negative influence on water user's health conditions (Gladwin *et al*. 2004; Rivett *et al*. 2008). These examples describe the water quality and the water network situation all over Lithuania.

Table 2. The analysis of sustainable development of water supply in urban areas of Lithuania

Water quality indicators	Total iron, Ammonium, Manganese, Turbidity	Total iron, Ammonium, Manganese, Nitrite	Total iron
Places of water quality changes	Main water pipelines end points	User taps	Main water pipelines end points and user taps
Water quality changes percentage of total water supply, %	43	43	14

Reviewing the above presented facts that show the existing situation of water distribution network of Lithuanian urban areas the main hypothesis of the research is confirmed. It says that materials of the drinking water supply network in urban regions do not correspond to sustainable development requirements, when water supply, instead of providing acceptable quality of essential drinking water, changes its primary indicators to the unacceptable values (Table 2). For example, in those described towns where the main part of water distribution network pipelines was made of cast iron, increased total iron concentration was detected.

Changes were observed in both places: at the users' taps and at the main water pipelines end points. These numbers illustrate how water changes its quality by the time when it gets from water treatment plant to the consumer (Verberk *et al.* 2009).

3. Water analysis approach and research methodology

In this investigation analytical and descriptive methods were used. The lab-scaled pipelines that were specially designed for the purpose of this research were the research instruments. Techniques of research were: field investigation, action investigation and combined techniques. The experimental pipeline's system was made from different material pipes and included: new galvanized steel pipe, 25-year-old steel pipe and polyethylene (PE) pipe. In certain experimental pipeline the system was provided with permanent water circulation. Water circulation rate was 0.3 m/s. Imitation of night regime, when water is standing still, was also provided in a certain experimental model.

The investigation included 150 samples that were obtained in different water stagnation times in pipelines, three pipelines of which had treated water quality and 3 pipelines had raw groundwater quality. Treated water was prepared from the ground water of Antaviliai (Vilnius, Lithuania) water treatment plant. Water and scale samples were taken from the system right after the night regime. The following indicators were set for the water quality and scale content: total iron, manganese, ammonium ions, nitrate and nitrite concentrations, turbidity and chemical oxygen demand (COD_{Cr}). All soft scale materials were analyzed following the procedures applied for diluted samples. Comparative approach has been taken into account when lab-scaled experiment was carried out. The results from the experimental investigation were statistically estimated from the registered analyses. The average concentration at the typical point was calculated from three measured values of one sample.

Collected water samples were then analyzed at International Standards (ISO) and/or European Norms (EN) approved methods for determination of water quality indicators and toxic parameters.

The quantitative results are presented as the arithmetic mean of six independent measurements (x±SD, n = 6). Significant differences ($p < 0.05$) were removed from the result estimations and the measurements were analyzed once again. The data from the experimental investigation were statistically calculated from the registered analyses. The concentration of substances (Fe, Mn and NH4+) was measured 11 times in raw water, in sampling taps and in treated water. The average concentration at typical points was:

$$\overline{c} = \frac{1}{n}\sum_{i=1}^{k} c_i m_i \ . \tag{1}$$

Where: c_i – concentration of substances at typical points; m_i – probability at the occurrence of concentration; n – number of days; k – number of different values of the concentration.

The average concentrations of substances, mentioned above, at the characteristic point were also calculated. The standard statistical estimation error of the arithmetic average was approximately 11%.

3.1. Laboratory scaled pilot equipment

Laboratory scaled pilot equipment was located in the laboratory of Vilnius Gediminas Technical University (Lithuania). The pipeline at the laboratory is a metallic or plastic till and the taps mainly used for sampling and control procedures. Treated water dominates the drinking water supply. The inside pipelines layer consist of PE (plastic pipes), corrosion layer (25 years old steel pipes), zinc layer (new galvanized pipes). Those three layers are very common for Lithuanian drinking water supply. For further details about the water quality see Table 3. Seven sampling taps (by the end of each pipe) were established 1.5 m apart within those pipelines, in a diameter of 15 mm. The dominate water flow velocity was 0.3 m/s and water stagnation was 9 h on night time.

Pipes sections were designed and constructed for three materials (plastic, 25-year-old steel, new galvanized steel) with an additional pipe section of plastic to serve as control. These systems helped to determine the variation of water quality, sediments growth, and formation of scaling on the pipe surface. Also, these sections allowed obtaining similar conditions to a water distribution system. Each system consisted of a 1.5 m long and 0.015 m inside diameter pipeline, which was connected at both ends with plastic pipeline to form a closed pipe section. Each section operated at two different conditions; at flow-through during 7 days in order to provide real operation condition of a distribution system and at recirculation-flow during each night in order to provide a longer retention time and to increase water-pipe wall interaction; the latter flow condition will allow a more clear evaluation of variations in water parameters. The adequacy of the system to operate in any configuration was accomplished through a series of valves. Each system had a pump, flow meter, sampling valve and a set of valves to adjust the operation of the system.

3.2. Sampling of water and sediments

Samples of water and pipelines sediments were collected from the 7 sampling sections in September-June 2009–2010. Four replicate water samples were collected from each section and directly from sampling taps within each of 7 sections. After the removal of junctions and valves, sediments scratches were taken to a depth of 1.5 m using a cylindrical steel tube with 12 mm diameter softly adjusted to the pipeline inside wall. These sediments samples were diluted with distillated water till 20 ml in the laboratory into separate flasks and stored in hermetically safe conditions at 4 ^{o}C until processed.

Water samples of the 7 different sampling taps collected were filtered of any suspended material, identified to sediments level in the laboratory and the fresh water sample was analyzed for determination of manganese, total iron, ammonium ions, nitrates and nitrites concentrations (see below). The samples were then analyzed at International Standards (ISO) and/or European Norms (EN) approved conditions for determination of water quality and sediments suspended solids. Solutions of sediments samples taken from pipelines inside walls were also used for chemical analyses.

The sediment samples (20 ml) were also diluted using the method described by determination instruction manuals for each indicator.

3.3. Chemical analyses

A water quality analyses were made and certain technological parameters were determined for the control and evaluation of water quality changes processes using international standard methods: manganese concentration, mg/L; total iron concentration, mg/L; ammonium ions concentrations, mg/L; nitrates and nitrites concentrations, mg/L; and other relevant parameters (e.g. pH, Chemical Oxygen Demands). Raw water samples were analyzed in the laboratory of drinking water, a department within the "Vilniaus vandenys", UAB, Vilnius (Lithuania). The analyses were accompanied by fast quality control measures by "MERCK-SYSTEM" quick tests. In case of any significant differences all samples were analyzed once or twice again.

Suspended solids from pipelines sediments samples were analyzed using International Standard method, including samples preparation procedures and heating till constant weight.

3.4. Statistical analyses

The quantitative results are presented as the arithmetic means of six independent measurements. Significant differences were removed from the estimation of results and the measurements were analyzed once again. The concentrations of the above mentioned substances were measured 11 times in raw water, treated water, in sampling taps and in the water storage reservoirs. The average concentrations at typical points were estimated. The standard statistical estimation error of the arithmetic average was approximately 11%.

The dependencies between different compounds concentrations and water quality indicators in different pipes were find out after statistical analyses using Mathcad 2001Professional software.

4. Results and discussion

The research carried out at lab-scaled pipelines shows: minimal total iron concentration was observed in plastic pipes, it was 0.13–0.38 mg/l. Manganese concentration was minimal in galvanized steel pipes 0.12–2.10 mg/l and after 295 hours manganese concentration began to decline further. Fluctuation of ammonium ions and nitrate concentration increased in all pipelines (plastic, galvanized steel and old steel pipes), when concentrations of nitrite were decreased in all pipes.

The determined ammonium ions concentrations (C_{AMMON}) in the treated water of the 25-year-old steel pipes operated with 12 h retention time are presented in dependency to nitrite concentrations ($C_{NITRITE}$) and can be estimated following 2nd equation.

$$C_{AMMON} = 3855 \cdot C^{3}_{NITRITE} - 450 \cdot C^{2}_{NITRITE} - 1.285 \cdot C_{NITRITE} + 0.96. \tag{2}$$

Measured nitrogen compounds did not exceed European Drinking Water Directive requirements (Table 3). The amount of particular components shown in Table 3 relates to the water enriched with dislodged from pipe scale.

Table 3. Results of experimental research

Water quality indicators	Initial water quality indicators	Indicating values depending on pipeline material		
		Plastic pipes (PE)	Galvanized steel pipes	Old steel pipes
Total iron concentration, mg/L	0.09–0.10	0.13–0.38	0.10–0.50	2.39–4.81
Manganese concentration, mg/L	0.02–0.05	0.18–0.85	0.06–0.79	0.12–2.10 mg/l
COD_{Cr}, mgO_2 /L	10–12	41–120	73–175	40–176
Fluctuation of manganese concentration in pipes	0.02–0.05	increase up to 1.35	no abnormal changes	decrease after 295 h

Total iron concentration and COD_{Cr} were minimal in PE pipes, when manganese concentration was minimal in galvanized steel pipes. In case of old steel pipes total iron and manganese concentrations were exceed EU Directive 98/83/EB requirements. Finally, it was found that there is no unique pipeline material that insures sustainability of water distribution network in all cases.

However, in order to satisfy consumer needs it is very important not only to choose suitable water treatment technology, but also, depending on water features, to choose suitable materials for water distribution network.

In conclusion of this research it was considered that the following model of actions must be applied:

1. Material of water network must be chosen depending on the quality of the drinking water.
2. If water contains manganese, it is inadvisable to use plastic pipes and it is better to choose a different metallic material for the water pipelines. During the research it was found that pipelines from plastic influenced the manganese concentration increase in the water network. Water also becomes black colored and is inappropriate to use for drinking purposes. These changes can be explained in the following way: plastic material is not polar and electron exchange with manganese is not possible, thus the manganese sticks to the inner pipe walls and form sediments. Pressure caused by the water flow between water and the pipeline wall increase the manganese emission from the sediments. Meanwhile, cast iron pipe internal surface has lots of electrons, which can be exchanged with manganese. Manganese concentration may also increase because of water stagnation in the pipes.
3. If water contains enlarged total iron concentration, it is better to use plastic pipes. This engineering solution helps to avoid corrosion process that creates adverse conditions in water network. Otherwise water can become turbid, brown colored and eventually unsuitable for drinking purposes.
4. If there is a possibility of microorganism occurrence and biofilm formation in the water network, it is better to use pipeline material that does not provide any opportunity for microorganisms to attach to the pipe wall. In this case it is needed to choose pipeline

material with smaller wall roughness, to avoid suitable conditions for microorganisms to develop. For this purpose it is recommended to use plastic material.

5. The necessity to proceed the EIA (Environmental Impact Assessment) is obvious in all cases of pipelines materials selection in order to be sure which option is really in accordance to the idea of sustainability.

Therefore, if environmental engineers wish to carry out all sustainable development requirements in each case they need to choose pipeline material that is most suitable for distributing water, depending on water quality indicators. If water network will be designed on the basis of sustainable development policy following positive changes will be achieved: less water reaction with pipelines, less water quality changes, more consumers satisfied with water quality, longer pipeline exploitation period, more sustainable usage of natural resources and water network development in urban areas. General compliance to sustainable development policy shows how suggested model of actions helps to provide more sustainable engineering solutions (Table 4).

Table 4. Compliance to sustainable development policy

Less	More
Water reaction with pipelines	Good quality water for drinking purposes
Sediment and biofilm formation	Pipeline water throughput
Water quality changes	Consumers satisfied with water quality
Spending money on water network rehabilitation	Longer pipeline exploitation period
Sustainable use of ground water resources	
Sustainable use of natural resources for pipeline material	
Sustainable water network development	

Nowadays when the environmental issues become crucial, researchers of all fields have to work hand by hand and water engineers are no exceptions (Baltrėnas, Kazlauskienė 2009; Ginevičius, Podvezko 2009; Sakalauskas, Zavadskas 2009), when the main research fields are operation research and sustainable development (Zavadskas, Turskis 2011). Urban utilities builders should take greater account of the environmental requirements during teritory planning procedures (Ustinovichius *et al.* 2011). It is essential to take into consideration that the technological intensity of products reduces energy consumption, which is related to restructuring of energy intensive industries into more advanced and energy saving ones with higher value added per unit of product, but with lower energy consumption per unit of product (Bojnec, Papler 2011). To make it more efficient, the modernization of apartment houses must be integrated – an entire block or residential area must be renovated and the principles of sustainable development must be followed (Raslanas *et al.* 2011).

Insurance of sustainability of water distribution network design and construction is leading to complex solutions on simplification issue.

5. Conclusions

Certain investigation was provided to study water quality changes depending on different pipelines material. Relevance of the topic arose from the sustainable condition of drinking water network in Lithuanian urban areas. During the research there was a review of existing situation of drinking water network in some typical towns of Lithuania and percentage repartition of pipeline material was defined. Carrying out the studies it was determinate causes of water quality changes and detected typical water network places where water changed its quality. All the results of experimental analysis are given in sustainable development point of view. When the results were estimated to insure sustainability of drinking water network a certain model of actions was suggested. This model of actions helps to structure the chemical content of pipeline material for further increase of supplied water quality and simplification of maintenance.

By taking a general view of the results of this research it can be affirmed that there is no unique pipeline material that insures sustainability of water distribution network in all cases. For this reason environmental engineers must take more responsibility in design of water distribution network. With the purpose to choose the most suitable pipeline material it is important to change a present-day attitude towards technologies to a more sustainable point of view. By choosing the best equipment for drinking water networks, it is important to follow a sustainable development policy: to evaluate the life quality of inhabitants and their water supply network's life cycle. Additional knowledge of these above mentioned facts would improve the sustainable development of urban water supplies, and also develop the correct attitude towards a globally sustainable living environment.

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GERIAMOJO VANDENS TIEKIMO SISTEMOS DARNAUS VYSTYMO VERTINIMAS

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Santrauka. Geriamojo vandens tiekimo sistema yra labai svarbus darnios miesto plėtros objektas. Siekiant išspręsti tam tikras aplinkosaugos problemas, būtina padidinti cheminių junginių, kurie gali kontaktuoti su vandeniu, kontrolę, taip užtikrinant tinkamą poveikio aplinkai priežiūrą. Šio mokslinio tyrimo tikslas – atlikti geriamojo vandens vamzdyno Lietuvoje analizę darnaus vystymosi aspektu, struktūrizuoti cheminę vamzdynų sudėtį, siekiant pagerinti tiekiamo vandens kokybę ir supaprastinti tolesnę vandentiekio vamzdynų priežiūrą. Mokslinio darbo metu buvo taikomi analitiniai ir eksperimentiniai tyrimo metodai. Buvo ištirta 150 mėginių, paimtų iš laboratorijoje sukonstruoto vamzdyno. Mėginiai tirti atsižvelgiant į vandens išbuvimo vamzdyne trukmę. Tyrimo metu buvo nustatomi šie cheminiai indikatoriai: bendroji geležis, mangano koncentracija, amonio jonų kiekis, nitritų ir nitratų koncentracijos, drumstumas ir cheminis deguonies suvartojimas ($ChDS_{Cr}$). Siekiant užtikrinti geriamojo vandens tiekimo sistemos tvarumą, tyrimo pabaigoje buvo pasiūlytas tam tikras veiksmų modelis. Jis rodo, kad vandentiekio vamzdynų medžiaga turi būti parinkta pagal tiekiamo vandens cheminius indikatorius, vandens sąveikos su vamzdyno medžiaga ir nuosėdų formavimosi priežastis. Todėl būtina imtis darnaus vystymo priemonių, mažinant neigiamą cheminių procesų įtaką tiekiamo vandens kokybei.

Reikšminiai žodžiai: darnus vystymas, geriamasis vanduo, vandens tiekimas, vamzdyno medžiaga, vandens kokybės indikatoriai.

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