Urban Forestry & Urban Greening 25 (2017) 36–42

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Original article

Geostatistical analysis to identify characteristics involved in sewer pipes and urban tree interactions

María Nariné Torres[a,*], Juan Pablo Rodríguez[a], João Paulo Leitão[b]

[a] *Departamento de Ingeniería Civil y Ambiental. Universidad de los Andes, 111711 Bogotá, Colombia*
[b] *Eawag, 8600 Dübendorf, Switzerland*

ARTICLE INFO

Keywords:
Logit and Poisson models
Pipe characteristics
Root intrusion
Sewer system
Urban trees

ABSTRACT

Tree roots cause significant and costly damage to sewer systems. However, the contributions made by tree and sewer characteristics to sewer system damage are not yet well understood. Previous research has proved inconclusive and there is a lack of agreement on the importance of the variables involved, which means that the results cannot be extrapolated globally. This study presents a methodology to improve the understanding of tree root-sewer conflicts through a geostatistical analysis of a tree inventory and CCTV video fault reports. The methodology is applied to a 11 km^2 case study in Bogotá, Colombia. The analysis used tree and sewer pipe georeferenced data, principal component analysis, and linear, Logit, and Poisson regression models. The proposed methodology identifies the pipe characteristics and the tree species most responsible for the root intrusion events into sewers. As expected, larger trees are prone to cause more pipe damage; therefore tree-pipe distance is a relevant parameter control for reducing potential deterioration. Cumulative precipitation and pipe length showed no effect on observed root intrusion events, and pipes made from brick had higher odds to present root intrusion in contrast with concrete pipes. The presented methodology uses readily available information and software, and can be modified depending on the requirements of each particular case study. This approach will therefore allow for more efficient use of costly, site-specific pipe investigations, and is especially useful for cases where there is a general lack of knowledge regarding the characteristics that favour the negative interactions between pipes and tree roots.

1. Introduction

Addressing blockages and structural failures has become a high priority in the maintenance of sewer system functionality (Rodríguez et al., 2012). It is necessary to maintain an adequate sewer operational performance based on an understanding of the processes involved in the sewer system's deterioration. Root intrusion has been identified as a major factor influencing blockages (DeSilva et al., 2011) and as a potential cause of flooding (Stål, 1998). Tree root growth interaction with urban infrastructure has been described and identified in several previous studies (e.g. Östberg et al., 2012; Rolf and Stål, 1994).

Although underground structures are difficult to survey, some cities and towns have carried out censuses of intruded pipes (e.g. Kuliczkowska and Parka, 2017; Randrup, 2000; Stål, 1998), and have shown that root intrusion is a considerable problem. For example, a survey conducted in Denmark noted that 97% of the surveyed towns and cities had root intrusion events (Randrup, 2000). In Sweden, 99% of the urban centres studied had pipe intrusions (Stål, 1998). McPherson (2000) estimated that in 1996, Californian cities were spending \$1.64 per capita on tree root-related problems (repairing street pavements, curbs, gutters, and sidewalks). In addition to the costs associated with the damage and maintenance of infrastructure (which also includes activities like root removal, pipe replacement, and pipe renewal), there are also high costs related to the damage to trees or their removal (Randrup et al., 2001a). Urban trees provide a range of benefits, the value of which is often under-appreciated (Bartens et al., 2008; Mullaney et al., 2015; Moore, 2009).

Rolf and Stål (1994) concluded that tree roots are attracted by the high moisture gradient generated by sewers, making pipes even more vulnerable than other types of urban infrastructure. Root-pipe interactions may cause, among others, structural and sediment-related failures (i.e. surcharged sewer pipes caused by the accumulation of sediments). Structural failure leads eventually to collapse of the structure (Schrock, 1994) and sediment-related failures may cause flow problems and the entrapment of suspended solids (Sullivan et al., 1977). In some cases, roots may not cause the initial crack, but they may expand existing openings, speeding up the weakening of the structure (Schrock, 1994). Roots also have a detrimental effect on sewer hydraulic conditions by

* Corresponding author.
E-mail addresses: mn.torres132@uniandes.edu.co (M.N. Torres), pabl-rod@uniandes.edu.co (J.P. Rodríguez), joaopaulo.leitao@eawag.ch (J.P. Leitão).

http://dx.doi.org/10.1016/j.ufug.2017.04.013
Received 11 October 2016; Received in revised form 28 March 2017; Accepted 11 April 2017
Available online 02 May 2017

generating a local flow restriction, which reduces flow velocity and favours the screening out of solids (Randrup et al., 2001a).

Studies carried out to understand the most relevant characteristics involved in the root-intrusion process have led to diverse and inconsistent conclusions. Some examples of these contradictory results include conclusions regarding pipes and trees. Rolf and Stål (1994) stated that PVC and glass reinforced plastic pipes are resistant to root intrusion (not considering pipe and joint construction and installation procedures), while Ridgers et al. (2006) stated that modern PVC and concrete are vulnerable to tree root-pipe interaction. In addition, while some studies suggest that interactions are more likely to occur at small pipe-tree distances (e.g. Randrup (2000) who defined small as up to 6 m), other studies suggest there is no correlation between pipe-tree distances and the frequency of damage (Kopinga, 1994). Some studies concluded that large and fast-growing tree species have a higher risk of root intrusion (e.g. Randrup et al., 2001b). However, Östberg et al. (2012) found that slow and moderate-growing tree species cause intrusion to the same extent as fast-growing trees. Conversely, consistent results have been found with other pipe variables. For example, studies have consistently found a positive correlation between tree root intrusion and pipe diameter, (Rolf and Stål, 1994), pipe age and depth (e.g. Pohls et al., 2004), and number of joints (Ridgers et al., 2006).

Root barriers can be used for preventing tree root-pipe interaction; these techniques are designed to avoid or delay the impact on infrastructure (Randrup et al., 2001b). The barriers are installed in the planting hole to reduce lateral growth, deflecting roots down below the depth of the barrier (Costello et al., 1997). Experiments carried out by Costello et al. (1997) showed that the number of roots found outside the barriers were 35–55% less than in controls. However, other studies have shown that root barriers are not always effective in protecting infrastructure (Kopinga, 1994).

These diverse and inconsistent results may be explained by the differences in the experimental designs used, which range from surveys or questionnaires (e.g. Randrup, 2000) to in situ visits (e.g. Rolf and Stål, 1994), experimental setups (e.g. Pohls et al., 2004; Costello et al., 1997; Ridgers et al., 2006), or GIS spatial analysis (Cook et al., 2008). Site variability may also account for these incongruences; for example, differences in construction quality, pipe and joints material, tree species under study, and type of root barriers tested. The lack of agreement in previous findings has precluded the extrapolation of results to other case studies.

There are additional characteristics that may affect the tree root-infrastructure conflicts, for example urban soil characteristics, environmental conditions, and geology (Sydnor et al., 2000; Pohls et al., 2004; Randrup et al., 2001b). Recent studies have shown that tree-related blockages are affected by seasonal variations (Marlow et al., 2010). In addition, irrigation of urban trees promotes additional root growth, increasing the roots propensity to penetrate pipes (Phene et al., 1991). Construction quality is also important; a deficiency in pipe construction will eventually lead to leaky joints and inadequate connections, enhancing the moisture gradient and direct root growth into the pipe (Schrock, 1994; Stål and Rolf, 1998). These variations make it difficult to extrapolate research findings to other sites with different characteristics. In big cities, such as Bogotá (Colombia), soil characteristics and other environmental variables present a high heterogeneity; also, drainage network pipes present a large range of diameters, materials, depths and ages. In order to obtain meaningful results, the present study focuses on a relatively small (approximately 11 km^2) and homogeneous area. Understanding which pipe and tree characteristics control the process of root intrusion would contribute to the development of a tree root-intrusion prediction tool. An improved understanding of tree–sewer interactions is especially useful for urban planners, water utilities, and tree planting authorities. An improved understanding may also assist the development of proactive sewer system rehabilitation and maintenance strategies, inform construction advice to mitigate tree root-pipe interactions, and facilitate vulnerability and hazard assessments in urban drainage safety plans (e.g. Möderl et al., 2015).

The methodology presented in this study can be applied where CCTV videos, sewer pipe cadastre and tree inventory records are available. To the best knowledge of the authors of this paper, no studies have yet been conducted using a complete and comprehensive tree inventory, which enables the analysis of large areas reducing the costs of in situ visits (e.g. to identify the tree species or to determine the tree size). Therefore, this research significantly advances the understanding of: (i) the pipe characteristics that make the sewer system more vulnerable to tree root intrusion, and (ii) the tree characteristics that make tree root intrusion events more likely.

The paper is structured as follows. In the next section, the case study is described. After, in Section 3, the proposed methodology to relate pipe and trees to tree-root intrusion events is presented. Then, in the following section, the results are presented. Finally, the results are discussed and the more relevant conclusions of this study are presented in Section 5.

2. Case study

The water utility of Bogotá operates approximately 8000 km of sewer pipes (including stormwater, foul and combined systems) and serves nearly 8.5 million inhabitants. Because of the city extension and the heterogeneity of the sewer system characteristics, the water utility subdivided the city in five management units, which are operated, maintained and surveyed independently. Currently, one of the utility's main concerns is to better understand the characteristics that make the sewer system more vulnerable. One of the issues of which the environmental authority is aware is the one related to the conflict between trees and pipes that is responsible for a considerable percentage of sewer system failures. Yet there is a general lack of information regarding root intrusion events; more specifically, in what regards the limited availability of CCTV videos that evidence root intrusion events.

Fig. 1 shows the case study area with nearly 11 km^2 in the central-east zone of Bogotá, which belongs to the Salitre and the Fucha catchments. The area has both commercial and residential uses and around 45,000 inhabitants. The sewer pipe network of the study area is of combined type and comprises about 245.3 km of pipes.

2.1. Urban tree inventory

The current tree inventory for Bogotá was compiled in 2007 and lists 1.3 million trees and 324 species planted in urban areas (Secretar&a Distrital de Ambiente [SDA], 2010). Along with the location of each tree, the census contains tree species, total height, physiology, equatorial diameter, basal perimeter, height and perimeter of the trunk, and a brief description of the leaves and the site location (Escobedo et al., 2015). From the 324 species identified, the urban tree planting authority has identified 54 species capable of causing root intrusion based on observations of visible infrastructure (sidewalks and ways). These species are classified, for this study, as intrusive species; among these species are *Pinus* spp., *Croton* spp., *Ficus* spp., *Acacia* spp., *Myrsine guianensis* (Aubl.) Kuntze, *Magnolia grandiflora* L., and *Querus humboldtii* Bonpl., which are all fast-growing species. The area of study counts on 28,428 trees, from which 9363 (33%) correspond to intrusive trees. Tree variables are described in Table 1.

2.2. CCTV records

The CCTV videos used in this study were recorded in 2011 and were processed by water utility operators to extract observed anomalies (such as root intrusion, sediments, structure collapse, exfiltration, FOG (fat, oil and grease), or rupture) and generate a sewer pipe failure database. The database is fed with a new record each time that an anomaly is observed, even if the observations are separated by short