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RAINWATER HARVESTING AND ITS RISK ASSESSMENT

The article presents a risk assessment using a risk analysis of the rainwater harvesting (RWH) system. The main focus is on the selected approach for the evaluation methodology. RWH system in the condition of the Slovak Republic is described in general, using information gathered from the used questionnaires. Summarized results from semi-quantitative approach and Analytic Hierarchy Process used for verification of RWH risk analysis.

Keywords: rainwater, potential hazards, risk analysis

INTRODUCTION

Rainwater represents a component of resources that in the whole water cycle ensures renewability of surface and underground waters [1]. There are numerous small-scale examples of rainwater harvesting for individual housing projects all around the world but also for larger scale projects in the industrial, commercial, municipal or residential areas, using rainwater harvesting. In the field of sustainable water usage, it is very important to use appropriate water quality for different purposes [2].

Questionnaire, as one of the methods of obtaining information, is a good example of how to obtain relevant information from practice about the design process, experiences and opinions. Two questionnaires were performed by us in our conditions for the purpose of obtaining information from users as well as designers and construction companies and it gave us plenty of ideas, opinions and experiences of the design process as well as from construction and operation of such systems.

The questionnaire was filled in by 35 respondents (construction companies and architects with some experience with RWH systems), but not all of the respondents felt knowledgeable enough to answer all of the questions so in this part we will summarize some highlights from the gathered information. Beginning of the questionnaire contains a couple of basic questions about respondent such as number of years of experience, position and what is his/her opinion about RWH. Generally we can say that most of the respondents have a positive attitude towards RWH and would install such system at home or in the workplace and most of them think that RWH is perspective in our conditions. Second group of questions was focused on practical experiences, for example: when did you do your first design, what kind of problems you were facing during design process, have you seen an

increased demand for RWH systems in recent years, wich standards or manuals do you use for your designs.

These questions revealed that one of our respondents made his first RWH design back in 1996 but in average, respondents made their first design around 2006. Approximately half of the respondents register an increasing interest in such systems in recent years. According to respondents' experiences, investors intend to use their system especially for irrigation and flushing toilets. Most of the asked would welcome some unified guidelines for the design in our conditions. Roughly half of the respondents think that users have lack of information about system's maintenance and usage what rivets our attention to this kind of risk as well. The target of the last group of questions was to obtain information about risks in RWH. All of these parts are strongly subjective and based on respondents' experiences and opinions. The results show that the riskiest parts of the system according to questionnaire are: *pump, filter* and *tank*. According to the questionnaire, we can say that the highest attention should be paid to the design, installation and maintenance of these three parts of the system [3].

1. RWH AND RISK MANAGEMENT

Risk management is a highly comprehensive topic. We can find risk analysis methods in many fields of science, practice or social life. The advantages of rainwater harvesting systems are well known. It is the same with other areas where according to risk management principles, some events could be categorized as risk-prone events. Therefore one of the objectives of risk analysis is to identify potential risks, compile a list of them, prioritize them and find out how to prevent or eliminate hazardous events [3].

We have chosen to assess the RWH system using methods of risk analysis because of their wide implementation in practice and enough information available. Well-known Water Safety Plan 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 have chosen the Analytic Hierarchy Process (AHP) described below.

Risk analysis should help to determine the likelihood of the risks and to determine the riskiest parts of the system and consequently appropriate risk management for the prevention of hazardous events.

For the purpose 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 an important step in AHP as well.

General hierarchy can be seen in Figure 1 and an example of evaluated system hierarchy can be found below in Figures 2-3.
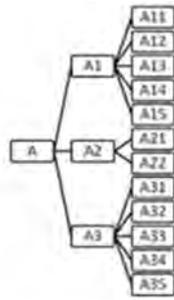
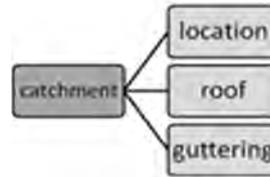Fig. 1. General hierarchy example - part A   Fig. 2. Sub-section hierarchy
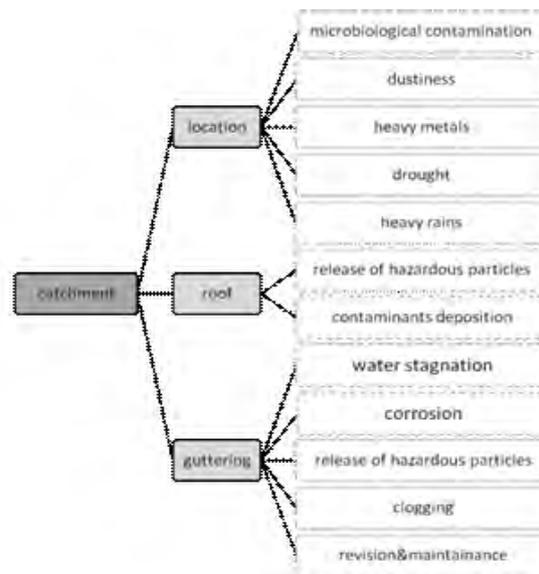

Fig. 3. Full hierarchy - part A

2. GOALS AND CHOSEN METHODOLOGY

The main goal 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. 4).

Installed system is brand new, supplied with 4 m^3 underground water tank. Rainwater is used for flushing toilets, irrigation, and maintenance and potentially for 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.
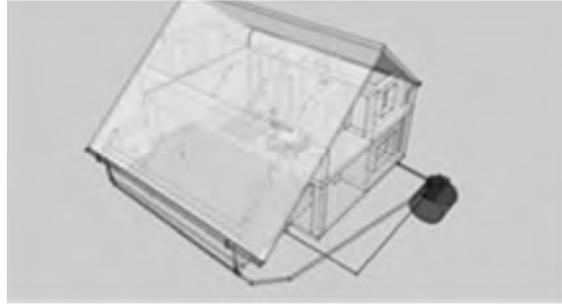
Fig. 4. Experimental house

The methodology is designed in accordance with Water Safety Plan and WSP Manual step-by-step and comprises following stages:

- I. Formation of a team of experts
- II. Description of RWH system
- III. Risk identification
- IV. Risk assessment
- V. Determination and evaluation of control measures [4]

Whereas the first 3 steps have already been published for example in [3], in this article we only take step 4 into consideration, which is risk assessment. 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/consequences [4]. 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 [5]. Using semi-quantitative risk assessment, team can calculate a priority score, for each identified potential hazard. The objective of the prioritisation 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 [6].

Table 1. **Semi-quantitative risk matrix approach, adapted from [4]**

Semi-quantitative risk matrix		severity of consequence				
		insignificant (1point)	low significance (2points)	moderate (3points)	significant (4points)	catastrophic (5points)
likelyhood of occurence	rare (1 point)	1	2	3	4	5
	unlikely (2points)	2	4	6	8	10
	moderate (3points)	3	6	9	12	15
	likely (4points)	4	8	12	16	20
	almost certain (5points)	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

3. PROCESS OF VERIFICATION

For the verification of the results, 3 mathematical methods were used. These are: empirical, entropy and the Analytical Hierarchy Process (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 (Saaty 1977; Saaty 1980; Saaty 1994), allows the analyst to do this by structuring the problem hierarchically and guiding them through a sequence of pair-wise comparison judgements [7].

AHP was conducted using the following steps:

 I. Set up the hierarchy
 II. Perform pair-wise comparisons
 III. Prepare a matrix (judgement matrix)
 IV. Compute the relative weights/ranks (according to [7])

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 [8] for each level, the scale for making judgements can be found in Table 2. 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 criterion in accomplishing the overall goal. AHP computes an overall priority value or weight for each decision element [7].

Table 2. **The scale for AHP pair comparison [8]**

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

Based on this method we were able to determine 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 [8].

4. 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 a highly improbable, especially for a newly installed system.

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 the way 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, sub-system 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:

    I.   Location
   II.   Pump
  III.   Filter
  IV.   Washing
   V.   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.

CONCLUSION

The 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 questionnaires 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.

Acknowledgments

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ZBIERANIE WODY DESZCZOWEJ ORAZ OCENA JEGO RYZYKA

W artykule zaprezentowano ocenę ryzyka z wykorzystaniem analizy systemu zbierania wody deszczowej (RWH). Główny nacisk kładzie się na podejście do metodologii oceny. System RWH w warunkach Słowacji jest opisany przy wykorzystaniu informacji zebranych na podstawie opracowywanych kwestionariuszy. Podsumowano wyniki z badań półilościowych i badań przeprowadzonych metodą AHP (Analytic Hierarchy Process), wykonanych w celu weryfikacji analizy ryzyka systemu zbierania wody deszczowej (RWH).

Słowa kluczowe: woda deszczowa, potencjalne zagrożenia, analiza ryzyka