Rainwater Harvesting, Risk Assessment and Utilization in Kosice-City, Slovakia

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Abstract

Water consumption in residential parts of urban areas is just one part of the water management problems. Contemporary potable water management is not sustainable whereas we use potable water for flushing toilets, irrigation or washing vehicles. The appropriate solution is to substitute potable water with rainwater for some purposes and this water source is considered sustainable. Submitted paper presents risk assessment using risk analysis of the rainwater harvesting (RWH) system. This paper does not deal with the system in details but informs about the selected approach of the evaluation methodology verified by analytical hierarchy process.

Keywords: Rainwater management; rainwater harvesting; urban water cycle; risk assessment; sustainability; AHP

1. Introduction

The total volume of water in the world remains constant. What changes is its quality and availability [1]. Starting with the quote “Water is not a commercial product like any other but rather a heritage which must be protected, defended and treated as such” presented in the statement when the Water Framework Directive (WFD) was introduced. The WFD supports sustainability in water management. The main objective of the WFD is to create a suitable mechanism that can establish the basic principles of sustainability in water policy and subsequently water management [2]. A major step towards sustainability in Europe is that water and waste water treatment are no longer seen in isolation but as integral part of the urban water cycle, which itself forms a part of the natural hydrological cycle [1].

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Rain, a form of precipitation is the first form of water in the natural hydrological cycle. It is a primary source of water that feeds rivers, lakes, and groundwater aquifers and they became the secondary source of water [3]. Rainwater may be collected from any hard surface, such as stone or concrete patios, and asphalts parking lots. However, once the rain hits the ground it is no longer referred as rain, but as the stormwater. Landscape can also be contoured to retain the stormwater runoff. Rainwater harvesting captures precipitations and uses it as close as possible to where it falls [4]. Stormwater management has been changing throughout years and it was caused by extensive urbanization which changed storm water runoff and infiltration patterns. Rainwater harvesting supports sustainability in stormwater management which in principle means managing storm water as a resource and as close to the source as possible [5]. The problems associated with urbanization originate in the changes in landscape, the increased volume of runoff, and the quickened manner in which it moves. The changes in the landscape occurred during the transition from rural and open space to urbanized land use [6, 18]. Urbanization causes a shift from sub-surface pathways dominating stream flow generating processes to overland flow as vegetation is removed and soils become compacted or covered with impervious paving or roofs. Stormwater runoff is largely caused by rain falling on asphalt or roofs and storms [7].

One of the objectives of using alternative water resources is to support adequate water quality use for different purposes. It is the fact that we use expensive and valuable potable water for flushing toilets, even though it doesn’t need to be water with such quality. This is for instance right place where to substitute potable water with one of the alternative water resources. Other examples are irrigation, washing and maintenance, washing vehicles or heating. Rain and stormwater harvesting contribute to the integrated management of urban water cycle. It has direct impact on volume and quality of stormwater runoff than reduction in flows to wastewater treatment plants and it of course conserves drinking water [8]. Climate changes impose important challenges to the water sector. Potential effects on the urban water cycle involve the aggravation of existing conditions as well as occurrence of new hazards or risk factors [9]. Risk management has its place in science and our everyday life as well. Water management in general comprises wide range of problems especially in recent years we see increasing need to dispose rainwater on decentralized way. That is the reason why we are interested in this topic and why we would like to increase awareness on this topic in our conditions. This paper does not deal with the RWH system in details but presents the semi-quantitative approach methodology verified by mathematical method - analytical hierarchy process (AHP).

| Nomenclature |
|---------------|
| AHP           | Analytical Hierarchy Process |
| RWH           | Rainwater Harvesting System |
| WFD           | Water Framework Directive    |
| WSP           | Water Safety Plan            |

1.1. Risk management and RWH

The comprehensive characterization of the urban water cycle has to be made by the experts to ensure the right steps while risks are identified, assessed and treated. The different systems and subsystems that integrate to urban water cycle have to be identified, and boundaries between them should be clearly defined [9]. Our aim is to assess the subsystem of Rainwater harvesting at the building level. Following the risk frameworks and strategies that have been developed and applied in many countries in last decades, we considered to use the Water Safety Plan (WSP) approach for our evaluation. It is grounded on the risk assessment and management approaches. We’ve chosen to assess the RWH system of a small family house using methods of risk analysis because of their wide implementation in practice and enough information available. Well known WSP and semi-quantitative approach were used as a template for our risk analysis. Since semi-quantitative assessment method is subjective, results should be verified. For the verification a couple of mathematical methods were applied but for the purpose of this article we’ve chosen the Analytic Hierarchy Process (AHP) described below. Risk analysis should help determining the likelihood of the risks and the riskiest parts of the system and consequently appropriate risk management for the prevention of hazardous events. To the aim of risk assessment, general system of RWH was divided into four parts (A - catchment, B - storage, C - distribution, D - user), each part was divided into sub sections (A1, A2, A3, B1, etc.) and the last level of our system contains potential
hazards (A11, A12, A13, A21, A31, etc.). This hierarchy development is important step in AHP as well. General hierarchy can be seen on Fig. 1a and an example of evaluated system hierarchy can be found below on Fig. 1b.

![Hierarchy Diagram]

1.2. Aims and Methods

The aim was to prepare a general risk analysis methodology for rainwater harvesting systems. This methodology can especially be applied for small scale projects such as family houses; in our case we applied it for a newly constructed family house with the RWH system (see Fig. 2). Installed system is brand new, supplied with 4m³ underground water tank. Rainwater is used for flushing toilets, irrigation, and maintenance and potentially or washing machine as well. One of the aims of the risk analysis is to prepare a check-list for this type of user. Check list should serve as a tool for the regular self-control of the system which can eliminate various types of risk events and inform user about the system as well. The methodology is designed in accordance with Water Safety Plan and WSP Manual step-by-step and comprises following stages:

1) Assemble team of experts
2) Description of RWH system
3) Risk identification
4) Risk assessment
5) Determination and evaluation of control measures [11].

In our previous research we described first 3 steps [10, 12]. This paper deals with the risk assessment part of the analysis. Risk assessment is a process, in our case carried out with the semi-quantitative approach including estimation of the likelihood / frequency and severity of impact / and consequences [11]. Semi-quantitative risk assessment provides an intermediary level between the textual evaluation of qualitative risk assessment and the numerical evaluation of quantitative risk assessment, by evaluating risks with a score [13]. Using semi-quantitative risk assessment, team can calculate a priority score, for each identified potential hazard. The objective of the prioritization matrix is to rank hazardous events in order to focus on the most significant hazards. The likelihood and severity can
be derived from the team’s technical knowledge and expertise, historical data and relevant guidelines [11]. Matrix below was used to determine risks rating and risks score of RWH system according to compiled list of potential hazards.

Determination of risk score according to semi-quantitative methodology is made according to this formula [11]:

\[
\text{Risk} = \text{likelihood of occurrence} \times \text{severity of consequence}
\]

The risk is determined by multiplying these two values. This allows us to distinguish serious risks to the minor ones and to determine priorities for their prevention or elimination (see Fig. 3).

| Semi-quantitative risk matrix | severity of consequence |
|------------------------------|-------------------------|
| likelihood of occurrence     | insignificant (1 point) | low significance (2 points) | moderate (3 points) | significant (4 points) | catastrophic (5 points) |
| rare (1 point)               | 1                       | 2                         | 3                    | 4                     | 5                       |
| unlikely (2 points)          | 2                       | 4                         | 6                    | 8                     | 10                      |
| moderate (3 points)          | 3                       | 6                         | 9                    | 12                    | 15                      |
| likely (4 points)            | 4                       | 8                         | 12                   | 16                    | 20                      |
| almost certain (5 points)    | 5                       | 10                        | 15                   | 20                    | 25                      |
| risk score                   | 1-3                     | 4-6                       | 8-10                 | 12-16                 | 20-25                   |
| risk rating                  | very low                | low                       | medium               | high                  | very high               |

Fig. 3 Semi-quantitative risk matrix approach [11]

1.3. Verification by the Analytic Hierarchy Process

For the verification of the results, 3 mathematical methods were used. These were: empirical, entropy and AHP. Not all of the mentioned methods are suitable for the verification of such system so we have chosen the AHP method for this article. The Analytical Hierarchy Process, which is a mathematical technique for multi-criteria decision-making, allows the analyst to do this by structuring the problem hierarchically and guiding them through a sequence of pair-wise comparison judgments [14]. AHP was conducted using the following steps:

1) Set up the hierarchy
2) Perform pair-wise comparisons
3) Prepare a matrix (judgment matrix)
4) Compute the relative weights/ranks (According [14])

This method is usually used in the process of deciding which material or technology is better to use or which candidate is the most suitable for which position. This is widely used multi-criteria evaluation, where quantitative as well as qualitative values can be compared. It is essential to divide the evaluated system using criteria, sub-criteria and sub-sub-criteria. In our case we need to divide it into system, sub-system itself and the potential hazards. This step is very important because the evaluation itself is easier when the system is broken down into elements.

We have made a set of pair-wise comparison matrices [15] for each level, the scale for making judgments can be found in a Table 1. Experts are required to carry out pair-wise comparisons among criteria to give the relative importance. Thus, in this step, the criteria are compared with each other to determine the relative importance of each criteria in the accomplishing the overall goal. AHP computes an overall priority value or weight for each decision element [14, 15]. Based on this method we were able to determined weight of each part of the system, the sub-system and the potential risks themselves. Comparing obtained weights we could compile the scale of risk importance of the system components and determine priority of our focus on the most risk-prone parts of the RWH. The results from AHP are comparable with the results from semi-quantitative method as described in next chapter. It is important to note that even when numbers are obtained from a standard scale and they are considered objective, their interpretation is always, subjective [14, 15].

| Intensity of Importance | Definition | Explanation |
|-------------------------|------------|-------------|
| 1                       | Equal Importance | Two activities contribute equally to the objective |
| 2                       | Weak or slight | Experience and judgment slightly favor one activity over another |
| 3                       | Moderate importance | Experience and judgment strongly favor one activity over another |
| 4                       | Moderate plus | An activity is favored very strongly over another; its dominance demonstrated in practice |
| 5                       | Strong importance | The evidence favoring one activity over another is of the highest possible order of affirmation |
| 6                       | Strong plus |
| 7                       | Very strong or demonstrated importance |
| 8                       | Very, very strong |
| 9                       | Extreme importance |

2. Results and Discussion

Selected methodology is based on the team members’ knowledge, experience and available documentation. We can say that in the phase of risks identification and risk assessment, valuable information was gathered from the questionnaire. Selected semi-quantitative methodology described previously was used to evaluate newly installed system of RWH in a family house. There were only 6 risks identified in the high rating category and 13 in the medium. It is important to say that the list of risks contains all of the risks that could potentially occur, even though they’re highly improbable, especially for a newly installed system.

| Sub-system | Potential hazards |
|------------|-------------------|
| location   | microbiological contamination |
We can summarize very briefly that risks with medium and high ratings are risks associated with the location, such as dust nuisance, microbiological contamination or drought. There are also risks associated with the revision and maintenance of gutters, filters and tank in general which has their impact on pump clogging as well. The last group of the risks are risks resulting from how the system is used and maintained. This last part is very important because, as it was mentioned in the beginning of this article, one of the results of the questionnaire is that respondents think that users are in general insufficiently informed about using the system itself and its maintenance. The result of this risk analysis is used to propose measures and appropriate risk management to eliminate all of the potential risks from the risk analysis in the high and medium rating and also eliminate risk to the lowest possible level. The AHP results are comparable with the results from the semi-quantitative method. Using AHP, weights of each part of system, subsystem and potential hazards/risk were calculated. For example, we can show first 5 results from the second level of evaluation process. Following 5 parts of the sub-system listed below were weighted as the most important during the Analytic Hierarchy Process:

1) Location
2) Pump
3) Filter
4) Washing
5) Tank

Using multilevel comprehensive evaluation with the weights from AHP method, overall risk of the system was also quantified. The value of riskiness of the system in the scale from 1 to 5 is 2.24. This value does not even reach the half level of the scale so we can say that the risk probability of the system is low. According to these results we are able to estimate that our conclusion from risk assessment using semi-quantitative approach is correct and semi-quantitative approach is suitable for this kind of system evaluation. It definitely has some limitations as it was described in WSP manual step-by-step but this is not the aim of this article.

3. Conclusion

New attitudes among governments and the public, new technologies and new management frameworks are all enabling the concepts of sustainability to become gradually accepted. The old ways of generation and disposal are now just too expensive, both economically and environmentally [1]. The detailed application of the water safety concepts should be carried out for each individual subsystem part. Risk analysis is valuable method for RWH system evaluation. In our case, we were able to collect helpful information from the questionnaires that helped us later in the risk identification as well as risk assessment phase along with the help of the brainstorming method within the team of experts. The results from the risk analysis led us to those parts of the system which need to be maintained with
higher attention. Appropriate risk management will hopefully eliminate potential risks to the minimum and prevent potential material or health damages. The output from the risk assessment is a checklist available for users of such systems, enabling them to use the list of questions to perform regular self-control of the system, inform users about their system and serving also as a tool for prevention. The results from the risk analysis were verified by the AHP and empirical multilevel comprehensive evaluation, which was found to be useful as well. The information from questionnaire also gave us a plenty of ideas which way we need to direct our attention in the field of rainwater harvesting in our conditions in the future. There is need to evaluate the risks and to sum up the solutions how to eliminate potential risks or unexpected consequences.

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