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RISK ANALYSIS FOR RWH SYSTEM AND ITS VERIFICATION BY MATHEMATICAL METHODS

Rainwater is an alternative and sustainable source of water which is in compliance with the idea of sustainable development. Risk analysis helps us to identify the risks associated with the rainwater harvesting (RWH) in general. In this article we identify that parts of the RWH system where potential hazardous events could occur. The potential hazardous events are evaluated by risk analysis and the most hazardous parts of the system are designated. Well known Water Safety Plan and semi-quantitative approach was used as a template for risk analysis. This method was verified by various mathematical methods as described in this article.

Key words: rainwater harvesting (RWH), stormwater management, risk analysis, semi-quantitative method.

Дощова вода є альтернативним і відновлювальним джерелом води та відповідає ідеям збалансованого розвитку. Аналіз ризиків дозволяє ідентифікувати ризики, пов'язані зі збором дощової води (RWH) в цілому. Визначено, що частини системи збору дощової води є потенційно небезпечними. Потенційні небезпеки були оцінені шляхом аналізу ступенів ризику і найбільш небезпечні частини системи були встановлені. Як зразок для аналізу використано відомий План Безпеки Води (Water Safety Plan) і напівкількісний підхід. Методика була перевірена різними математичними методами.

Ключові слова: збір дощової води (RWH), аналіз ступеня ризику, напівкількісна методика.

Introduction

Rainwater could replace potable water in the following cases: flushing toilets, maintenance and cleaning, irrigation, washing vehicles, process water or fire water. Principle of this system, used for many years all around the world is collecting the rainwater and/or stormwater in the tanks (under or above ground) and storing it until it is used.

The system is much more sophisticated nowadays since our demand is higher and necessity of water quality is taken into consideration. We usually collect water from impervious surfaces such as roofs, paths and parking lots etc. It is further transported by gauges and downpipes through filter/screen to prevent organic material particles and debris reaching the system. Very important part of the system is the first flush device which retains initial runoff because of the stored water quality. In addition, it is possible to install different types of filters and treatment devices. The level of treatment of the stored water depends on purpose for what the water will be used. There are disinfection devices using for instance UV radiation, chlorine or activated carbon filters. Pumps and pipes, necessary for transporting the water to the consumer, are of course inseparable parts of the system and cannot be interconnected with potable water network.

The advantages of rainwater harvesting are:

- free and relatively clean source of water,
- acceptable and sustainable source of water,
- source of water with responsible attitude to environment,
- save potable water consumption,
- supporting sustainable stromwater management,

- supporting use appropriate water quality for different purposes,
- it’s a source of water in place where needed,
- rainwater is more suitable for irrigation,
- money saving.

The disadvantages of rainwater harvesting are:

- the system is not reliable in dry periods,
- necessity to design optimal storage volume,
- periodical maintenance and cleaning.

Risk analysis

The risks are associated with any activity performed in our everyday life and we see risk analysis methods in many fields of science, practice or social life where they serve for identification of risks and risk factors in different areas. Risk assessment includes the risk analysis, which is the process aiming at the determination of the consequences of the failures (undesirable events) in the water supply system, their extend, source of their occurrence and the assessment of the risk level. [1]

It is undisputed that rainwater harvesting systems brings a lot of benefits but it is the same as in the other areas that according to risk management some events can be categorized as risk events. [2]

Effective risk management requires the identification of potential hazards and their sources, to estimate or determine the presence of potentially hazardous events and to assess the importance of risks.[3]

The methodology of risk analysis is prepared according to Water Safety Plan and WSP Manual step-by-step. Although this manual discusses risk management of potable water system, we used it as a model because in most cases, steps of risk analysis are the same.

Steps of risk analysis:

- Build up a team of experts
- Description of RWH system
- Risk identification
- Risk assessment
- Determination and evaluation of control measures [4]

Table 1

Risk score of evaluated RWH system processed by semi-quantitative method [7]

sub-system	**potential hazards**	**risk score**
location	*microbiological contamination*	**9**
	dustiness	**12**
	drought	**12**
guttering	*revision and maintenance*	**9**
filters	*revision and maintenance*	**9**
tank	*under sizing*	**9**
	microbiological contamination	**9**
	revision and maintenance	**9**
pump	*clogging*	**12**
WC flushing	*toilet lid closing*	**15**
	bathroom joint with toilet	**15**
	inhalation of dangerous microbes	**12**

Semi-quantitative risk assessment is a system for sorting out risks, focusing on the big issues, and managing the entire risk portfolio better. The scoring system is inherently imperfect, but so is any other risk evaluation system. [6]

The likelihood and severity can be derived from the technical knowledge and expertise, historical data and relevant guidelines. The team needs to determine a cut off point above which all hazards will be retained for further consideration.[5]

We have calculated risk score by multiplying two values (likelihood and severity). This allows us to distinguish serious risks from the minor ones and to determine priorities for their elimination or reduction.

Risk = likelihood of ***occurrence x severity of consequence → determination of risk score***

In the table 1 can be found only the potential hazards with the risk score medium (8-10) and high (12-16) from this process of risk assessment. This methodology was applied on new family house with rainwater harvesting system.

Risk analysis verification

For the verification of the results, 3 mathematical methods were used. These are: empirical, entropy and AHP. The most important part and the beginning of whole process is to make a hierarchy. At this point it is the same with the risk analysis itself. The RWH system was divided into 4 parts (catchment, storage, distribution and user). These four parts were divided into sub-systems (for example sub-systems of distribution are pump, piping and water backup) and the level under sub-system contains potential hazards where all of the hazards even very improbable one are listed. The list of potential hazards is evolving document and the information was gathered from the personal knowledge and experience of the team of experts as well as from questionnaire filled by architects and construction companies. Since the hierarchy is the same, results are comparable with the semi-quantitative method.

The evaluation method used for verification was multilevel comprehensive evaluation. Input data (the weights) for this evaluation was gathered from 3 mathematical methods (empirical, entropy and AHP). The results of this comprehensive evaluation is the riskiness of the system expressed by the value from the set of numbers from one to five, where one means the lowest risk and 5 means the highest risk. There is another result from this process and it is comparison of the individual weights where these weights can present the significance or riskiness as well.

The first used method is empirical method. This method is the most subjective one as the experts determine the weights used later in multilevel comprehensive evaluation of each part of the system by themselves. After that each expert determines the riskiness of potential hazards according to his knowledge and experiences. The result is a calculation of the total potential riskiness of the assessed system. Based on this empirical method, riskiness of the assessed system was calculated to the value of 2.16 from the interval 1-5. [7]

The second applied method is the method of entropy, where the experts made an individual assessment of the riskiness of potential hazards same as in the previous method. But in this case the weights are automatically calculated by the method of entropy. But we have found this method as not suitable for this type of evaluation because of main character of this method so we have decided not describes more extensively this method for the purpose of this article.

The third method we have used to verify the semi-quantitative method is the analytic hierarchy process (AHP), where the weights for the multilevel comprehensive evaluation are calculated precisely using this method. The inventor of the AHP is Professor Thomas L. Saaty [9] and this method can be considered as the most objective from these three methods. This method is usually used as a decision making tool for example in which technology or system is better to use or which candidate is more suitable for the position, etc.. But we have decided to apply it in this verification process and found which potential hazard is the most important and should be considered in the control measures process. First step was to prepare comparison matrix of each part of the system according to the hierarchy. Hierarchy described above remained the same. Based on comparison matrixes the team of experts is required to carry out pair-wise comparisons among the criteria to give the relative importance on each hierarchy level. Thus, in this step, the criteria are compared with each other to determine the relative importance of each criteria. AHP computes an overall priority value or weight for each decision element. [8] 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. [7]

Conclusion

In the conclusion we would like to briefly sum up and compare the results from the risk analysis and the verification methods. It is very important to mention that even if we work with the numbers and methods which can be considered objective the interpretation of evaluation and the evaluation inputs are subjective and based on team of experts knowledge. In this kind of evaluation there is not possible to exclude some subjectivity level. There was calculated by multilevel comprehensive evaluation that the overall riskiness of the system in both cases is lower than half what should in mathematic expression means almost medium riskiness but our team has considered is as a low riskiness because of the subjective element in the evaluation. In risk analysis we have calculated risk score as can be seen in table 1 where are shown potential hazards with the risk score higher than 9 what is the point of division from which the potential hazards were taken into consideration and there will be designed measures to prevent this potential hazards even if they are not so high. Whilst in verification methods we have obtained the weights on each evaluated level and for this purpose there will be shown results/weights from the second level (sub-systems). So on this level the highest weights by AHP were attributed to the location, pump, filter and tank which is the same with the empirical method as well. These four sub-systems can be found in the results from semi-quantitative methodology of risk analysis as well. The verification methods shown that the results from semi-quantitative method can be considered as suitable and we can design control measures on this results. To sum it up, parts of RWH most prone to the risk events are the pump, the filter and the tank and the location itself can have some contribution to some kind of potential hazardous events as well. Our target is to design appropriate risk management to prevent potential hazardous events especially for small scale RWH projects according to this experimental one.

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1. Zeleňáková M., Ondrejka Harbuľáková V., Šlezigr M. et al., Design, performance and oparation of selected water sturtures, Košice 2012, ISBN 978-80-553-0939-2 2. Karelová Z., Vranayová Z., Káposztásová D. Quantification of risks for systems using rainwater. In: 11. Zdravotno-technické stavby – malé vodné diela – krajina a voda: Zborník z konferencie s medzinárodnou účasťou, 2012, ISBN 978-80-89385-22-5 3. Očipová D., Teoretická a experimentálna analýza distribučných systémov teplej vody z hľadiska mikrobiologického znečistenia, Dizertačná práca, TUKE, 2009 4. Water safety plan manual: step-by-step risk management for drinking-water suppliers. WHO, Geneva, 2009 5. Water Safety Plans, Managing drinking-water quality from catchment to consumer WHO, 2005, Geneva, http://www.who.int/water_sanitation_health/dwq/wsp170805.pdf 6. Microbiological Risk Assessment Series, No. 17 , Chapter 4. Semi-quantitative risk characterization ISBN 978 92 4 154789 5, WHO 2009, http://www.who.int/foodsafety/publications/micro/MRA17.pdf 7. Karelová Z., System of RWH evaluation , In: Young Scientist 2013, Košice, TUKE, Stavebná fakulta, ISBN 978-80-553-1305-4 8. Vairavamoorthy, K., Gorantiwar, S. D., Yan, J. M., Galgale, H. M., Mohamed-Mansoor, M. A., and Mohan, S. – Water Safety Plans: Book 3, Risk Assessment of Contaminant Intrusion into Water Distribution Systems, WEDC, Loughborough University, UK, 9. Saaty, T. L., Decision making with the analytic hierarchy process, Int. J. Services Sciences, Vol. 1, No. 1, 2008. http://www.colorado.edu/geography/leyk/geog_5113/readings/saaty_2008.pdf