Decision making tool applied to the management of stormwater sewer systems

Cascais Próxima, E.M., S.A. case study

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Abstract

With regard to infrastructures that meet the needs of modern communities and in the context of consolidated urban spaces, the core of asset management lies in the use stage. Indeed, in most developed countries the need to expand these infrastructures tends to be marginal and, although the components reach the end-of-life, the infrastructures don't In the specific case of stormwater drainage systems, where the operation activities are limited, in practice the utilities responsible for their management mainly deal with the rehabilitation (definition of EN 752) of the systems.

With the aging of these infrastructures and the consequent increase in the number of failures, there was a transition from reactive management models to proactive models. However, approaches based on age and condition require significant resources, which has led to the development of risk-based approaches. The latter establish the intervention priorities considering the likelihood of occurrence of failure and the consequence of this failure, allowing to differentiate in terms of priority components that have the same age or condition in terms of physical degradation.

In the present work, a decision support tool for intervention in risk-based stormwater drainage systems is presented. The tool was developed for the particular context of the municipality of Cascais. Given the limitations in terms of information, an expert approach was adopted, complemented by documentary and bibliographic information in the definition of the parameters that characterize the likelihood and consequences in the event of system failure.

Key-words: asset management, proactive approach, risk, decision making, analytic hierarchy process

1. INTRODUCTION

Drainage infrastructures in general, although fundamental to quality of life, have often been neglected until failure occurs due to their lack of visibility (WEF-ASCE, 1994). These infrastructures differ from others in terms of rehabilitation methodologies due to the following aspects (Almeida and Cardoso, 2010): i) they are exempt from the market mechanisms that encourage efficiency improvements because they are natural monopolies, in addition to the lack of market rules; ii) are mostly buried, which makes it difficult to assess the condition; iii) are a paradigmatic example because, despite being an essential public service, they are neglected because they are assumed to be obvious by the populations; and iv) behave as a system and not as a sum of components.

Historically, interventions in these infrastructures were carried out in a reactive way as the failures occurred. This may not be the most economically advantageous solution and certainly does not contribute to optimizing system performance (Boulos, 2009; Wirahadikusumah et al, 1998). In fact, the aging of the infrastructure can result in costly emergency repairs and reduced service levels. It has been found that in many cases reactive management is not sustainable because of the high costs of emergency interventions and due to increased pressure from users and regulators (Moteleb, 2010). As a consequence, it has been observed that in the last 40 years there has been an evolution towards proactive strategies (Sægrov et al, 1999; Rostum, 2000), which see maintenance as a function that adds value (Petersdorff, 2013).

More recently the maintenance issue has been encompassed by the broader concept of asset management. The publication in 2014 of the ISO 55000 family of international standards has provided a basis for requirements that an asset management system must meet, representing a broad international consensus on this subject. According to these standards, asset management covers the entire life cycle, from acquisition to end of life, incorporating the different values of the stakeholder involved and the vectors that may influence the value of the assets. It should also explicitly consider risk, to take into account the effect of uncertainty on the goals set for asset management.

Given the complexity of these infrastructures and the values / objectives involved in their management, decision-makers need to safeguard hydraulic, structural, environmental and operational performance and respect financial constraints, imposed service levels and regulatory requirements (Moteleb, 2010; al, 2012; Vanier, 2001). According to The Institute of Asset Management (2011), risk-based decision making is a vital element underlying a successful application of physical asset management. The goal is to determine the optimal combination of performance and risk by conducting an assessment of exposure to risk, indirect or intangible impacts, and long-term effects. Consequently, this requires the understanding of various quantification techniques, including how to assess risk, the actual complexities of asset deterioration, engineering confidence, and financial calculation methods. In order to consider these complexities in a disciplined and understandable way, not only as an independent asset, but as a system of interdependent factors, sophisticated tools and experience of interpretation of the information obtained are needed (Petersdorff, 2013).

In urban areas with large drainage networks, infrastructure sustainability benefits greatly from the implementation of these asset management systems to ensure their smooth operation at the lowest possible cost. The efficiency of an infrastructure asset management is largely dependent on the use of decision support tools to plan operations and maintenance activities (Sousa, 2007; Zhao et al, 2001).

In this work, a tool to support decision-making in the management of stormwater drainage systems is developed. The application of the methodology proposed to some sections of the drainage system of the municipality of Cascais is also illustrated.

2. PROPOSED APPROACH

2.1. General Formulation

The tool developed consists in a multicriteria model for prioritizing sewer sections based on the risk of failure. A total of 2 factors and 10 parameters were identified to evaluate the likelihood of failure and 5 factors and 19 parameters to evaluate the consequences of failure. For the determination of the relative weights of the factors and parameters, the Analytical Hierarchical Process and relative weighting evaluation were used, respectively. The level of risk was estimated using the risk matrix.

The classification of the sewers according to the likelihood of failure and with the consequences of failure can be formulated by Equation 1.

$$Classification = \sum [K_n \times [\sum (P_{nm} \times a_{nmi})]] \quad (1)$$

in which "n" represents the number of factors identified; "m" is the number of parameters in which each factor is divided; "i" is the number of possible categories for each parameter; A_{nmi} represents the set of categories corresponding to each parameter, F_{nm}, which refer to the main factors, C_n; K_n represents the weights attributed to the main factors; P_{nm} corresponds to the weight of each parameter; and a_{mni} represents the weight of each corresponding category.

The methodology translated by Equation 1 corresponds to a weighted sum, being used in the classification of the likelihood of failure and the consequences of failure based on the weights assigned to the parameters and criteria considered relevant in each case. Additionally, the classification of the sewers in terms of the risk of clogging, related to the maintenance operations (cleaning), and the risk of collapse related to the rehabilitation interventions are also differentiated.

The result obtained by the application of Equation 1 is between 0 and 100 (or 0-1), and is converted in a scale of 1 to 5 using Table 1.

Table 1 - *Classification conversion to a level of likelihood or consequence*

Classification	Likelihood or consequence level
[0,0;0,2[	1
[0,2;0,4[	2
[0,4;0,6[	3
[0,6;0,8[	4
[0,8;1,0]	5

In this process, the levels of collapse likelihood (P_R) and consequence (Q_R) are obtained, allowing to estimate the risk of collapse and establish relative rehabilitation priorities. The risk of clogging is also estimated to establish relative cleaning priorities based on the levels of clogging likelihood (P_{OM}) and consequence (Q_{OM}). Regarding the likelihood of failure, the sewers classified with level 5 are the ones that are more likely to fail than those that present level 1, which are those that are less likely to fail. In the same way, sewers classified with level 5 are apt to cause larger damages, in contrast, sewers classified as level 1 represent sections with very insignificant effect of failure. The level of risk is obtained according to the risk matrix shown in Table 2.

Table 2 - *Risk matrix*

		Consequences of failure				
		1	2	3	4	5
Likelihood of failure	1	Reduced risk	Reduced risk	Average risk	Average risk	Average risk
	2	Reduced risk	Average risk	Average risk	High risk	High risk
	3	Average risk	Average risk	High risk	High risk	High risk
	4	Average risk	High risk	High risk	High risk	Very high risk
	5	Average risk	High risk	High risk	Very high risk	Very high risk

In addition to the risk of clogging and collapse, the tool also allows the determination of the risk of global failure. For this, it was necessary to obtain unique values for the likelihood of failure and for the consequences of failure, thus encompassing situations of clogging and rupture. From Equation 2 we determine the likelihood of failure ($P_{failure}$) as the inverse of the likelihood of not occurring any failure. Equation 3 allows to estimate the consequence of global failure ($Q_{failure}$), corresponding to a weighting of the consequences of failure associated with clogs and collapses.

$$P_{failure} = 1 - ((1 - P_{OM}) \times (1 - P_R)) \quad (2)$$

$$Q_{failure} = \frac{P_{OM} \times Q_{OM} + P_R \times Q_R}{P_{failure}} \quad (3)$$

After obtaining the likelihood value and the consequence of failure in general, the same procedure described above is followed to convert $P_{failure}$ and $Q_{failure}$ into levels and determine the corresponding risk of failure.

The possibility of analyzing separately the level of risk of collapse and of clogging or jointly, represented by the level of risk of failure, allows the decision maker to choose the alternative that best suits each specific situation. The risk-of-failure classification can be used to obtain an overview of the harmonized network in a single indicator, however it is operationally less useful because it does not directly relate to the type of intervention required.

2.2. Calibration

To assign a classification regarding the level of risk of the sewers, based on the likelihood of failure and the level of consequences that a failure can potentiate, the tool uses the weighting of factors, parameters and their categories through the attribution of weights. These weights reflect the relative importance they have in the performance of stormwater drainage systems.

The weights were determined using an inquiry, developed based on the bibliographical data collected to list the factors, parameters and categories relative to the likelihood and the consequence of sewers failure. Table 3 shows the characterization of the interviewed subjects, all employees of Cascais Próxima.

Table 3 - *Characterization of the interviewed subjects*

Id	Position
E1	Engineer of the Subunit of Intervention in Public Space
E2	Director of the Department of Intervention in Public Space and Urban Regeneration
E3	Surveillance and construction management engineer
E4	Engineer of the Department of Intervention in Public Space and Urban Regeneration
T1	Operational assistant of the Subunit of Intervention in Public Space
T2	Civil construction technician in contract management

However, different methods were used to assign weights to factors, parameters and categories. In particular, the attribution of weights to risk factors was done using the Analytical Hierarchical Process. The Analytical Hierarchical Process, introduced by Thomas Saaty (1980), is an effective tool for dealing with complex decision making and can help the decision maker to prioritize and make the best decision. By reducing complex decisions to a series of comparisons in pairs, and then synthesizing the results, the process helps in capturing the subjective and objective aspects of the decision. However, since it requires the comparison of all variables among them, it is a difficult method to apply when the number of variables increases. Thus, for the parameters and categories the weights were determined directly, imposing only that their sum was unitary.

Regarding the application of the Analytical Hierarchical Process, the inquiry was divided in two parts, one corresponding to the risk factors regarding the likelihood of occurrence of failure, admitting that the condition is unknown (no inspection of the sewer), and a second part corresponding to the risk factors with respect to the consequences of failure (assuming that the failure occurs). Respondents were asked to first assess the relative importance of risk factors using a Likert scale (Table 4) for both parties, likelihood and consequence of failure.

Table 4 - *Likert scale*

Scale	Importance
1/9	Extremely inferior
1/7	Very inferior
1/5	Inferior
1/3	Moderately inferior
1	Iqual
3	Moderately superior
5	Superior
7	Very Superior
9	Extremely superior

Note: It can be used the values ½, ¼, 1/6, 2, 4, and 6 to represent intermediate points of relative importance.

Next, the respondents were asked to order the "n" parameters that characterize each risk factor by assigning the value of "1" to the sub-factor of major importance and "n" to that of the minor. This procedure was adopted for both likelihood and consequences, distinguishing between clogging (related to maintenance operations) and collapse (related to rehabilitation operations).

The values adopted for factor weights, both of likelihood of failure and of consequences, were determined from the following steps: i) determination of a value of relative importance for each relation between factors, resulting from an analysis of the results obtained through the average, mode and median (not all respondents gave the same importance to the comparison by a pair); and ii) application of the Analytical Hierarchical Process, obtaining the weights by determining the comparison matrix values per pair. The results obtained are shown in Figure 1 and Figure 2 for the weight of factors related to the likelihood of failure and the consequence of failure, respectively.

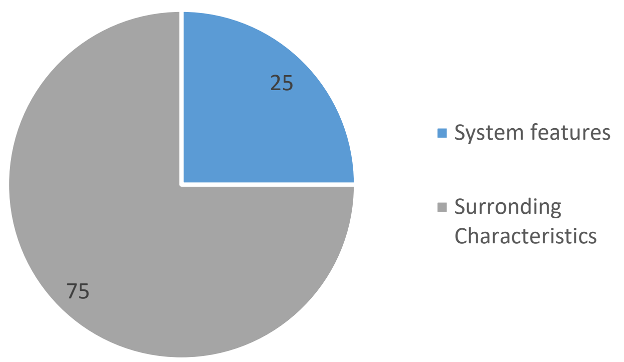

Figure 1 *- Weights of the factors with influence on the likelihood of failure*

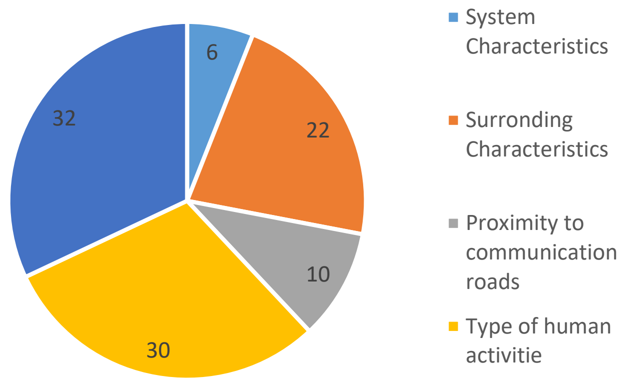

Figure 2 *- Weights of the factors with influence on the consequences of failure*

For the attribution of the weights to the parameters, the results of the surveys were also used. However, the classification was made in a different way, following the approach: i) determination of the relative classification between parameters, within the same factor, according to the answers obtained in the surveys and using the operations of average, mode and median; ii) assignment of weights to each parameter, so that the sum of the weights corresponding to each factor was equal to 100. In this case, the final weights were obtained with review by the respondents. Table 5 and Table 6 show the weights of each parameter relative to the likelihood and consequences, respectively, distinguishing maintenance and rehabilitation operations.

Within each parameter, categories were defined, even for the parameters that could be used on a continuous scale (e.g., depth, diameter), and the respective weights were determined in a direct manner with help of the respondents. In each parameter there is always a category with a weight of 100, corresponding to the situation with greater likelihood or consequence of failure, and there may also be categories with weight 0. Table 7 and Table 8, present the weights assigned to each of the categories defined in each parameter.

Table 5 *- Weights of the likelihood of failure parameters*

Parameters	Weights (O&M)	Weights (R)
System features:		
- diameter	15	12
- depth	6	8
- age	8	13
- material	10	15
- slope	17	6
- number of lateral conexions	13	10
- soil condition	12	17
- number of occurences	19	19
Surrounding features:		
- surface actions	43	43
-surface activities and occupation	57	57

Table 6 *- Weights of the consequences of failure parameters*

Parameters	Weights (O&M)	Weights (R)
System features:		
- diameter	40	10
- depth	30	30
- number of lateral conexions	20	40
- soil condition	10	20
Surrounding features:		
- occupation density	57	57
-environmentally sensitive areas	43	43
Proximity to communication roads:		
- primary road network	40	40
- secundary road network	30	30
- railway network	20	20
- others	10	10
Type of human activitie:		
- residential	20	16
- comercial	16	18
- industrial	13	13
- educational	18	20
- health	22	22
- turistic and leisure	11	11
Intervention constraints:		
- proximity to water lines	22	33
- Landslide risk	44	44
- access dificulties	33	22

3. CASE STUDY

3.1. General considerations

The case study that follows aims to demonstrate the application of the tool to sections of the stormwater drainage system of the municipality of Cascais. The drainage system is separative, although in practice it is likely to be pseudo-separative because of the frequent existence of erroneous connections (domestic extensions connected to the stormwater drainage system and storm drains connected to the wastewater drainage system) in drainage systems in Portugal and also around the world.

Presently, there is no complete and systematized information about the stormwater drainage system of the municipality of Cascais. Because of the information limitations, different sources of information were used, including records (GIS system) and experts (Cascais Próxima technicians).

From the collection and analysis of information carried out, the system has a development of about 490 km and the oldest sewer dates back to 1944. According to the current municipal regulation, sewers cannot have a diameter of less than 400 mm, in concrete, or 315 mm, in PVC. The minimum diameter of the connecting branches is 250 mm. The largest sewer recorded is 4000 mm in diameter. The predominant materials of the pipes are concrete (older sewers) and corrugated polypropylene (more recent sewers).

The application of the tool involved three main steps, namely: i) selection of the sections to be analyzed; (ii) collecting data on the selected sections; and (iii) analysis of the data collected. For the operation of the tool, an Excel spreadsheet was developed, gathering the collected information and automatically classifying the sewers in terms of risk of collapse, clogging and failure.

Table 7 - *Weight of the categories of likelihood of failure*

Fators	Categories	Description	Weight
System features:			
- diameter	<300mm	-	75
	≤ 300 - 600mm <		100
	≤ 600 – 1000 mm <		45
	≥ 1000mm		15
- depth	1 – 2 m ≤	-	100
	< 2 – 3 m ≤		65
	< 3 – 6 m		25
- age	Until the 50's	-	75
	60's and 70's		45
	80's and 90's		100
	After 2000		25
- material	Cement or ceramic	Concrete, sandstone or asbestos cement sewers.	100
	Plastic	PP or PVC sewers.	15
- slope	0 – 1% <	-	100
	≤ 1 – 4 % <		85
	≤ 4 – 10% <		25
	≤ 10 – 15%		5
- number of lateral conexions	+3	-	100
	2		70
	1		35
	0		0
- soil condition	Waterproof	Sewer located on a waterproof area.	100
	Permeable	Sewer located on a permeable area.	50
- number of occurences	3 or more occurences per year	Record of tree or more occurences per year.	100
	2 occurences per year	Record of two occurences per year.	75
	1 occurence per year	Record of one occurence per year.	25
	0 occurences	No record of occurences.	0
Surrounding features:			
-surface actions	Level 1	Sewer located on an area of supra municipality road.	40
	Level 2	Sewer located on an area of main distribution road.	100
	Level 3	Sewer located on an area of secondary distribution road.	85
	Level 4	Sewer located on an area of local distribution road.	65
	Level 5	Sewer located on an area of local access road.	10
Surface activities and occupation	High impact	Sewer located on an area with the presence of big trees and with the existence of sand or other particles.	100
	Medium impact	Sewer located on an area with the presence of big trees or with the existence of sand or other particles.	60
	Not applicable	Sewer is not located on any of the described areas.	0

Table 8 - *Weight of the categories of consequences of failure*

Fators	Categories	Description	Weight
System features:			
- diameter	<300mm	-	25
	≤ 300 - 600mm <		50
	≤ 600 – 1000 mm <		75
	≥ 1000mm		100
- depth	2 m ≤	-	25
	< 2 – 3 m ≤		50
	< 3 – 6 m		100
- number of lateral conexions	+3	-	100
	2		70
	1		35
	0		10
- soil condition	Waterproof	Sewer located on a waterproof area.	100
	Permeable	Sewer located on a permeable area.	50
Surrounding features:			
- occupation density	High impact	Sewer located on an urban area.	100
	Low impact	Sewer located on an rural area.	45
- environmentally sensitive areas	High impact	Sewer located on the proximity of the coast line.	100

	Medium impact	Sewer located on the proximity of a riverside area.	60
	Not applicable	Sewer is not located on any of the described areas.	10
Proximity to communication roads:			
- primary road network	Applicable	Sewer located on the proximity of a primary road network.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- Secondary road network	Applicable	Sewer located on the proximity of a secundary road network.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- Railway network	Applicable	Sewer located on the proximity of a railway network.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- Outhers	Applicable	Sewer located on the proximity of another communication road.	100
	Not applicable	Sewer is not located on any of the described areas.	10
Type of human activity:			
- residential	Applicable	Sewer located on a residential area.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- comercial e services	Applicable	Sewer located on a comercial area.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- industrial	Applicable	Sewer located on an industrial area.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- educational	Applicable	Sewer located on an educational area.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- health	Applicable	Sewer located on an health area.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- turistic and leisure	Applicable	Sewer located on a turistic and leisure area.	100
	Not applicable	Sewer is not located on any of the described areas.	10
Intervention constraints:			
- water lines proximity	High impact	Sewer located on the proximity of the coast line.	100
	Medium impact	Sewer located on the proximity of a riverside area.	60
	Not applicable	Sewer is not located on any of the described areas.	10
- landslide risk	Applicable	Sewer located on the proximity of an area with landslide risk.	100
	Not applicable	Sewer is not located on any of the described areas.	10
- Access difficulties	Applicable	Sewer located on an area with access dificulties.	100
	Not applicable	Sewer is not located on any of the described areas.	10

3.2. Study sections

Given the differences in the sources and formats in which the information necessary to implement the tool is available, it was necessary to limit the scope of this work to the demonstration of the application of the tool and not to the exhaustive analysis of the whole system. In addition, taking into account the existence of information gaps, it was sought to select sections that would allow the tool to be tested in real-life situations in conjunction with the Cascais Próxima technicians.

As a result of this selection process, twelve study areas were defined, each of which includes a set of four to seventeen sewer reaches. These areas were defined according to the available information and trying to cover different typologies of location, portraying in the best way the diversity of situations of the factors, parameters and categories defined in the methodology and present in the drainage network. Table 9 presents a characterization of each of the studied areas, comprising a total of 110 sewer reaches.

Table 9 - *Characterization of the studied areas*

Study area	Number of sewers	Total length (m)	Parish	Locality	Main street
Zone 1	10	351,06	Alcabideche	Alcabideche	Estrada das Tojas
Zone 2	8	238,58	U.F. Cascais e Estoril	Estoril	Avenida do Ultramar
Zone 3	6	261,73	U.F. Cascais e Estoril	Cascais	Avenida Marechal Carmona
Zone 4	9	432,82	U.F. Cascais e Estoril	Fontaínhas	Rua das Fontaínhas
Zone 5	17	209,83	Alcabideche	Pai do Vento	Rua Marquês do Soveral
Zone 6	5	100,32	U.F. Cascais e Estoril	Cascais	Paredão Praia das Moitas
Zone 7	15	345,20	U.F. Cascais e Estoril	Cascais	Avenida Dom Pedro I
Zone 8	6	229,21	U.F. Cascais e Estoril	Guincho	Rua da Areia
Zone 9	11	386,06	U.F. Cascais e Estoril	Birre	Rua das Papoilas
Zone 10	9	212,05	U.F. Cascais e Estoril	Aldeia de Juzo	Estrada da Malveira da Serra
Zone 11	4	143,77	São Domingos de Rana	Caparide	Rua do Campo
Zone 12	10	206,12	São Domingos de Rana	São Domingos de Rana	Rua da Nova Aliança

3.3. Data collection

The characteristics of the stormwater drainage system required for the implementation of the tool were provided mainly by Cascais Próxima. The sources of information and the information collected were: i) SIG of the Municipality of Cascais, through the site "geocascais.cm-cascais.pt/", for the exporting of information regarding the location and physical characteristics (diameter, material, depth, slope) of the stormwater system, including manholes and pipes, existing constructions, layout of the hierarchical traffic network and ground altimetry; ii) "Book of operations - LO" containing Excel database of operations carried out in the last four years; and iii) Google Earth for identifying the characteristics of the surrounding areas of interest when this information was not available in the GIS application (e.g., Hospitals).

3.4. Data analysis

A significant part of the data could be used directly or almost, without the need for any further analysis. An example of this type of information is the diameter, the material of the sewers, inclination or depth. Other aspects, however, required some additional analysis and the need to make choices.

Regarding the sewers age, the date indicated as "Approval in a council meeting" was considered. However, it was verified that most of the sewers did not present this information.

From the SIG system further information was withdrawn by observing or crossing data. The number of lateral connections was determined by the analysis of the network configuration, also in the GIS of the Municipal Council of Cascais, observing if there were direct connections between sewers, not being made through manholes. To determine the surface actions, the information between the layer corresponding to the stormwater network and the road hierarchy was crossed, verifying the level of the road in which each sewer is located. The risk of landslide was evaluated by the analysis of the GIS altimetry layer, then calculating the maximum slope verified at the location where the analyzed sewer is located.

The soil condition, surface activities and occupation, occupancy density, proximity to environmentally sensitive areas, proximity to communication routes, predominant nature of human activity and difficulty of access were determined through the analysis of the area in question in Google Earth. The methodology used was the same for all these parameters, except for proximity to environmentally sensitive areas, specifically for proximity to streams. In this case, the GIS was used to analyze the layer referring to the location of streams to verify their proximity to the sewers studied. Since the GIS tool used does not allow the creation of new layers, only allows data analysis, it was necessary to use an alternative method. Thus, areas were printed near water lines, coastlines and streams, and a geometric measurement was made using drawing material to determine which sewers were within the water domain. For the other factors analyzed using Google Earth, their evaluation was made only by observing the area where each sewer is and the characteristics that define it.

The number of occurrences in the past was determined through the analysis of the record of interventions in the "Book of operations - LO" of Cascais Próxima. All operations arise from a complaint, so it was assumed that the number of interventions resulting therefrom corresponds to the number of known failures. The search of the interventions was carried out by the name of the street where the sewer under analysis is located, since the operations are not defined by sewer ID. As there are multiple sections of sewer per street, this procedure can result in an overestimation of the number of occurrences.

3.5. Analysis and discussion of results

In order to allow greater sensitivity to the results from the application of the proposed tool, the following aspects were analyzed separately: i) quantification of the failure likelihood; ii) quantification of the failure consequences; and iii) quantification of the risk of clogging, collapse and failure.

3.6. Quantification of the failure likelihood

In order to verify the number of sewers within each category of likelihood of failure, the distribution of the proportion of sewers in each one is presented in Figure 3.

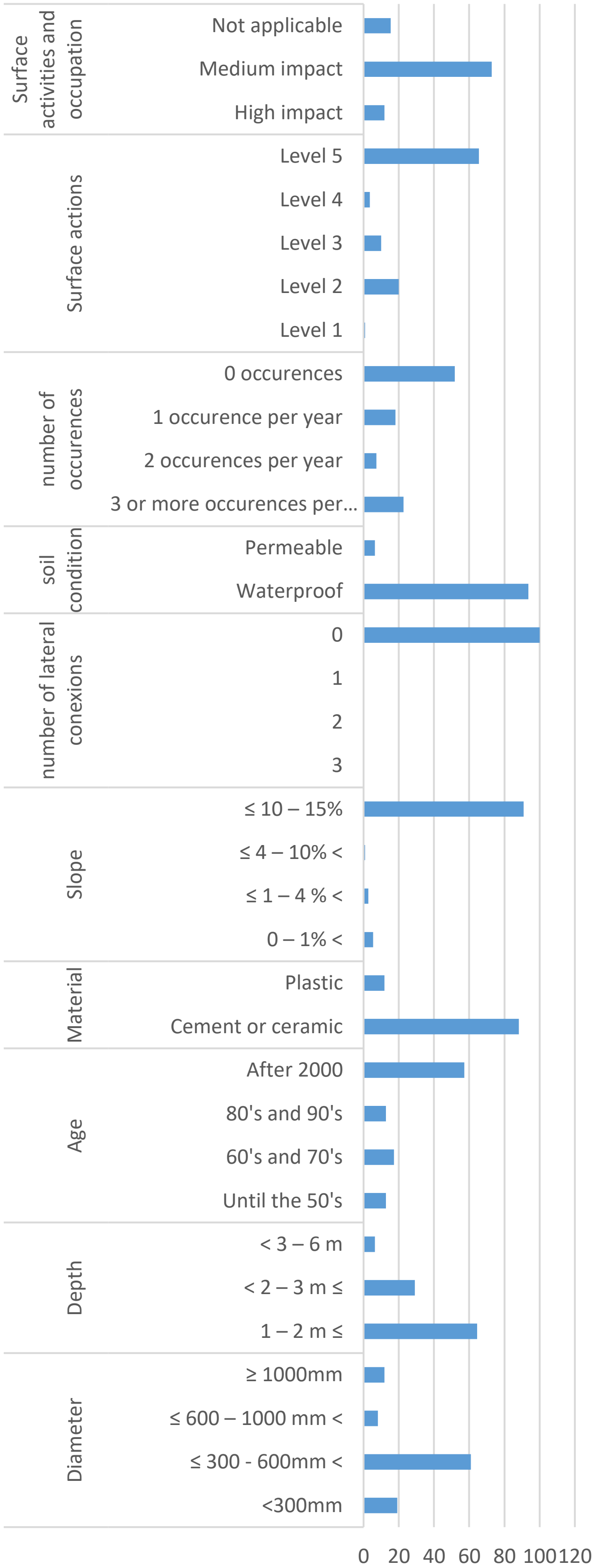

Figure 3 *- Percentage of sewers studied by category of failure likelihood*

3.7. Quantification of the failure consequences

In order to ascertain the number of sewers within each category defined for quantification of the consequences of failure, the distribution of the proportion of sewers in each is presented in Figure 4.

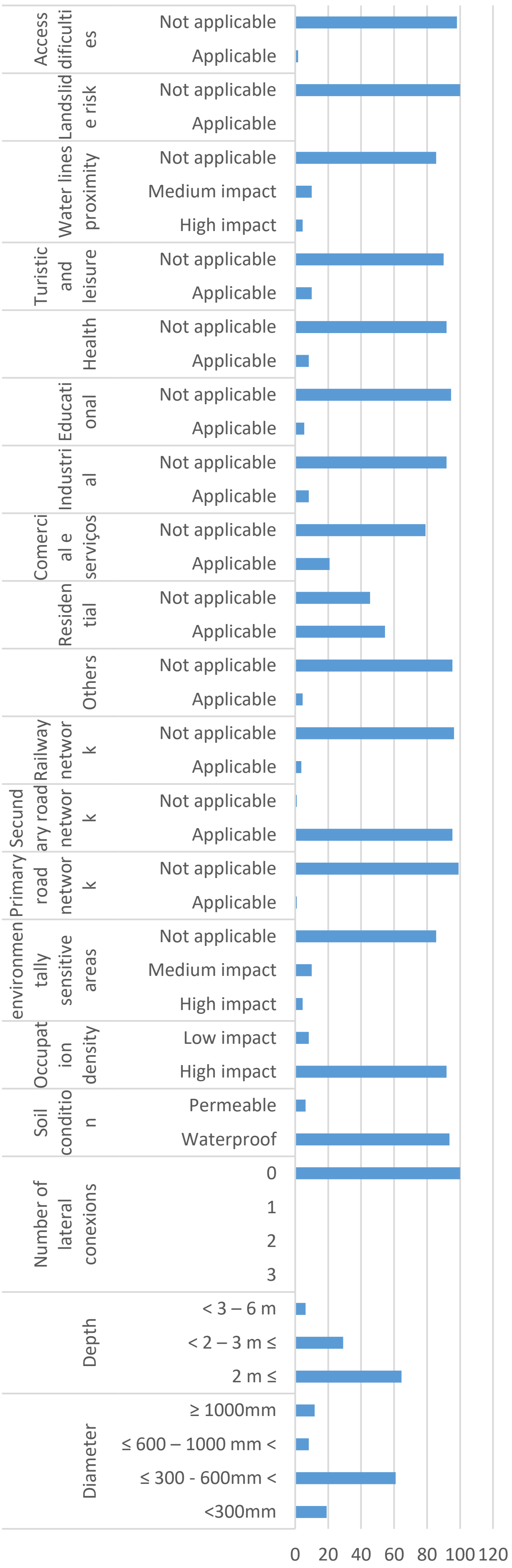

Figure 4 *- Percentage of sewers studied by category of failure consequences*

3.8. Quantification of the risk failure

Regarding the risk of clogging, almost half of the analyzed sewers are medium risk (Figure 5). Although there is no sewer with a very high risk level, the percentage of sewers with high risk is very significant, 38%.

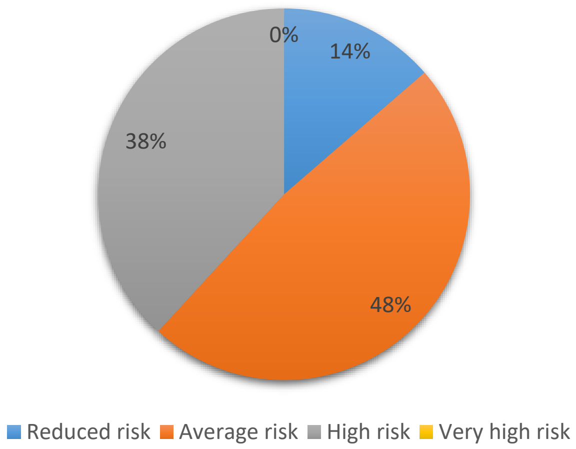

Figure 5 *- Classification of clogging risk level*

Figure 6 shows the percentage of sewers per level of clogging risk per study zone. All sewers of Zones 8 and 10 are high risk while in zone 12 almost all sewers are reduced risk.

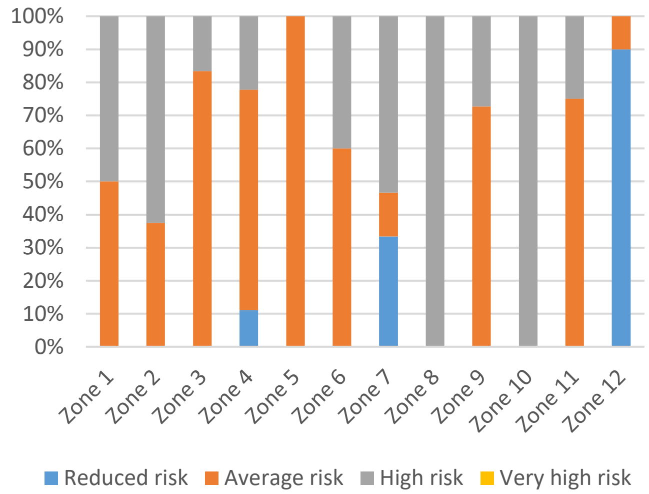

Figure 6 *- Classification of clogging risk level per study zone*

Regarding the risk of collapse, the percentage of sewers classified as medium risk and high risk is similar (Figure 7). There is also no sewer with very high risk.

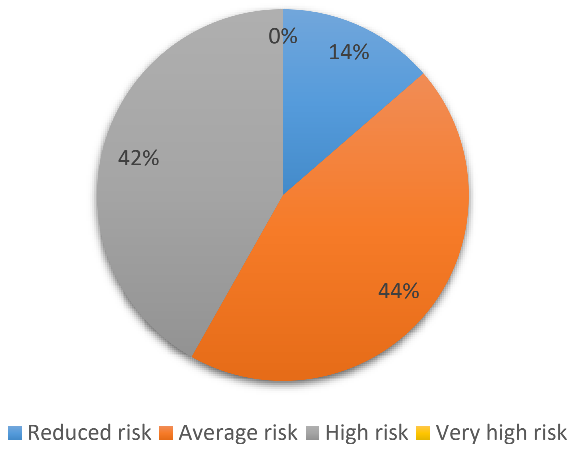

Figure 7 *- Classification of collapse risk level*

By analyzing the distribution by zones, we can see that the results are similar to the ones in the previous case, also highlighting zone 8 and the zone 10 for having all sewers classified with high level and the zone the zone 12 for most seres being of reduced risk (Figure 8).

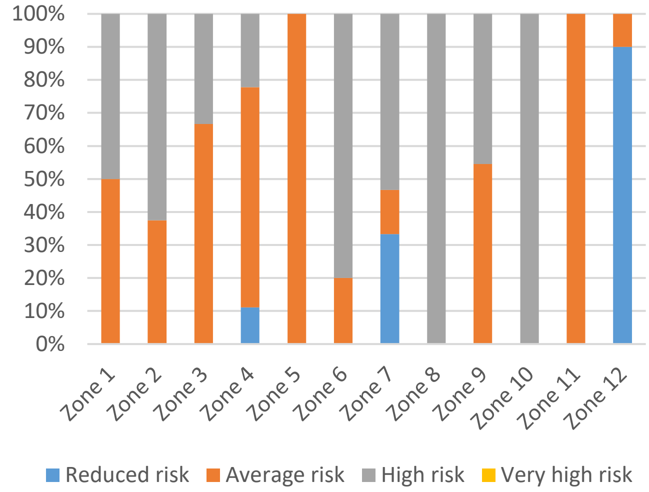

Figure 8 *- Classification of collapse risk level per study zone*

Figure 9 and 10 represent the results about the risk of failure. The majority of the sewers evaluated present a high level of risk, and there is no situation of reduced risk nor very high risk. The distribution by zones will also be quite uniform, with most areas only having sewers with a high risk of failure.
The results obtained for the risk of failure, although limited by the reduced scope of the study, point out that the use of the same scale of risk levels used for the level of risk of clogging and collapse may not be indicated to differentiate the sewers and assist in setting priorities.

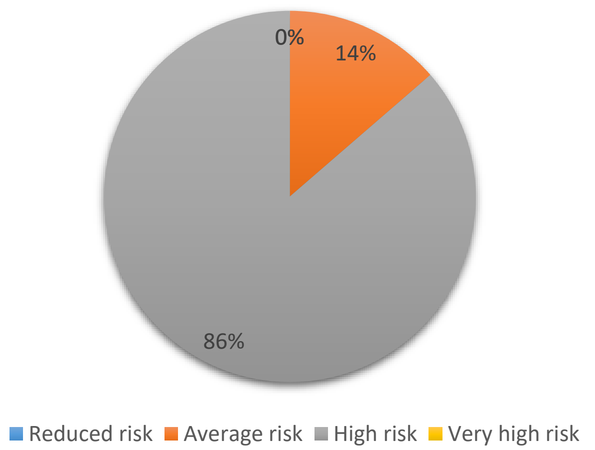

Figure 9 - Classification of failure risk level

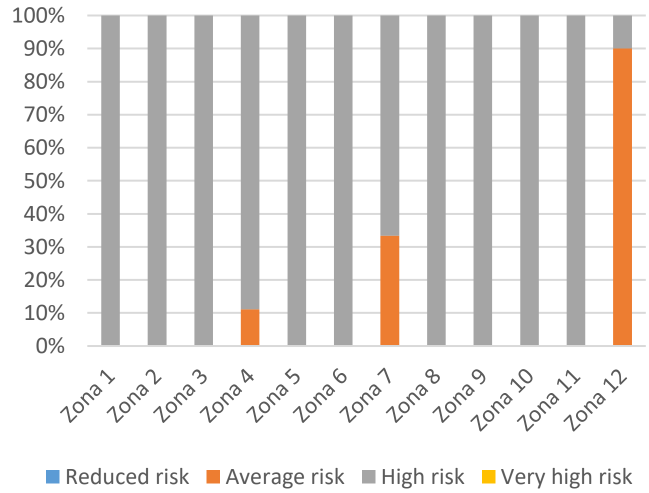

Figure 10 *- Classification of failure risk level per study zone*

3.9. General analysis of the network

To calibrate the model according to the network, an analysis of occurrences was performed to determine the weights of clogs and collapses and thus to have a better perception of the incidence of both types of failure.
For this purpose, the "List of Operations - LO" (database of all operations, composed of fields relevant to the characterization of each operation, such as date, value, type of operation and location) was used and 381 occurrences that took place over the past 4 years were analyzed. Table 10 shows the distribution of occurrences by type of intervention.

Table 10 *- Types of occurrences recorded*

Clearance	Cleaning	Repair	Total
39	332	10	381

Although each occurrence is identified, sometimes the activity to which it is associated is not correct. According to Cascais Próxima experts, it is estimated that 5% of the "Cleaning" operations include clearings and 20% of the activities described as "Clearance" actually correspond to repairs (Table 10).

Table 11 *- Distribution of percentages corresponding to each operation*

<table>
<tr><th colspan="2">Cleaning</th><th colspan="2">Clearance</th><th>Repair</th></tr>
<tr><td>Cleaning</td><td>Clearance</td><td>Clearance</td><td>Repair</td><td rowspan="2">100%</td></tr>
<tr><td>95%</td><td>5%</td><td>80%</td><td>20%</td></tr>
</table>

It was determined that of the totality of documented occurrences, about 70% correspond to clogging and 30% to collapses.
Assuming as a value of reference that in one year there are about 96 occurrences, corresponding to 381 occurrences in 4 years, according to the calculated weights in the network under analysis occur about 67 clogs and 29 collapses annually. This means that there is 1 blockage every 7.4 km and 1 collapse for every 17.2 km. Therefore, in an attempt to avoid the occurrence of such failures, maintenance operations should be carried out at approximately 2 km of the network in relation to clogging and of approximately 860 m in respect of collapses. Assuming that the failures will occur in different sewers, this makes a total of 2.86 km that should be cleaned, inspected and repaired.
In an international level, it is usual to consider collectors' livespan between 50 and 100 years, which corresponds to a failure probabilitie of 1% to 2% per year. This indicates that the network in question, of total of about 490km, must undergo maintenance and repair operations in a length between 4.9km and 9.8m annually. These values are higher than those obtained in the previous paragraph which indicates that these are pessimistic estimates in comparing to what occurs in the network. Thus, if maintenance operations are performed according to these values, the attempt to avoid the occurrence of failures according to the data is guaranteed.
Although the estimated values have been calculated specifically for the Cascais network, they can, however, be used as reference values in the analysis of other stormwater drainage networks that lack occurrence records.

3 CONCLUSIONS

This work aims to contribute to the improvement of the management of water systems in Portugal. Although developed specifically for stormwater drainage systems and in the particular context of the municipality of Cascais, the underlying principles, approaches and methodologies adopted and the formulations can be generalized to other infrastructures. Factors, parameters and categories also have many points in common with water supply and wastewater drainage systems, although they have to be adjusted for each particular context. The weights should reflect the performance of the system to which the tool will be applied, and therefore the direct transposition of the values estimated in the present study may incur significant errors.

The tool presented is a starting point that should be improved and refined by increasing knowledge about the system. Ideally, the likelihood estimation should be replaced by assessing the condition of the sewers based on inspections and estimating the consequences based on models that would allow assessing the financial, environmental and social impact of the failures. In this evolution, a risk-based and sustainability-based tool would be used.

However, regardless of the limitations of the tool in its current form, it has the advantage of being a basis for transparent decision making that allows the organization to debate the assumptions and results in a transversal way. In addition, when setting intervention priorities and considering the failure rates recorded, it represents a starting point for the preparation of intervention plans, allowing the transition from the current reactive approach to an at least mixed approach.

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