Measurements of the quality of rainwater run-off and its potential for savings of potable water in TUKE campus

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Abstract: Rainwater harvesting is significant nowadays because in our conditions we face unsustainability in water management in general and there are also many countries around the world being confronted by new approaches and changes. The main objective of this article is to evaluate the potential for potable water savings by using rainwater in buildings of TUKE campus for the planned concept of rainwater management for TUKE campus, measurements and evaluation of volume of incoming rainwater from the roof of the actual building PK6 and also information about the quality of rain water from this building located at the TUKE (Technical University of Kosice) campus site.

Key-Words: potable water, rainwater harvesting, rainwater harvested from surface runoff, quality of water

1 Introduction

There are at least two very important facts which need to be considered when dealing with the SWM. It is increasingly changing climate, resulting in short term but more intensive precipitation in one hand and increasing droughts in some countries in the other. The second fact is increasing urbanization over the last years which has changed the natural water processes and increased the urban runoff significantly. These facts have influenced urban drainage and it is assumed that they will influence it even more in the future.

There are several definitions of stormwater management regarding different approaches. According to Marsalek and Chocat (2002), stormwater management is a process employing various non-structural and structural measures to control stormwater runoff with respect to its quantity and quality [1].

Prior to development, stormwater is a small component of the annual water balance. However, as development increases, the paving of pervious surfaces with new roads, shopping centres, driveways and rooftops all adds up to mean less water soaks into the ground and more water runs off. Overall, urban drainage presents a classic set of modern environmental challenges: the need for cost-effective and socially acceptable technical improvements in existing systems, the need for assessment of the impact of those systems, and the need to search for sustainable solutions. [2].

Combination of rainwater harvesting and infiltration system should provide sustainability in stormwater management especially for new industrial developments. Rain and stormwater as an additional sustainable water supply should provide water consumption conservation and in combination with infiltration should be effective stormwater management source control solution.

RWH technique creates more added values than any other stormwater management measure. It supports sustainable water use, helps to conserve potable water consumption and contributes to the integrated water cycle as well [4].

When we know what affect water in general, we can understand the importance of conserving water and helping to protect it from pollutants [8,9]. It is even more important when we realise that demand is continuously increasing also because of urbanization and development. It is up to us therefore to ensure that the Water Framework Directive is implemented effectively, that there is enough water for future generations and that this water meets high quality standards [3].

This article contributes to the theme of reuse of rainwater for buildings captured from their rooftops and its quality as a source of water. The aim of this article is to analyze the possible use of rainwater in the actual school building and potential for potable water savings through replacing by rainwater for all buildings at the TUKE (Technical University of Kosice) campus site. This article also describes the

experimental evaluation of the effect of roofing material affecting the quality and quantity of the amount of rainwater collected and stored in the Kosice city area. The source of this data was an actual school building (PK6 building) at the TUKE campus site.
The rainwater quantity and quality measurements taken from the PK6 building roof show a big potential for potable water savings through replacing by rainwater and also demonstrate that the rainwater meets quality standards for the purposes of collection, storage and re-use, as well as for the purposes of rainwater infiltration in Košice area.

2 TUKE campus – current situation

Figure 1 shows the average daily consumption of water of a household - 150 l/person per day. It shows that about 60% of potable water may be replaced by rainwater.

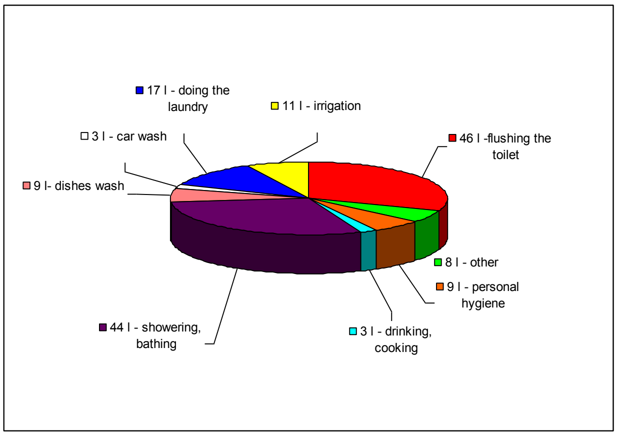

Fig. 1 average water consumption of a household (average consumption 150 l/(person per day))

In the case of school-type buildings potential of water savings replaced by rainwater is significantly higher. It result from absent purposes as showering, bathing (30%), laundry, etc., so the most volume of potable water is consumed for flushing toilets.

Figure 2 represents view of the Technical University of Kosice campus site in Kosice-city. Blue rectangles indicate school buildings for all faculties of Technical University of Kosice. These buildings have a classical drainage system for rainwater runoff consist from traditional direct channelling of surface water through networks of pipes to sewer system.

Fig. 2 TUKE campus

But there are two buildings – PK6 and PK5 which have a drainage system for rainwater runoff designed through an infiltration facilities – infiltration shafts. Measured real volumes from PK6 building are shown in chapter IV.

3 TUKE campus - planned situation - potential savings of potable water by the use of rainwater in tuke campus

A planned situation of rainwater management in TUKE campus consider about replacing of traditional rainwater drainage into the sewage system by the use of rainwater in the school buildings. All of school buildings respectively the roofs of these buildings in TUKE campus (figure 2) represent a potential source of rainwater for non-potable purposes especially for flushing toilets [17].

The rooftop area of school buildings (table 1) determine maximum volume of rainwater possible to capture and accumulate.

Determination of the theoretical volume of rainwater from the catchment area can be determined by the equation:

$$V_{rain} = z_{year}.A.C \quad (1)$$

Where:
V_{rain} – theoretical volume of rainwater

z_{year} – average precipitation depth for chosen locality (mm),
A – roof or another catchment area (m^2),
C – runoff coefficient (non–dimensional coefficient).

Tab. 1 roof areas of buildings in TUKE campus

Building	Roof area (m^2)
BN3	1766
BN5	1511
L9	6091
PK10	1615
PK2	1003
PK3	407
PK4	563
PK5	425
PK6	548
PK7	777
PK8	746
PK9	489
PK11	1506
PK12	1640
PK13	841
PK14	2572
PK15	854
PK17	497
PK19	3591
UK	1946
V4	3453
W4	1525

For the determination of theoretical volume of rainwater we need also data of rainfall intensity. The resource that provide us information about the rainfall intensity is rain gauge and is located on the roof of University Library.

Rain gauge is joined with its own concrete foundation using a steel rod. Flat roof helped us fixing the rain gauge into horizontal position which is the first condition for receiving correct data. We use recording heated rain gauge for all year round measuring. There are known unheated rain gauges as well used for limited part of year when the temperatures aren't so low. Heated rain gauge is used for measuring liquid precipitation (rain) and solid precipitation (snow) as well. Rain gauge is made of stainless material. Rain gauge's round catchment area is 200 cm2 and its function is based on tipping bucket mechanism. Tipping bucket is located inside the rain gauge body right under the funnel outlet. Rain or snow fall down the funnel outlet into the divided bucket. The bucket does not move until it is filled with calibrated 0.2 mm amount of water, then it tips and second half of bucket can be filled with rain water. When the bucket tips it empties the liquid from the half of the bucket into a drainage hole. Tipping bucket is made of plastic with very thin layer of titanium and it is hanged on stainless steel axial holder. Tipping continues according to the length of rainfall (figure 3) [12].

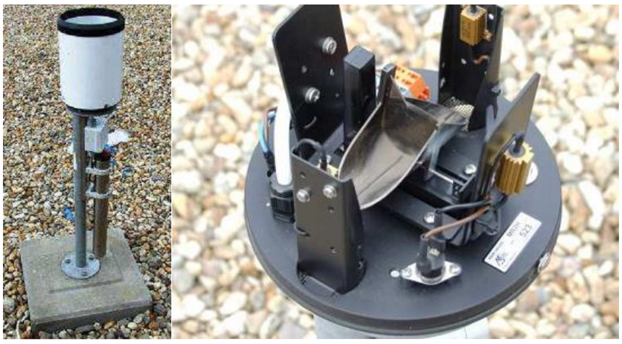

Fig. 3 rain gauge

Figure 4 represent the measured monthly rainfall totals during our research. Data are presented for the period August 2011 to December 2014.

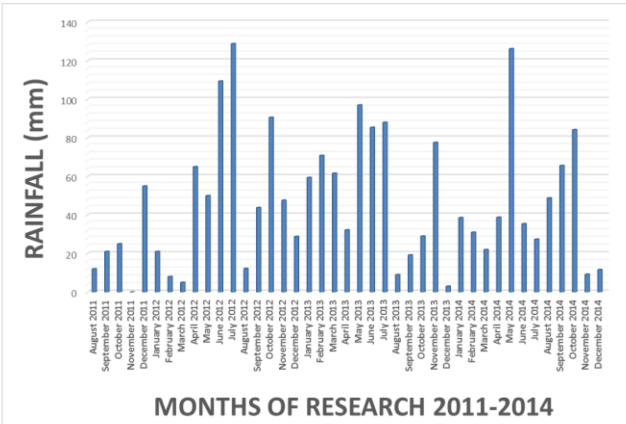

Fig. 4 measured values of rainfall during our research August 2011-December 2014

According our measurements of monthly rainfall totals, figure 5 represent theoretical monthly volumes of collected rainwater from roof areas of buildings in TUKE campus. Data are presented for the period August 2011 to December 2014.

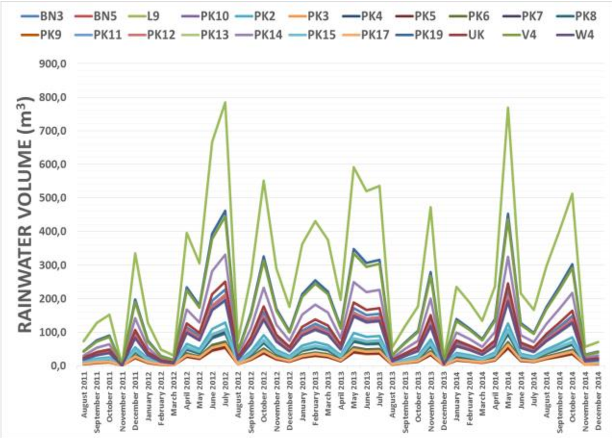

Fig. 5 measured values of rainfall during our research August 2011-December 2014

Tables 2-5 summarizes theoretical volumes of collected rainwater for all building in TUKE campus according the measured yearly rainfall totals as potential savings of potable water by the use of rainwater. Data are presented for the period August 2011 – December 2014.

Tab. 2 roof areas of buildings in TUKE campus

Building	Roof area (m^2)	V (m^3) - 2011
BN3	1766	200
BN5	1511	171
L9	6091	688
PK10	1615	182
PK2	1003	113
PK3	407	46
PK4	563	64
PK5	425	48
PK6	548	62
PK7	777	88
PK8	746	84
PK9	489	55
PK11	1506	170
PK12	1640	185
PK13	841	95
PK14	2572	291
PK15	854	97
PK17	497	56
PK19	3591	406
UK	1946	220
V4	3453	390
W4	1525	172

Tab. 3 roof areas of buildings in TUKE campus

Building	Roof area (m^2)	V (m^3) -2012
BN3	1766	1078
BN5	1511	922
L9	6091	3717
PK10	1615	985
PK2	1003	612
PK3	407	248
PK4	563	344
PK5	425	259
PK6	548	334
PK7	777	474
PK8	746	455
PK9	489	298
PK11	1506	919
PK12	1640	1001
PK13	841	513
PK14	2572	1569
PK15	854	521
PK17	497	303
PK19	3591	2191
UK	1946	1187
V4	3453	2107
W4	1525	931

Tab. 4 roof areas of buildings in TUKE campus

Building	Roof area (m^2)	V (m^3) -2013
BN3	1766	1116
BN5	1511	955
L9	6091	3851
PK10	1615	1021
PK2	1003	634
PK3	407	257
PK4	563	356
PK5	425	269
PK6	548	346
PK7	777	491
PK8	746	472
PK9	489	309
PK11	1506	952
PK12	1640	1037
PK13	841	532
PK14	2572	1626
PK15	854	540
PK17	497	314
PK19	3591	2270
UK	1946	1230
V4	3453	2183
W4	1525	964

Tab. 5 roof areas of buildings in TUKE campus

Building	Roof area (m^2)	V (m^3) - 2014
BN3	1766	952
BN5	1511	814
L9	6091	3282
PK10	1615	870
PK2	1003	540
PK3	407	219
PK4	563	303
PK5	425	229

PK6	548	295
PK7	777	419
PK8	746	402
PK9	489	263
PK11	1506	811
PK12	1640	884
PK13	841	453
PK14	2572	1386
PK15	854	460
PK17	497	268
PK19	3591	1935
UK	1946	1049
V4	3453	1860
W4	1525	822

4 Measurements of quantity of rainwater runoff in TUKE campus

We have started our research and own measurements in scope of stormwater quantity and quality parameters at the campus of Technical University of Košice within the project relating to the management of stormwater. The objects of research represent two infiltration shafts in the campus of TU Kosice that were made before the start of our research. These infiltration shafts represent drainage solution for real school building PK6 and all of the runoff rainwater falling onto the roof flows into these underground shafts (figure 6) [6,10].

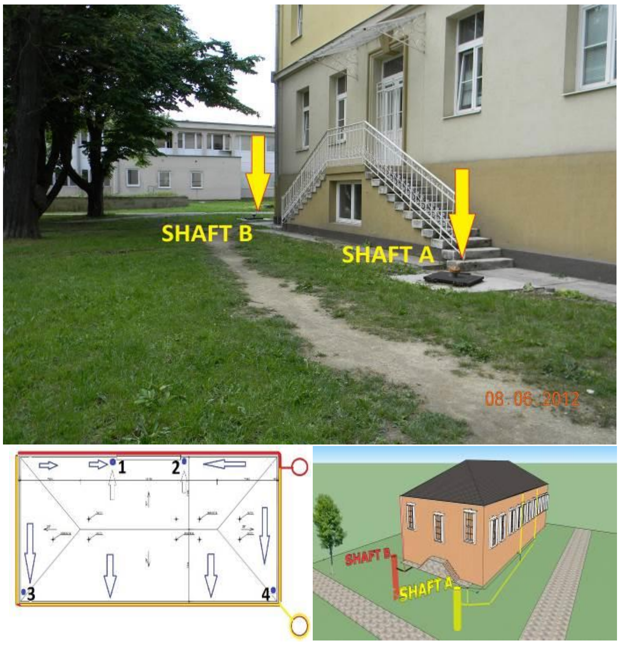

Fig.6 location of drainage shafts near the PK6 building [6]

The measuring devices for information about volume of incoming rainwater from the roof of the building PK6 and also information about the quality of rain water are located in both infiltration shafts [11]. All devices are connected with registration and control unit M4016. Unit M4016 automatically sent measured and archived data into the server database (data hosting) via GPRS in regular intervals [5]. Under inflow, respectively rain outlet pipe in the shaft, there are measurement flumes for metering of inflow rainwater from the roof of a building PK6 in both of infiltration shafts. Rainwater from the roof of the building PK6 is fed by rainwater pipes directly into measurement flumes, which are placed under the ultrasonic level sensor which transmitting data of the water level in the measurement flumes to the data unit M4016 (figure 7) [6,10].

Fig. 7. measurement devices - Data unit M4016 in shaft A, Measurement flume with ultrasonic level sensor

Table 6 summarizes the measured monthly rainfall totals with corresponding theoretical volumes of collected rainwater. Data are presented for the period April 2012 to December 2014 because at that time began measuring of the flow from all roof area of the building PK6 and precipitation measurements simultaneously. (Notice: August 2012 without data due to equipment failure) [11].

Tab. 6 theoretical volume of rainwater from PK6 building (548 m^2) according to the measured values of precipitation from April 2012 to December 2014

Month	Rainfall (mm)	Theoretical volume from 548 m^2(m^3)
April 2012	65	35,6
May 2012	50	27,4
June 2012	109	60,0
July 2012	129	70,6
August 2012	12	6,7
September 2012	44	24,0
October 2012	91	49,6
November 2012	48	26,1
December 2012	29	15,8
January 2013	59	32,6
February 2013	71	38,8
March 2013	62	33,8
April 2013	32	17,6
May 2013	97	53,2

June 2013	85	46,8
July 2013	88	48,2
August 2013	9	4,9
September 2013	19	10,5
October 2013	29	15,9
November 2013	78	42,5
December 2013	3	1,6
January 2014	39	21,2
February 2014	31	17,0
March 2014	22	12,1
April 2014	39	21,3
May 2014	126	69,2
June 2014	35	19,4
July 2014	27	15,0
August 2014	49	26,7
September 2014	66	35,9
October 2014	84	46,1
November 2014	9	5,0
December 2014	12	6,4

Tab. 7 measured monthly rainfall totals with corresponding theoretical volumes of collected rainwater and real amount of rainwater from roof of PK6 building (548 m^2)

Month	**Rainfall (mm)**	**Theoretical volume from 548 m^2(m^3)**	**Real volume from 548 m^2(m^3)**
April 2012	65	35,6	26,7
May 2012	50	27,4	18,9
June 2012	109	60,0	40,8
July 2012	129	70,6	49,6
August 2012	12	6,7	-
September 2012	44	24,0	17,9
October 2012	91	49,6	36,5
November 2012	48	26,1	16,9
December 2012	29	15,8	12,1
January 2013	59	32,6	19,9
February 2013	71	38,8	23,5
March 2013	62	33,8	22,8
April 2013	32	17,6	11,8
May 2013	97	53,2	30,6
June 2013	85	46,8	30,2
July 2013	88	48,2	36,6
August 2013	9	4,9	3,8
September 2013	19	10,5	8,9
October 2013	29	15,9	13,7
November 2013	78	42,5	38,4
December 2013	3	1,6	1,3
January 2014	39	21,2	10,9
February 2014	31	17,0	12,4
March 2014	22	12,1	8,3
April 2014	39	21,3	13,3
May 2014	126	69,2	44,9
June 2014	35	19,4	12,6
July 2014	27	15,0	13,9
August 2014	49	26,7	20,8
September 2014	66	35,9	-
October 2014	84	46,1	-
November 2014	9	5,0	4,1
December 2014	12	6,4	4,7

Another step of our research was to compare the current total consumption of potable water in PK6 building with volume of rainwater runoff from the roof which represent a potential source of water in PK6 building.

Table 8 represent real volumes of rainwater from 548,55 m^2 roof of PK6 building and comparison with total consumption of potable water use for every activities in this building measured during 2014. (Note: September and October 2014 without data due to equipment failure).

Tab. 8 measured values of rainwater from PK6 building with comparison of total consumption of potable water in this building

Month	**Real volume from 548,55 m^2(m^3)**	**Total consumption of potable water in PK6 building (m^3)**	**Excess/lack of water (m^3)**
January 2014	10,9	-	**+10,9**
February 2014	12,4	**6**	**+6,4**
March 2014	8,3	**18**	**-9,7**
April 2014	13,3	**14**	**-0,7**
May 2014	44,9	**14**	**+30,9**
June 2014	12,6	**15**	**-2,4**
July 2014	13,9	**9**	**+4,9**
August 2014	20,8	**6**	**+14,8**
September 2014	-	**4**	**-**
October 2014	-	**11**	**-**
November 2014	4,1	**23**	**-18,9**
December 2014	4,7	**17**	**-12,3**

5 Measurements of quality of rainwater runoff in TUKE campus

Potable water quality is evaluated according to basic indicators:

• microbiological and biological indicators (coliform bacteria, thermotolerant coliform bacteria and faecal streptococci),

• physico-chemical parameters (pH, conductivity, levels of heavy metals and chemicals that could harm human health),

• sensorial characteristics (taste, odor, color) [7,8,13].

Factors affecting the quality of RHSR are:

• environment in which the system for stormwater harvesting operates (proximity of roads, traffic density, proximity of the manufacturing and construction industries, heavy industry, housing sector, agriculture),

• meteorological conditions (temperature, amount of rainfall periods and dry periods, course of fronts), SWR system (material used, its sustainability, filtration),

• human factors (proper sizing, regular maintenance, information about the operation of system as a whole and also about individual components) [9,14].

System for monitoring of RHSR quality from PK6 Building consists of the following components:

• Roof - roof material: Ceberit – fibrecement small-area coating with smooth surface (Figure 8).

• Gutters – material: steel.

• Two concrete infiltration shafts with a diameter of 1000 mm.

• Monitoring devices placed in shafts (flowmeter - runoff of rainwater from the roof, water level sensor - water level in shaft, multi-parameter sensor of water quality (pH, conductivity) [16].

Fig. 8 roof of PK6 building- roof material: Ceberit – fibrecement small-area coating with smooth surface

A multiparameter water sensor took qualitative measurements of pH and conductivity readings from late 2011 onwards. The sensor was installed in a measurement flume inserted in one of the drainage shafts (shown in figure 9). Values for pH and conductivity were recorded on a continuous basis. According to the NV SR regulation (number 269/2010 Z.z.), the pH value should be in the range of 6 to 8,5 [15].

Fig. 9 the multi-parameter water sensor in the drainage shaft near the PK6building

The Box-Plot graphs shown in Figures 10-13 depicts the pH values of the rainwater from the PK6 building throughout years 2012-2015. Figure 9 shows that the average pH value varied each month. The pH values indicated RHSR levels of acidity in some months during research period.

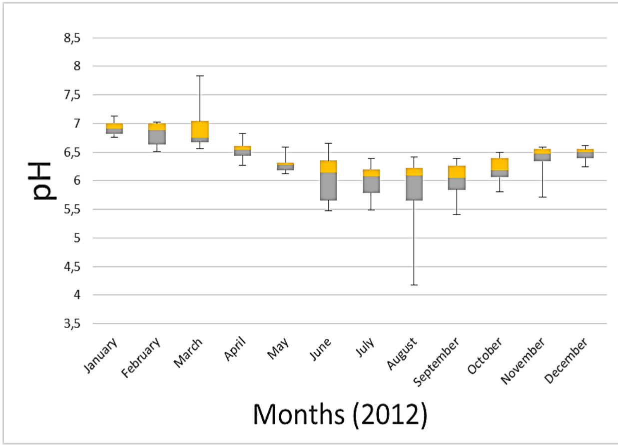

Fig. 10 pH values of rainwater collected from the PK6 building during 2012

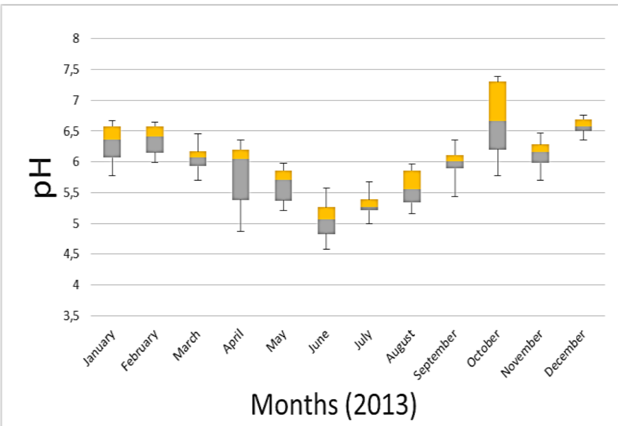

Fig. 11 pH values of rainwater collected from the PK6 building during 2013

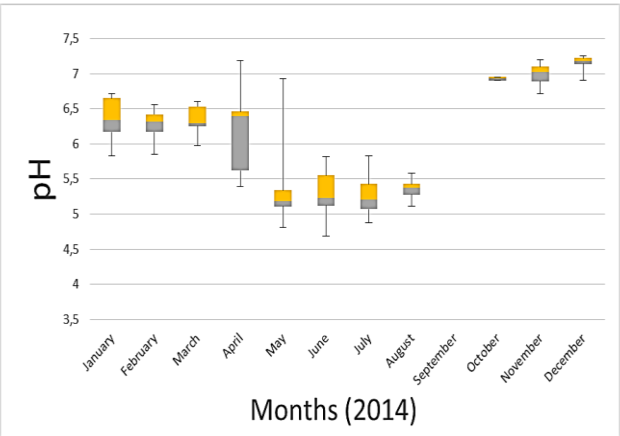

Fig. 12 pH values of rainwater collected from the PK6 building during 2014

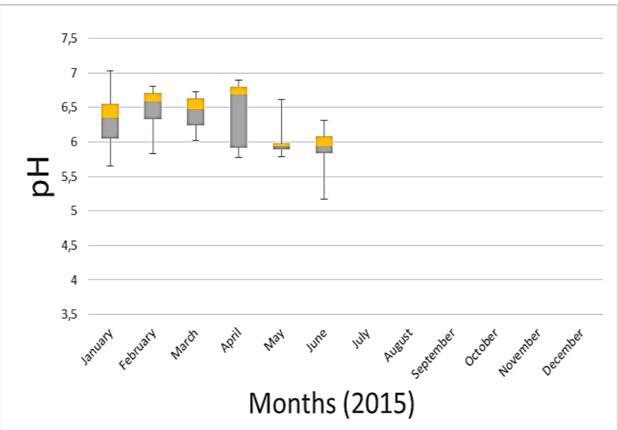

Fig. 13 pH values of rainwater collected from the PK6 building during 2015

Another water quality indicator is the conductivity of the water collected from the PK6 building. As with the pH values, the conductivity levels were also measured on a continuous basis using the same multi-parameter sensor (figure 9).

Conductivity refers to the approximate rate of the concentration of electrolytes in water. Conductivity values of rainwater during the 2012-2015 period are shown in the Box-Plot graph in Figures 14-17.

According to the NV SR regulation (number 269/2010 Z. Z), the conductivity limit for water in portable storage represents 100 mS/m which is equal to 1000 mg/l. In optimum conditions, portable water supplies should be less soluble in substance, i.e. 200–400 mg/l (about 25–50 mS/m). In most cases, the conductivity values did not exceed the standard value of 100 mS / m [15].

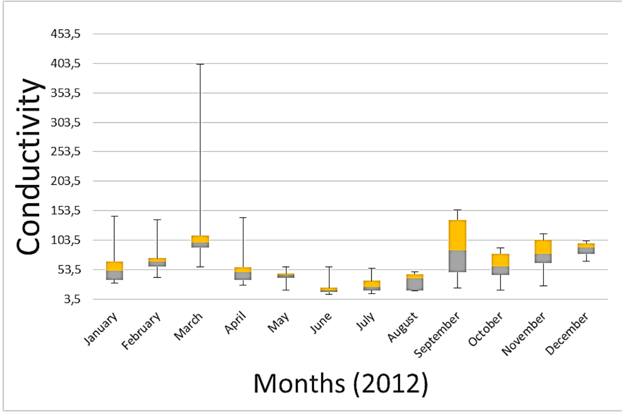

Fig. 14 conductivity values of the rainwater from the PK6 building during 2012

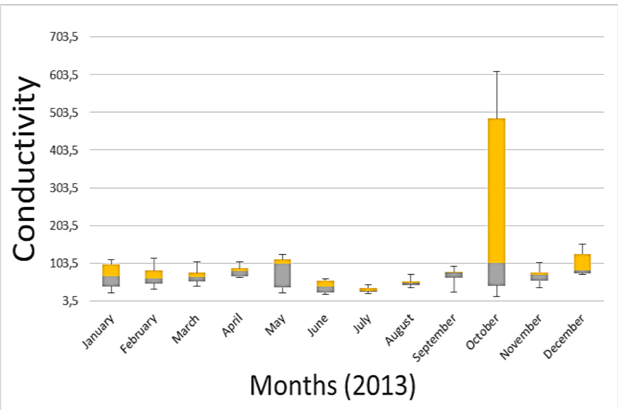

Fig. 15 conductivity values of the rainwater from the PK6 building during 2013

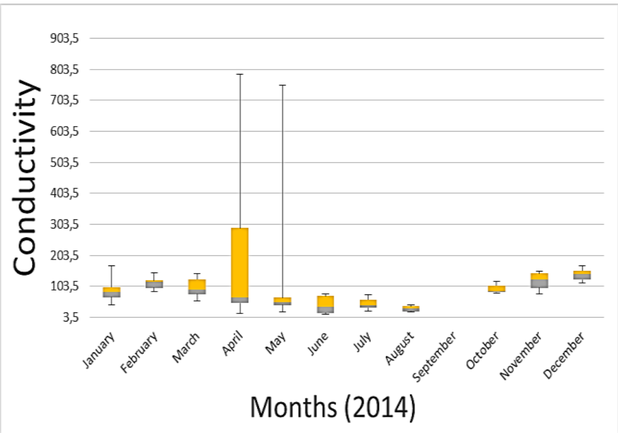

Fig. 16 conductivity values of the rainwater from the PK6 building during 2014

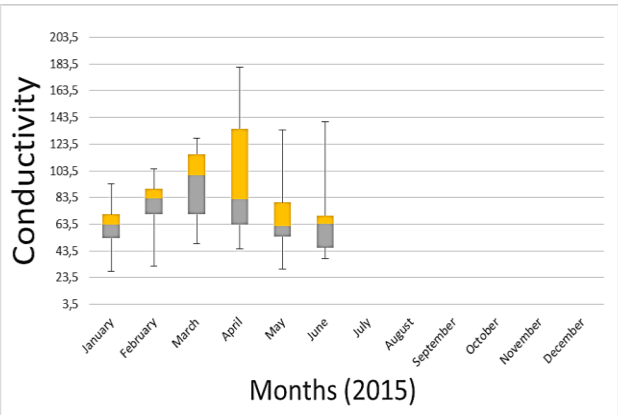

Fig. 17 conductivity values of the rainwater from the PK6 building during 2015

From these graphs, we can see that the average value for each month varied, but in most months the values were satisfactory. Limits were exceeded during periods of rainfall, however most occasions the conductivity levels were within acceptable standards and were occasionally satisfactory. The measured values of conductivity have been influenced by the addition of potable water during research (in case of cleaning, calibration of devices…) [6].

6 Conclusion

Using of rainwater as another source of water in the buildings provides a lot of advantages for users. This source of water is free of charge and independent source of water contrary to the water supply from the water company. Of course, these systems have also some disadvantages which we must be taken into account, e.i. irregular unpredictability of precipitation, increased demand for maintenance of this system given by required water quality etc.

But the theoretical as well as real volumes from our measurements show a big potential for savings of potable water by the use of rainwater in the TUKE campus. In the case of school-type buildings potential of water savings replaced by rainwater is significantly higher which is caused by the absence of purposes such as showering, bathing, laundry, etc. The most volume of potable water at school buildings in TUKE campus is consumed by flushing toilets, apparently the most suitable purpose for the use of rainwater.

The rainwater quality measurements taken from the PK6 building roof demonstrate that the rainwater meets quality standards for the purposes of collection, storage and re-use, as well as for the purposes of rainwater infiltration.

Clearly, it is necessary to take each project on a case-by-case basis, because rainwater collection and storage systems are sensitive to, and dependant on, local site and building design conditions [6].

Rainwater harvesting in educational type of building has not only financial benefits but also educational and ethical benefits. Education of students leads to awareness of value of potable water and would avoid of wasting precious potable water which is used for example - for flushing toilets in our society.

The next step of our research should focus on effect of using different roofing materials affecting the amount and quality of rainwater in the Kosice city area. Future research of rainwater harvesting systems should focus also on development of a legislative framework for the design and operation of rainwater harvesting systems and infiltration systems in Slovakia and the preparing and implementation of the planned concept of rainwater management for all buildings at TUKE campus site.

Acknowledgement

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