Asset management of sewerage systems using risk information

Contribution to the quantification of failure consequences

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ABSTRACT

Despite their importance for the communities, sewer systems are frequently taken for granted. The water sector in general is monopolistic in nature, which in addition to the lack of visibility to the public of the majority of their components and the fact that a significant part is reaching or already reached their service life contribute to explain the situations of poor condition and the continuous decline of several systems. The degradation of these infrastructures increase the vulnerability of the populations to unexpected failures, some of which with catastrophic consequences not only to the system but also its surroundings.

Due to the importance of this subject, the present work is focused on the development of a decision support tool that aims to analyze consequences of sewers structural and functional failures. The main goal of this tool is to help decision makers prioritize actions and investments, reducing the number of failures and both emergency repair and preventive costs.

KEY-WORDS: Asset management systems; Risk management; Consequences; Prioritization; Decision making.

1. INTRODUTION

In a context of scarce resources and to increase the sustainability of the wastewater utilities, the implementation of a physical asset management system is of utmost relevance. This system assists the organizations to operate, maintain, rehabilitate and replace the components of the sewer system in order to comply with the requirements and using fewer resources.

The concept of physical asset management isn't new in the water sector, with European projects such as CARE-S and CARE-W as examples of the work that has been carried out on the topic. Recently, the publication of the ISO 55000 sets out an international baseline for the implementation of physical asset management systems. One important feature of the ISO 55000 is the acknowledgment of the importance that the uncertainties may have, with an explicit reference to risk management.

2. ASSET MANAGEMENT

In January 2014, the International Organization for Standardization published the ISO 55000 series of standards. These standards, that provide an overview about asset management, principles and concepts, define asset management as the "coordinated activity of an organization to realize value from assets" and an asset management system as a "set of interrelated or interacting elements to establish asset management policy, asset management objectives and processes to achieve those objectives".

The implementation of asset management strategies enable organizations to develop a set of tools to support decision making in all its areas. Regardless the complexity of the selected approach, the main objective of an asset management system is to maximize the value of the organization's assets (Alegre and Almeida, 2007; Jones and Lewis, 2012).

2.1 MANAGEMENT OF WASTEWATER SYSTEMS

The significant investment made on wastewater infrastructures during the last century resulted in a major progress in the quality of life of the populations and allowed the compliance with increasingly stringent legal environment and public health requirements.

Despite the importance of the wastewater systems and the poor condition of many of these infrastructures, tends to persist some neglect on their management. In fact, despite all of the developments over the past decades, a significant number of wastewater utilities still manage the systems reactively. Even in many of the cases where proactive approaches have been implemented, there is a significant prevalence of non-formal expert methods in the decision making processes. The negligence can be explained in large extend by the fact that the wastewater infrastructures are predominantly buried and many lack or have deficient access points impairing assessment operations. This scenario is aggravated by the lack of basic historical records and the monopolistic nature of this sector that doesn't promote competitive induced management efficiency improvements (Ariaratnam et al., 2001; ASCE, 2009; Almeida and Cardoso, 2010).

3. RISK MANAGEMENT

Men have always taken into consideration risk in their decisions, initially using non-formal personal or collective memories of past experiences and later using formal approaches using more or less sophisticate methods and historical data collected over space and time (Sousa, 2012). In the wastewater sector the risk management principles are mostly applied in the form of "instincts" or "golden rules". Nevertheless it's important to make decisions in a more systematic way, based on more accurate and formal assessment which allow to assess the relative importance of events or elements (Johansen et al., 2007).

In 2009, the International Organization for Standardization published the ISO 31000 standards series providing an internationally harmonized view of risk management. These standards consist in a set of fundamental principles and guidelines to support the implementation of risk management systems in an organization and defines risk as “the effect of uncertainty on the objectives” and risk management as a “set of coordinate activities, aiming to control the organization in terms of risk”. To achieve the goals of management these activities should be planed and not merely seen as a way of response to adverse events. In addition, these standards suggest that the process of risk management should ensure the acceptance of the residual risk level and the selection of the most appropriate and effective treatments (Sousa, 2012).

Risk assessment in wastewater systems can be used to promote a conscious and proactive prioritization of the organization's resources (Johansen et al., 2007).The main difficulties to quantify the level of risk are associated to two factors. First the difficulties in the identification and analysis of the multiple causes and consequences generated by an event. Second, the fact that this type of analysis requires collecting a great amount of information is among the reason for many organizations to avoid risk management (Aven and Renn, 2010).

4. DECISION MAKING

The aging of the wastewater infrastructures is a natural and unavoidable process and, as they get closer to the end of their service life, the quantity of defects and failures get more frequent, increasing the costs of maintenance. Therefore, the management entities are facing the need to make decisions aiming at prioritize the interventions (operation, maintenance, rehabilitation, replacement or deactivation) (Hahn et al, 1999).

According to Berardi (2009), the implementation of a proactive approach is the key to prevent the deterioration of the system performance and to reduce the direct and indirect cost of failures (e.g., social, environmental, damage in other elements). A proactive approach allows the managers to plan and program the intervention activities based on the criticality of the sewers, before an emergency situation occurs. A strategy based on interventions activities in critical sewers proves to be more advantageous and, historically, the criticality of the sewers was first set based solely on the costs of failure (WRC, 2001).

5. PROPOSED APPROACH

Regarding the high importance of applying risk management strategies in wastewater utilities, the present work proposes an approach to assist in the implementation of risk-informed physical asset management systems for sewers. Following Gomes (2013) work, the presented approach pretends to emphasize the importance of the quantification of failure consequences in risk analysis. This approach aims at prioritizing the sewers in need of rehabilitation and maintenance based on the level of risk due to structural and functional failure, reducing the number of failures and both emergency repair and preventive costs. The level of risk is determined based on the semi-quantitative evaluation of the likelihood of failure and the consequences of failure. Therefore, to evaluate the sewers risk level of failures two different methodologies were applied. In order to analyze the likelihood of failure it was adopted a methodology suggested by Gomes (2013). According to this methodology the likelihood of failure corresponds to the condition rating of the sewers determined from closed circuit television (CCTV) inspection. On the other hand, an expert methodology was developed with the purpose to analyze the consequences of failure. To evaluate the impact of the potential consequences induced by a pipe failure event this methodology considers 8 parameters to classify its magnitude and extension, regardless of being an obstruction or a collapse.

The referred approach was applied to SANEST,S.A sewer's network. With the purpose to include a wide range of scenarios six outfalls, identified in Figure 1, were analyzed.

The SANEST - Sanitation of the Coast of Estoril, SA is the organization responsible for the construction, management and development of the Multimunicipal Sanitation of the Coast of Estoril, under concession until 2020. This organization aims to collect, treat and make the final rejection of urban wastewater from about 800 000 inhabitants-equivalent.

Figure 1 - SANEST, S.A.'s sewerage system

5.1 QUANTIFICATION OF THE RISK

To proceed to the combination of consequences and likelihood analyses, it was applied a risk matrix. According to the risk classification the analyzed sewers were classified according to 3 levels. Based on the outcome of the risk analysis, sewers with higher risk should be considered as a priority by the management entity in the intervention activities.

5.2 DETERMINATION OF THE LIKELIHOOD OF FAILURE

On the wastewater system of SANEST,S.A., all reports of the inspections activities are made with CCTV and based on the European Standard EN13508-2. To overcome the limitation of the European Standard EN13508-2, concerning the inability to assign assets a quantitative classification based on theirs physical conditions, it was applied a methodology developed by Gomes (2013). This methodology suggests an approach to convert the codification related to the defects recorded during the inspection activities according to the European Standard in the codification adopted by protocol WRc. These conversions allowed the use of the SANEST,S.A. inspection activities' records to assign the quantitative classifications to the sewers based on their physical condition, in a scale of 1-5, where sewers classified with level 5 have higher likelihood of failure.

5.3 DECISION SUPORT TOOL - DETERMINATION OF THE CONSEQUENCES OF FAILURE

The developed tool can be implemented in any wastewater system, with limited data resources, not requiring the collection of large amounts of extra information, beyond the data that is already part of management entities databases. Although consequences are frequently associated to cost, this tool doesn't have the purpose to calculate the direct and indirect costs induced by sewers failures. Through evaluation parameters, this tool classifies the importance of the potential impact induced by a specific sewer failure, establishing a comparison between analyzed sewers and identifying those who present higher potential to generate worst consequences. Therefore, with the support of SANEST, S.A.'s employees, the following procedures were conducted:

- definition of evaluation parameters;
- definition of categories;
- definition of weights.

On an initial phase, factors which were considered to significantly influence the effects generated by sewer's failures were identified. These factors were assigned as "evaluation parameters". Then, a set of alternatives circumstances were identified to characterize all situations in which sewers can be found. These alternatives were assigned as "categories". In a final phase, to distinguish the level of importance of these elements, weights were assigned to the evaluation parameters and categories, making it possible to classify sewers in terms of failure consequences. Evaluation parameters, categories and weights used in this methodology are represented in Table 1.

Table 1- Weight assignment of evaluation parameters and categories

Parameters Weight	Evaluation parameters	Categories	Categories Weight
20	Sewers diameter	≤400 mm	15
		≤800 mm	35
		≤1200 mm	65
		>1200 mm	100
14	Sewers depht	≤2 m	5
		≤4 m	15
		≤6 m	25
		≤8 m	45
		≤10 m	70
		>10 m	100
11	Circulation impact	Low impact	20
		Medium impact	50
		High impact	100
7	Population's ativities impact	Low impact	20
		Medium impact	50
		High impact	100
		Not aplicable	0
16	Receiving environment	Low impact (shore)	15
		High impact (shore)	40
		Low impact (waterlines)	50
		High impact (waterlines)	75
		Impacto elevado (crossings)	100
		Not aplicable	0
8	Infratructures impact	Low impact	20
		Medium impact	50
		High impact	100
15	Sewers with access problems	Low aggravation	20
		Hight aggravation	100
9	Sewers in areas where exist incompatibility between the manager entitie and the landowner	Low aggravation	10
		Hight aggravation	100

Concerning the classification based on failure consequences, the developed methodology uses a weight classification system. Therefore, to assign an individual classification associated to the level of potential consequences, this methodology suggests the application of the Equation 1. In this equation "n" represents the number of the existing evaluation parameters, "a_{ij}" represents the categories' weight and "W_{ij}" represents the evaluation parameters' weight.

$$\text{Clasification} = \sum_{j=1}^{n} a_{ij} \text{ x } W_j \qquad (1)$$

According to the value obtained in Equation 1, sewers' final assessment is obtained through Table 2. Sewers classified as level 1 are those that in case of failure show low potential to cause adverse effects. On the other hand sewers classified as level 5 are those who have greater potential to cause damage in case of failure.

Classification obtained with Equation 1	**Sewers final assessment**
[0;0,2[	1
[0,2;0,4[	2
[0,4;0,6[	3
[0,6;0,8[	4
[0,8;1[	5

Table 2- Conversion matrix of the obtained values from the application of Equation 1

6. TOOL APLICATION

In order to apply the developed tool in SANEST.S.A. sewer's network, it was required to manage a significant amount of information, thereby to characterize the analyzed sewers based on evaluation parameters, represented on Table 1, it was necessary to formulate different types of approaches.

For the diameter and depth, the information related to these elements were treated based on record data provided by SANTEST,S.A.. For the consequences generated at the population activities, receiving environment, infrastructures, circulation and additionally for the evaluation parameters that aims to assess existing problems to access sewers, it was necessary to promote a detailed analysis in ArcGIS (Figure 2). Part of this analysis required crossing data between ArcGIS and Google Earth. Finally regarding to the evaluation parameters that assess the existing of incompatibility between the manager and the landowner, it was necessary to analyze a database provided by SANEST, S.A..

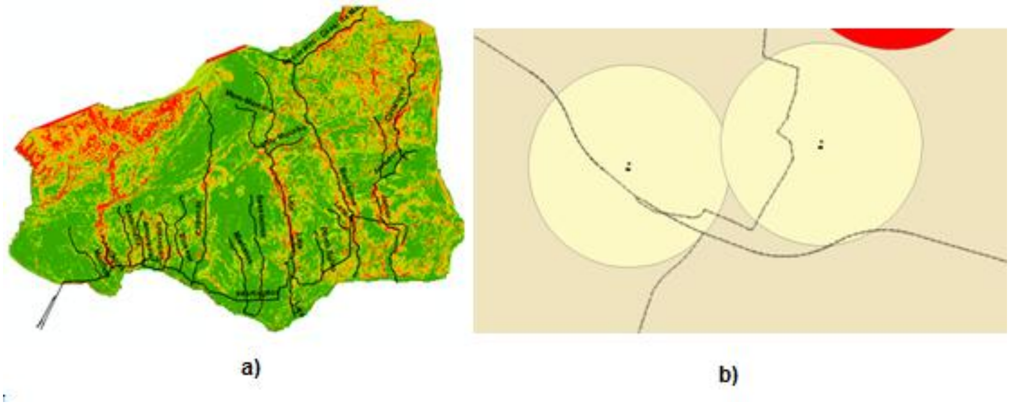

Figure 2- a) Slope map of the analyze area b) Spatial analysis performed in ArcGis

6.1 RESULTS

In terms of physical condition, the results obtained showed that a major part of the sewers, around 44%, were classified with the third level of physical condition. In a general way, it was concluded that the sewers analyzed exhibit a reasonable physical condition (Figure 6.1a).

Concerning consequences of failure, although a very significant part of the network, about 43%, were classified as level 2, 49% was considered as level 5 (Figure 6.1b). From all the 6 studied outfalls, Castelhana was concluded to be the one to generate bigger impacts in case of failure events, since 78% of the sewers were assessed with level 5. On the other hand, Laje results proved that the impacts caused by the failure of its sewers are the smallest, since 67% of them were assessed with level 2.

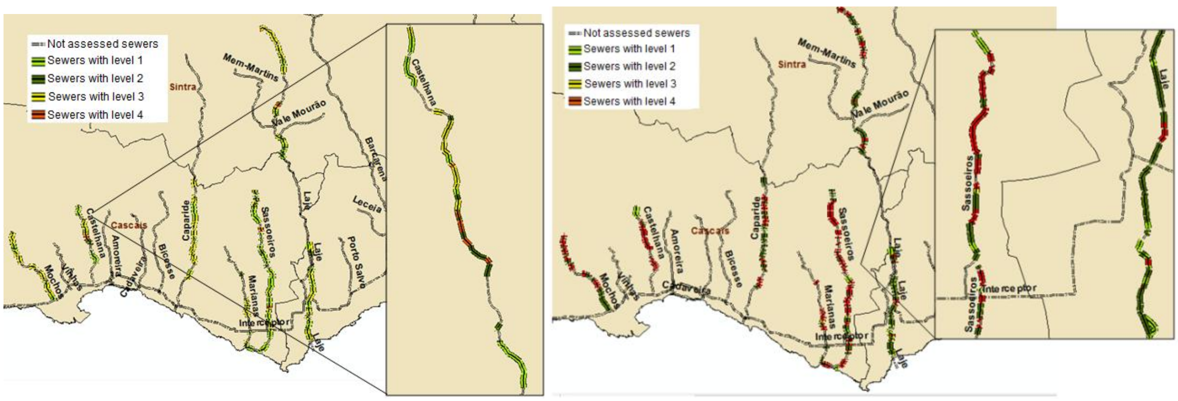

Figure 6.1- a) Results obtained in terms of likelihood of failure b) Results obtained in terms of consequences of failure

Finally, in terms of risk the analysis results revealed that 54% of the sewers analyzed are associated with a medium level of risk. However, the percentage of sewers which have high risk level is very significant, approximately 20% (Figure 6.2).

Despite the sewers' condition level were considered to be satisfactory, this analysis showed that most of the studied sewers can generate serious consequences in case of failure. In part, these results are justified with the fact that, in this study, it was considered the proximity to streams as one of the evaluation parameters with greater impact on the failures events and the fact that the analyzed sewers are located along of the main existing waterlines.

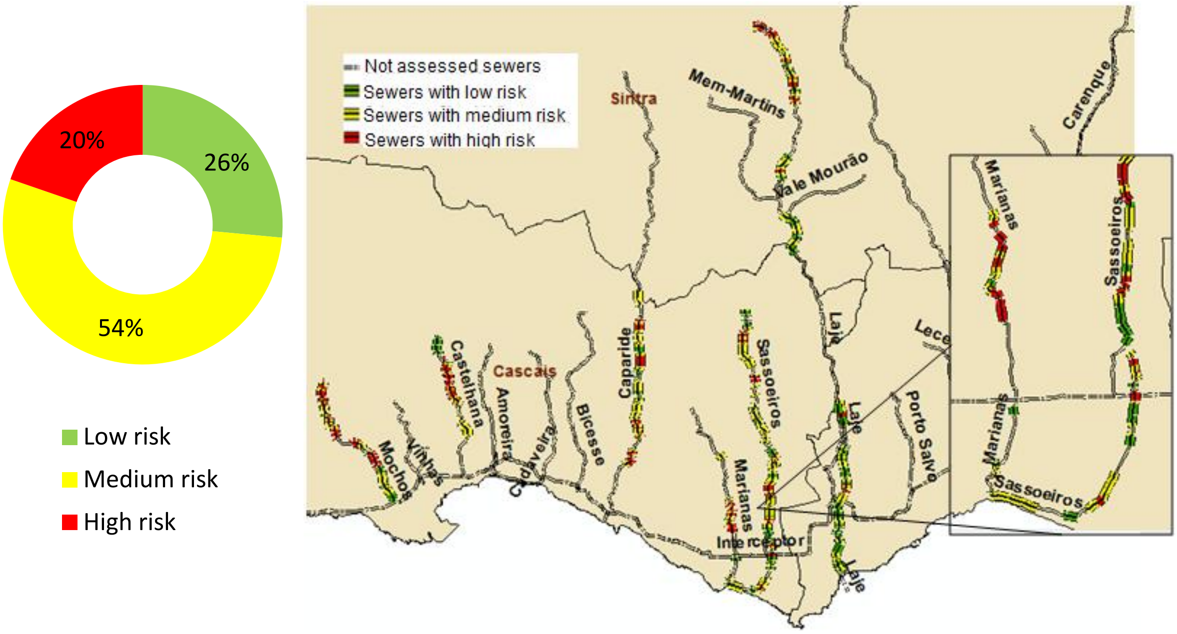

Figure 6.2 - Results obtained in terms of risk of failure

7. FINAL CONSIDERATIONS

To establish a proactive strategy management based on risk information in order to improve the performance of sewerage systems, it is crucial to assess the assets' surroundings, in order to identify the different potentials impacts that a failure can generate. In the other hand, is essentially to develop inspection campaigns on the assets, to assess its structural and functional conditions, in order to develop a real understanding of the current condition. The detail and accuracy used in these assessments are crucial to, in the context of risk management, obtain satisfactory results.

According to the limitations of capital and resources that many organizations currently going through, it is critical that, in wastewater sector, implemented risk management strategies, prioritize assets with higher intervention needs, preventing all situations that can harm the system and its surroundings. Therefore it is essential that sewers with higher needs are proactively managed.

In terms of future developments it is suggested the expansion of the assess of the consequences' study, particularly in the following aspects:

- evaluation of direct and indirect costs, associated to the damage caused by failures, according to social, environmental and economic perspectives;
- increase the range of evaluation parameters;
- assess of the consequences taking into account different types of failure.

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