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Entry

Challenges in Sewer System Maintenance

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Definition: A sewer system is an important infrastructure of every settlement. A sewer system is a set of construction facilities used for the quick removal of wastewater from the humans' immediate environment and its transport to a wastewater treatment plant or direct discharge into an appropriate recipient. In order for the sewer system to perform its purpose properly, its proper maintenance is required. Maintenance of a sewer system is very demanding since the system is mostly underground which makes it difficult to be accessed and maintained. The maintenance of a sewer system can be preventive (regular) or corrective (reactive). The regular maintenance occurs at certain intervals, whereas the reactive maintenance occurs in the case of some unforeseen event. This paper presents the history of sewer systems, as well as basic and alternative types of sewer systems. Furthermore, challenges that arise during sewer system maintenance and difficulties that maintenance employees face in their work are presented in this paper, as well as the ways in which sewer systems are maintained.

Keywords: maintenance; rehabilitation; sewer history; sewer system

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1. Introduction

The sewer system, along with the drinking water supply system, is the most important asset of a city's public health system. When properly maintained, a sewer system drains wastewater from houses and buildings to a wastewater treatment plant and protects human health [1].

Rapid population growth and a high level of migration to urban areas create large and unplanned urbanisation [2], thus increasing pressure on settlement infrastructure [3].

As the growth of the population on Earth has accelerated, and, thus, the needs of the population for water for life and work, human population is becoming an important factor for taking care of water conservation.

Water is the key element of sustainable development, a global matter that significantly affects the development or destruction of life on Earth. Due to the trend of population concentration in cities, it can be said without exaggeration that their functioning will depend on the quantity and quality of the management and distribution of water resources within cities [4] and that water-related risks will increasingly be concentrated in cities [5].

Through urban construction, more and more natural terrain is turned into impermeable drainage surfaces that have a drainage coefficient close to one, which brings a greater amount of stormwater or rainwater into the sewer system, [6] thus increasing its load.

UN General Assembly Resolution 64/292 of 2010 affirmed the right to safe and clean drinking water and wastewater drainage as a human right essential for the full enjoyment of life and all human rights [7,8]. Sufficient quantities of water must be provided to all [9].

A reliable infrastructure is the basis for the socio-economic development of the state. The phenomena of material ageing and natural disasters represent a great risk and impact on buildings and infrastructure. Ageing due to various environmental impacts reduces the safety and reliability of existing buildings and infrastructures [10], part of which is the sewer system. The sewer system is the basic city infrastructure for the preservation of public health. The construction of sewer systems requires large amounts of money and labour [11].

With the increase in the number of inhabitants in cities as a result of the industrial revolution in the 19th century, it can be observed that wastewater can no longer be discharged without treatment into the natural environment, and the development of wastewater treatment plants is starting [12].

Today, with a growing population and industrial development worldwide, wastewater is also growing [13].

Once, there was an understanding that the water supply system is a basic necessity, whereas the sewer infrastructure is a luxury, but such an opinion has been largely abandoned for a long time, although there are still some such opinions [14]. Sewer systems have been in the function of public health for centuries and are largely responsible for supporting continuous economic growth [15]. By increasing urbanisation, wastewater management is becoming increasingly important in the sustainable development of the community [16].

The sewer system together with the water supply system is classified into the municipal hydrotechnics, that is, into the municipal technical system as the infrastructure of settlements [17]. One of the most important infrastructure systems of a city is the sewer system. It helps to maintain the human health of a city and is a precondition for public hygiene [18]. That alone is enough to show its importance, and since it is of great importance, it should be maintained properly.

Maintenance of a sewer system is very demanding since it is mostly located underground and the access for and maintenance of inspections are difficult.

When looking at building management, which is also true for sewer system management, there are several requirements that need to be met. The requirements of a limited budget are set here, and certain standards must be met, including a growing number of regulations and the degree of public acceptance [19].

The challenges within the construction management activities, and, thus, the sewer system management, are presented in Figure 1.

Figure 1. Challenges within building management activities (Sketch by D. Obradović).

This is also evident in the management of sewer systems. Every day, sewer system maintainers are placed under certain conditions and requirements that can be illustrated as easily as possible in Figure 1. Different aspects of maintenance activities are shown in Figure 1. Maintenance does more—as an example, personnel must be adequately trained. Then there should be specific maintenance standards, procedures and practices to know how proper maintenance is done. Proper maintenance also requires data. In general, Figure 1 shows that maintenance is intertwined with several components. Some of the challenges and constraints are a limited budget, as it rarely foresees a certain maintenance budget. If the budget is not calculated or estimated in advance, it is usually not sufficient. Furthermore, it faces social pressures to ensure that the sewer system is used without any interruption in operation and without interference. Companies' operating sewer systems are facing increasing legal requirements—e.g., it is necessary to meet certain parameters of treated wastewater that is released into the recipient (river, sea), and strive to increase efficiency in every respect. All this is intertwined through personnel, costs, abilities, user culture, different procedures, building materials, users, reference service life of the building components and materials, environment, standards and regulations, available data, etc.

2. History of Sewer Systems

Much has been written about the history of water supply systems, but there is a lack of adequate information about wastewater management [20]. For centuries, people did not pay attention to the importance of waste management, and in many cultures, wastewater was released onto the streets or within cities, thus endangering the health of the city's population. This can be seen from numerous epidemics that appeared in Europe in the 19th century [21]. If it had not been for epidemics of infectious diseases such as typhoid, cholera, plague and others, probably the awareness in Europe of the need for proper sewer drainage and sewer systems would not have arisen, and sewer systems would not have been built to such an extent.

It has already been noted that the investment in sanitary infrastructure and in its development has a significant impact on the reduction of population mortality [22–24], as authors [23,24] researched and established in their papers. The area they studied and analysed was England, Wales, Switzerland, Finland and Sweden. The authors of the study [23] deal with the issues and research of the impact of the improvement of sanitary infrastructure on mortality in urban environments. Their special focus was to study the improvement of water supply and the development of efficient sewer systems [23]. These studies were conducted for the period from the end of the 18th to the beginning of the 19th century, so it can be said that this is a newer period when compared with the time before our era. Looking at the above, it seems a little unlikely that old civilizations knew before our era that sanitary conditions were very important and took care of the sanitary conditions. Various studies have confirmed that good sanitary conditions in a city have a major impact on public health [25]. The biggest reduction in mortality from infectious diseases transmitted by water was due to the establishment of improved sanitary conditions [26].

It is relatively difficult to precisely define and safely say where wastewater extraction was first used, but it is certain that this was the case with old civilizations in the Middle East, North Africa and the Middle and Far East [27]. The oldest found pipe was made of baked clay (4th century BC) [28]. The need to drain polluted water from the settlement was noticed a long time ago by the oldest nations such as the Egyptians, Babylonians, Phoenicians and others. Sewer remains exist in several Greek cities, such as Athens, Knossos and others [29]. The remains of faecal channels were found in the ruins of Babylon, and the Babylonians were best-known for making pipes that were mostly made of baked clay but also copper or lead [28]. In Jerusalem, they took unclean water through channels to the sedimentation basins and later the sludge was used as fertilizer, which is one of the oldest examples of wastewater treatment [30].

The drainage on the streets dates back to the Mesopotamian Empire in Iraq from 4000 to 2500 BC. However, a well-organised sewer system for the first time in human history was the sewer of the Minoan and Harappan civilizations in Crete [31]. The most famous sewer of the old age was the one in Rome. It is known as the "Cloaca Maxima", which was up to 4.2 m high, 3.2 m wide [32] and 738 m long. There were also public toilets [30]. There is a high probability that the Cloaca Maxima was built on the bed of a watercourse whose original purpose was the drainage of wetland surfaces. Later, its function was extended to wastewater drainage [27]. The cities of the Roman Empire were familiar with the sewer system and wastewater drainage and gave great importance to this [22], and it can be concluded that the ancient Romans took care of water and sewage [33].

Today, sewer systems are underground structures and are so well integrated into infrastructure that we are not even aware of them [28]. Once, the sewer was on the street, as it was, for example, in Paris, under the name Lutecia. However, this concept has been abandoned, and the sewer system went under the street—it became an underground structure [34]. The beginnings of building the sewer system that we all know today in large cities of Europe date back to the end of the 19th century. Its construction was prompted by major epidemics of infectious diseases [28], such as plague and cholera. The systematic construction of sewer systems took place at the beginning of the 19th century in Great Britain, France, Germany and then in other European countries. At the end of the 19th century almost all major European cities had some basic sewer system skeleton. The first larger sewer system in Europe was completed in 1842 in Hamburg [27]. Moreover, in the 19th century, various construction materials were used in the construction of gravity sewer systems that are still being implemented today, and throughout that time, laws that encourage the construction of sewer systems were developed [4].

3. Sewer System Types

The sewer system is a set of construction facilities used for the quick removal of wastewater from the human-immediate environment and their transport to the wastewater treatment plant or their direct discharge into the appropriate recipient [35]. Therefore, from this definition, it can be seen that the main objective of the sewer system is to take all wastewater to a suitable location safely and to include it in the circulation of water on Earth [36]. The sewer system plays a key role in the process of water resource circulation [37]. In practice, drainage systems are commonly referred to as sewer (or sewerage) systems [38].

In urban environments, the sewer system is used to collect rainwater and, thus, prevent urban floods. Inundation for rainwater retention should be provided as much as possible to protect against floods. Water-permeable surfaces enabling water infiltration into the soil should also be used in urban environments, thus reducing the load on the sewer system.

The sewer system is slightly younger than the water supply system. The end point of this system is the wastewater treatment plant, i.e., the discharge into the recipient. In short, the basic tasks of the sewer system are as follows:

- Continuous collection of wastewater in a defined system area;
- Safe transport of wastewater to wastewater treatment plants;
- Necessary treatment of the processing to a required level prior to its release into the recipient [39].

The sewer system of a domestic or sanitary sewer and an industrial sewer versus storm water (or rain water) distinguishes between the two types of objectives to be achieved. These are the main and technological objectives.

The main objectives for a sewer system of a domestic or sanitary sewer and industrial sewer versus storm water (or rain water) are as follows:

- Collection of all wastewater;
- Treatment of all wastewater;
- Wastewater treatment to the level prescribed by law;
- Sustainable solutions according to the lifespan of the building;
- An acceptable level of protection for people and their property;

- An acceptable level of environmental protection and water resources [40].

Technological objectives for a sewer system of a domestic or sanitary sewer and industrial sewer versus storm water (or rain water) are as follows:

- The simplest solution;
- The smallest construction costs;
- The minimum costs of use and maintenance [40].

Sewer systems, according to their way of collection and drainage of wastewater, are one of the following:

- Combined sewer system;
- Separated sewer system;
- Partially separated sewer system.

Sewer systems according to system operational characteristics are one of the following:

- Gravity;
- Pressure;
- Vacuum [38].

In Europe, the two most used types of sewer systems are the combined sewer system and the separated sewer system, as well as modified versions of the two aforementioned systems [41].

A combined sewer system (Figure 2) is a sewer system where a domestic or sanitary sewer and an industrial sewer as well as storm water (or rain water) from the city area are drained with one drainage system to the wastewater treatment plant. This is the oldest type of sewer system, and it was used as the cheapest solution for collecting and draining urban waste and rain waters to the recipient. The combined sewer system is characteristic of relief structures, i.e., sewer overflows [42].

The relationship between domestic or sanitary waters and storm waters (or rain waters) in the channels is between 1:20 and 1:60, which is why the storm waters are important for the dimensioning. However, regarding the duration of drainage, the longest duration is household wastewater, and the shortest duration is storm water, resulting in a situation in which the influence of domestic waters is constant [40] and it adversely affects the sewer system due to different chemical processes and substances. This sewer system is characterized by two flow regimes: rain and dry.

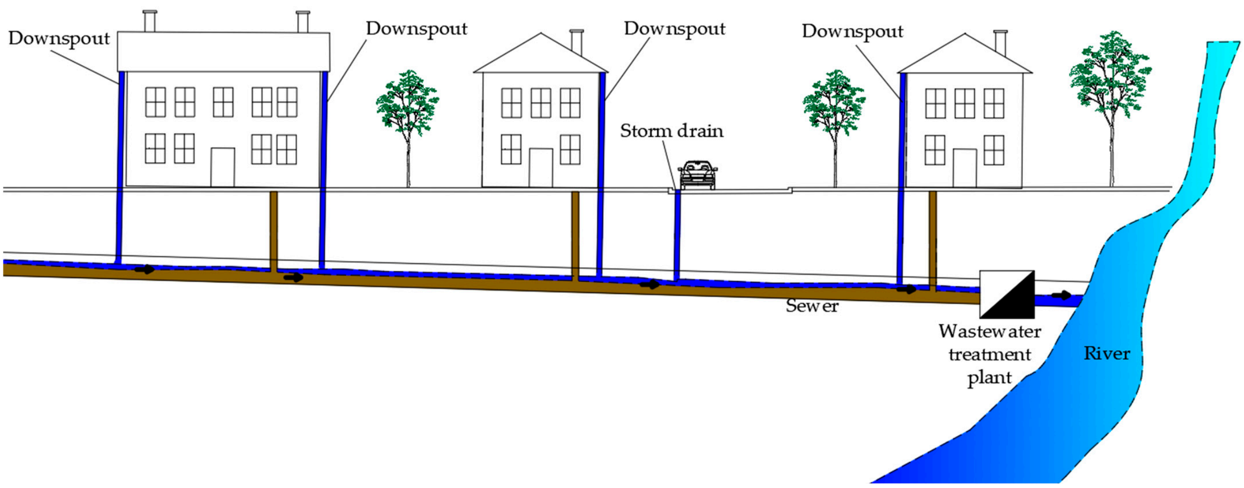

Figure 2. Combined sewer system (Sketch by D. Obradović).

In the case of a separated sewer system (Figure 3), there are mainly two sewer networks—one used for the drainage of rainwater and the other intended for household and industrial wastewater (if there is an industry in the area). In this case, the storm water channels are the same in dimensions as in the combined sewer system, while the wastewater channels are adjusted to their quantities [38]. Normally, pipes for the drainage of sanitary water from houses have lower diameters than pipes for the drainage of rainwater [43]. Since the construction of the sewer network is expensive, a lot of cities first build a sewer network for sanitary wastewater and then build a network for rain water [44].

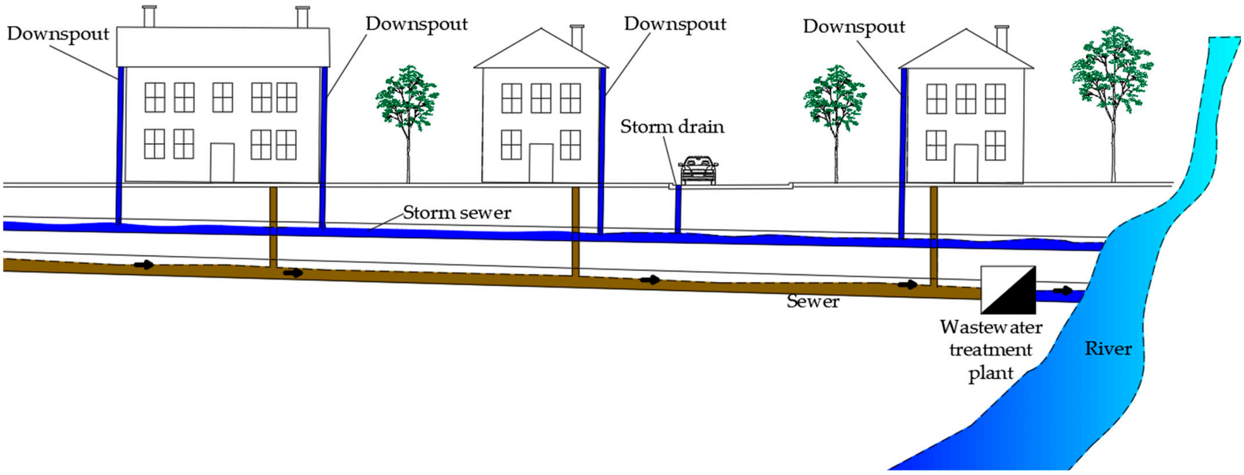

Figure 3. Separated sewer system (Sketch by D. Obradović).

A partially separated sewer system is characterized by the same network as in the separated sewer system, with the difference that the storm sewer has special complementary devices by which water from street washing and rain water is automatically drained into the sewer network of the house sewer during low intensity rain. In this way, the first, more polluted, smaller inflows of storm water are drained to the wastewater treatment plant while the remaining, relatively clean rain waters that are larger in quantity are released directly into the recipient [38].

In addition to the above-mentioned common types of sewer systems, there are alternative sewer systems, some of which will be presented below including the pressure sewer, the vacuum sewer, the condominial sewer and the gravity system of small profiles.

Some reasons why alternative drainage systems are suitable are here listed: suitability for mountainous areas, terrains with small slopes, areas with a high level of groundwater, when wastewater occurs periodically, terrains with unfavourable geological composition, commercial and industrial centres and locations where high safety is sought against groundwater pollution.

A pressure sewer system is applied in those parts of the sewerage network where there are no conditions for gravitational drainage [39], and the pressure sewerage as a whole is rare [38]. The pressure sewerage has been applied since the beginning of the 1960s, and over the years, the system has been developing continuously; today, in many developed countries, it represents a safe, technically economically feasible drainage system, especially for small rural settlements and isolated city quarters [45]. Generally speaking, the pressure sewer system may form a ring or a branched network. In addition to the sewer network, the pressure sewer can be performed as an individual section. When used in small rural settlements, the gatherer network consists of shallow buried pipelines lying below the freezing depth, with a diameter of 90 to 200 mm, with a nominal pressure of 10 bar. The pressure flow is supported by additionally inflating compressed air, using separate cells that pressure the air in the network during the initial sub-loading condition. A pressure sewer can be applied on all types of terrain regardless of the position of entry and exit points, and it is currently used in settlements with fewer than 15,000 inhabitants [46].

There are two basic pressure sewer systems: GP (Grinder pump) and STEP (Septic Tank Effluent Pump). In the case of the GP system, fresh wastewater flows directly into the pumping shaft located within the yard of the house, where a smaller compressive unit is installed, on which the grinder is installed. Its function is to combine large particles to the size that will enable the smooth passage of wastewater through the system [46].

Wastewater at the STEP system is first poured into a septic tank consisting of one or more chambers. The pumping pane can be placed inside or outside the septic tank, which usually consists of an inlet (wastewater supply) and a discharge chamber. The water coming out of the septic tank is treated from large, swimming particles deposited in the tank; there is no need to install the grinders [46].

Vacuum sewer systems were first used in 1860, and their mass application followed in 1950 in Sweden [47–49]. A vacuum sewer is used in special circumstances, e.g., in dry areas. It requires the installation of special pipes, facilities and sanitary devices, so it has no wider application. It works on the principle of negative pressure, so the entire net is under pressure, and the highest negative pressure is in the collection pool, i.e., in the discharge site [38]. Vacuum sewerage is applied in cases where the ground is completely flat, where the groundwater level is high, where there is an unfavourable longitudinal profile, where there is unstable soil, etc. [47].

The condominial sewer system is an alternative sewer system that is conceptually similar to the conventional gravity sewer system. The name "condominial" comes from the Portuguese noun "condominio", which translates into a residential block. The condominial sewer system is a sewer system/network consisting of small diameter pipes placed in shallow trenches with as minor a slope as possible in order to reduce total construction costs. The main reason for this name is the fact that the condominial sewer system is laid as a network of pipes most often within a residential block and not on a public surface as is the case with conventional sewer systems. This means that this system is located on private property, in the yard in front of or behind the household, and, in some cases, under the sidewalk of the dwelling block [50]. Since small diameter pipes need less water to transport faeces, this saves water [51]. It is applicable to densely populated, peri-urban areas on different soils, from sandy to rocky, in areas of high groundwater [52]. These systems are much cheaper than conventional ones, that are not even applicable in these areas, and significantly affect the sanitary or health conditions of living.

Typically, in small-diameter gravity sewers (SDGS) systems, the wastewater from one or more households is discharged into an interceptor tank or a single compartment septic tank [53]. The advantages are as follows: construction is fast; it requires less time to function, i.e., to start working; the elimination of manholes reduces a source of inflow, further reducing the size of pipes, lift/pumping stations, final treatment, and ultimately, reference cost; reduced excavation costs since trenches for SDGS pipelines are typically narrower and shallower than for conventional sewers; reduced material costs [54]; reduced water volume needed for the transport of suspended solids [55].

4. Challenges of the Maintenance of Sewer Systems

4.1. Types of Sewer Maintenance

Companies with one "water" department usually deal with water supply, water drainage and wastewater management; however, sewer system maintenance is not easy.

Just like every structure, the sewer system gets obsolete and decayed over time due to the influence of different physical and chemical factors. Failures in this critical infrastructure can cause social, environmental and economic impacts [56] and also can have a catastrophic effect on transport and business [57]. Sewer pipes are a very important and critical part of the sewer system—not only because they play an important role but also because their purpose is to transport waste and rain water to wastewater treatment plants or recipients and, therefore, their construction and repair are expensive but necessary [58]. Limitations in data availability and quality are common for sewer system status data [59].

Long-term planning using the Life Cycle Cost Assessment (LCCA) for sewer systems can help reduce construction, use and maintenance costs. When deciding how to maintain or rehabilitate the sewer system, it is important to decide according to the life cycle costs instead of relying solely on construction costs. This way of deciding on alternatives by using a life cycle cost analysis can greatly help reduce capital costs [60].

Maintenance is divided into two main types of maintenance: preventive maintenance and corrective maintenance. Some authors divide maintenance into three types: preventive, corrective and condition-based maintenance [61]. If a reactive sewer system maintenance strategy is used, the sewer system is not cleaned on a regular basis but only when necessary, as in the case of clogging. In the case of preventive maintenance, the sewer system is maintained at certain intervals according to a certain maintenance and cleaning plan [61].

Corrective maintenance is a bad maintenance mode because it leads to the sewer system being out of function for a certain period of time and is expensive, so sewer systems that are sustained with this maintenance mode will not work well, and users will not be satisfied with it. Corrective maintenance can also be called incidental maintenance because it occurs only when an incident occurs and needs to be answered as soon as possible. Incidents can include a pipe bursting, excessive load, waste clogging or various materials. Breaking the pipes can lead to street collapse; street degradation; and road, sidewalk and environmental pollution because the wastewater flows into the environment [38].

Condition-based maintenance is such a maintenance strategy that uses all available methods to determine the technical level of the condition of the system and equipment with the aim of accessing maintenance only when the condition of the components of the system falls below a certain critical level [62]. It consists of three main steps: data collection, data processing and maintenance decision-making [63,64]. During condition-based maintenance, the appropriate maintenance strategy shall be decided, inter alia: the order of operations, which repair or replacement to make and the priority of the tasks to be completed [65].

The possibility of maintenance must already be considered when designing the sewer, and maintenance requires limiting the minimum pipe diameter. For example, at the beginning of the pipe sections, sewer water quantities are often very small, especially for the drainage of sanitary wastewaters in the distribution system. When considered, it would be theoretically possible to use very small pipe proportions based on small initial flow rates and longitudinal slopes, but experience from practice has shown that the use of small pipe diameter is unfavourable and that closures often occur. Using small channel profiles increases the costs of maintaining the gravity sewer system significantly, all due to the need for frequent cleaning and rinsing. Due to all of the above, in public sewers with a gravity flow of wastewater, it is common to use minimum profiles of 250 and 300 mm, respectively [46]. One of the phenomena worthy of attention that can cause major problems in the maintenance and functioning of the system is the occurrence of “bottlenecks”. This phenomenon in the sewer system causes multiple harmful effects—it makes new connections of buildings more difficult and causes slowing in the existing network. The emergence of a slowdown in the network increases the possibility of flooding from wastewater into spaces that are low, such as cellars, rooms in the basement, etc. Therefore, this should already be taken into account when designing [22]. The life expectancy and durability of the system largely depend on proper maintenance [66].

The proper functioning of the sewer system is conditioned by the regular maintenance of all parts of the sewer system [14]. Good and proper maintenance of the drainage system is the basic precondition for rational management of this expensive urban infrastructure for adequate sanitary conditions in the urban environment and for good environmental protection. Moreover, this is one of the preconditions for sustainable development and urban health standards, so it needs to be given a lot of attention [38,67,68]. The phrase good and proper maintenance is considered appropriate, i.e., a maintenance strategy that foresees possible deficiencies and failures (the focus is on preventive maintenance) and is economically efficient [69]. Costs of corrective actions, i.e., maintenance costs, are two to ten times higher than costs of preventive maintenance [70]; therefore, preventive actions should be given priority. Furthermore, unexpected failures, pipe cracks, operating failures or anything else in the sewer system can cause environmental pollution, floods or any number of other problems [71].

Every sewer network needs maintenance. The aim of the maintenance is to maximize the duration and level of functionality of the sewer system. This is achieved through various maintenance activities [72]. Proper use and maintenance of the sewer system is important in order to ensure proper flow through sewer pipes to prevent the blocking and leakage of wastewater [73].

The sewer system, i.e., the sewer network, is liable to malfunction and must be maintained. It is known that malfunction is susceptible to those sewer networks that are very old and that have any of the following:

- Longitudinal slopes less than the minimum allowed;
- Small minimum pipe profiles;
- Poorly performed joints, longitudinal slopes and shafts;
- A large number of cracks, deformations and fractures due to poor installation;
- Undisciplined users who omit substances and things that they should not omit into the sewer [74].

Some of the conditions for a well maintained sewer system are acquaintance with the system and its characteristics, a sufficient number of employees who are well organized and a sufficient amount of financial resources. All these conditions are interconnected. Without sufficient financial resources, among other things, it is assumed that the number of employees maintaining the sewer system will not suffice. Without a good organisation and maintenance plan, employees will not be able to maintain the system effectively, although there are sufficient numbers. Even if these conditions are met, without good knowledge of the sewer system, one cannot count on an adequate level of maintenance of the sewer system. Since each sewer system is unique to its environment, this requires a unique approach to its management and maintenance. Each part of the sewer system requires an appropriate management and maintenance plan [38,75].

All maintenance activities must be monitored to ensure that they are operated carefully and safely, according to standards, at eligible costs and within the given time. Good supervision is based on the following:

- Knowledge of the work to be done;
- Importance of the work done;
- The designation of persons responsible;
- Specification of measurable standards;
- All of these require good education and supervision training [76].

Many malfunctions in the sewer system are not accidental but represent a certain change preceded by gradual deterioration and deterioration of conditions [77], which supports the importance of preventive maintenance. It can be concluded from the above that sewer system maintenance is a complex task [78,79].

In sewer system management, one problem is that the state of this underground infrastructure system is not fully documented. Moreover, a lot of cities do not have data on the previous condition but also on the current sewer situation, which makes it impossible to assess the priorities of reconstruction [80] and, thus, makes the accuracy of the required maintenance budget more difficult. The task of determining the budget is a major problem in all sewer system maintenance activities [81]. One big challenge is that sewer pipes are underground, and it is very difficult to detect pipes that have an increased risk of cracks or of a malfunction of some other types. It is also clear that the inspection of all sewer pipes is impossible due to limited budget, time and available technologies for assessing the state of the sewer system [82].

Preventive maintenance can also be called regular maintenance. Regular maintenance of the sewer system mostly consists of recording the condition, the pipe and channel cleaning, the rainy grids and all facilities (e.g., pumping stations) and the change of worn out pipe sections as well as overseeing the condition of all sewerage network facilities. Cleaning should be done due to sand and sludge depositing, entry of tree roots into pipes or clogging caused by the irresponsible throwing of user waste into the sewer [38]. In order to ensure the operation and use of the sewer system according to the purpose for which the system was designed, maintenance should aim to minimize the number of stoppages and the spread of odours. To achieve this, the sewer system is cleaned according to a predetermined maintenance and cleaning schedule in order to remove accumulated residues and debris in the sewer pipes. Accumulated debris in pipes reduce pipe capacity, i.e., decrease pipe diameter and possibly lead to congestion which may result in wastewater spilling to the surface or to surrounding buildings with underground floors. Roots and corrosion can also cause serious damage to the pipeline system [75]. The usual lifespan of sewer pipes ranges from 50 to 100 years [83].

The study conducted by Bauer (1990) has shown that the excavated PVC sewer pipes after 15 years do not show any damage during that period [84], and another author's research showed that the excavated 25-year-old PVC sewer pipes also had no damage and concluded that the PVC sewer pipes can last at least 100 years [85]. Furthermore, some research conducted on excavated sewer pipes shows that the sewer pipe has a lifetime of 100 to 300 years [86]. However, the life expectancy of sewer pipes ranges from 40 to 80 years. Different factors such as construction methods, soil, geological conditions, streams, loads, maintenance and ageing of pipe material will determine the actual lifespan of sewer pipes [87].

One of the systems that can be of great help is the Geographic Information System (GIS) which provides information such as sewer location, user connections, type of land use, place of damage and planned repair sites [88]. Therefore, sewer systems that use the GIS support system are more favourable in terms of management and maintenance than those that do not use GIS, especially if they are longer. Sewer pipes are one of the rarely examined infrastructures [59,89]. Due to their good functioning, it is important that they are regularly examined and recorded, cleaned and repaired. One of the most frequent activities of maintaining the sewer system, that is, sewer pipes, is cleaning the sewer pipes.

A study performed by the American Society of Civil Engineers reported that the most important maintenance activities are cleaning and CCTV (closed-circuit television) inspections [90] (Table 1).

Table 1. Frequency of maintenance activities for sewer system, Reprinted from ref. [90].

Maintenance Activity	Average (% of System/Year)
Cleaning	29.9
Root removal	2.9
Manhole inspection	19.8
CCTV inspection	6.8
Smoke testing	7.8

4.2. Sewer System Cleaning

To clean the sewer system, tools such as a pickaxe, tripod, warning flags, batteries, lamps, ropes, hooks, etc., are needed, as well as special equipment and devices (brushes, sediment-breaking chains, cutting and root-pulling knives, buckets for mud, etc.).

Sewer cleaning can be by mechanical means or flushing.

Cleaning by mechanical means is done using special devices such as brushes, sediment-breaking chains, cutting knives and pulling roots, hooks, buckets for mud. These tools are dragged through the channel manually or mechanically [38]. For these jobs, there are different models of cleaning machines on which various cleaning units can be mounted, depending on what is intended to be cleaned—roots, sediments, penetration of blockage, removal of rags, discovery of lost steel wire rope, etc.

Recently, high pressure cleaning has become the most used method for maintaining flow capacity in small and medium diameter pipes of sewer systems [91]. Washing a sewer under pressure is such a way of cleaning that water under very high pressure is used with high pressure pipes and nozzles to wash sewer pipes and clean them from accumulated impurities. The nozzle has several types, and, usually, the nozzle has one opening forward and several smaller openings that are directed back so as to wash the wall of the pipe. All mentioned equipment (high pressure pipes, water reservoir and wastewater tank, nozzles, high pressure pump, etc.) is located on trucks specially equipped that are manufactured for cleaning sewer systems. Usually, such trucks also have a wastewater tank so that the accumulated impurity or residue can be sucked by means of a pump into the truck tank and disposed of in an appropriate manner and place. Any undertaking operating a larger sewer system should have an appropriate number of such special trucks and all necessary equipment, since proper and regular maintenance is possible with appropriate equipment [92]. The nozzles and the sewer cleaning truck are shown in Figures 4 and 5.

Figure 4. Nozzles for sewer cleaning, Reprinted with permission from ref. [93]. Copyright 2022 HENNLICH d.o.o.

Figure 5. Sewer cleaning truck (Photo by D. Obradović).

Often, trees planted too close to the pipe can cause the sewer pipe to clot by penetrating the pipe and preventing (partially or fully) the flow of wastewater. There are different methods for the removal of roots from pipes, e.g., using razor shapes, high pressure, chemical substances (herbicides, acids, alkali, etc.) However, when the roots reach the pipe, the removal process is complex and expensive and does not ensure a lasting effect. In this case, it is recommended that the roots be removed mechanically, followed by chemical treatment. The chemical method for the removal of roots is particularly useful in order to prevent further growth of roots in pipes for some time (3 to 5 years) [18].

Furthermore, it is particularly important to note that it is necessary to take into account the species of trees planted near the sewer system and the place where they are planted. During the installation of sewer pipes, it is important to take into account that all joints are well sealed, either by rubber seals or in other ways, and that the testing of the pipes for water permeability has been performed. Moreover, pipe sections (lengths) should be as long as possible to minimize the number of joints and necessary seals [18]. When the roots penetrate the sewer pipes, in most cases, the pipe is irreversibly damaged (of course it depends on the amount of roots that came into the pipe, as well as the type of pipe), and it is important to point out that prevention is the most important measure that can be taken. As regards the choice of the tree species planted near the pipe, trees that have a weaker, smaller root system and lower growth should be selected since they have a lower possibility of penetration of roots in the pipe [94]. Roots of trees, in more than 50% of the cases, cause congestion of pipes (Figure 6) so that the costs of the removal of the roots from sewer pipes are significant. For pipes with a smaller diameter, it is not unusual to remove roots every year or every other year [95].

A sewer pipe clogged with roots and a root cutter are presented in Figure 6.

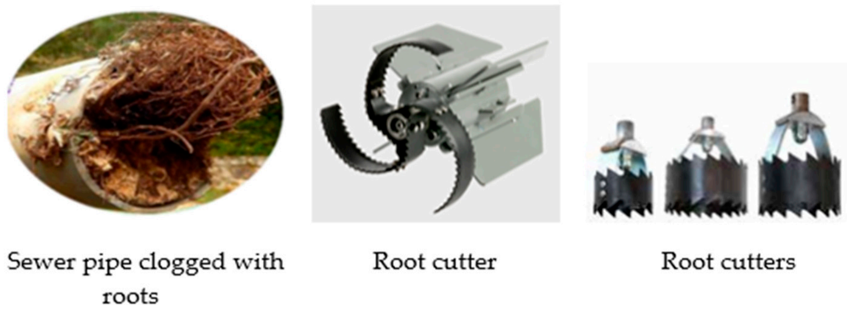

Figure 6. Maintenance of sewer pipes when clogged with tree roots. Adapted with permission from ref. [93]. Copyright 2022 HENNLICH d.o.o.

In the sewer network, deratization is necessary because it contains a constant source of food for rats, has favourable microclimatic conditions for growth and reproduction and represents the simplest and best communication of the same. The deratization of the sewerage network is done in two ways. The first way is defensive where rats are prevented from communication through internal sewer and household connections using different lids. The other way is offensive where poisons are used. Today, only paraffin blocks are used for the deratization of sewer networks [96].

4.3. Damages and Repairs of Sewer Pipes

The most frequent damage to sewer systems are cracks/broken pipes, penetration of roots into the pipe, sediment deposition, corrosion, extraction of joints, leakage and pipe bending. However, pipe damage varies depending on the type of pipe (material from which it is made) and the diameter of the pipe. Since sewer systems are mostly gravitational and are made of various materials, they are susceptible to different types of damage [97]. The most common damages in sewer pipes are presented in Table 2.

Table 2. Most common damages in sewer pipes. Reprinted from ref. [97–99].

Defect	**Types of Sewer Pipes**								
	C	**AC**	**PCCP**	**CI**	**S**	**CL**	**Br**	**PVC**	**HDPE**
Roots	•	•	•	•	•	•	•		•
Fat, Oil and Grease	•	•	•	•		•	•	•	•
Cracks	•	•				•			
Inner corrosion	•	•	•	•	•				
Outer corrosion			•	•	•				
Infiltration/inflow (I/I)	•	•		•		•		•	
I/I of joints	•		•		•				
I/I of house connections				•					•
Wrong procedure				•				•	•
Wrong connection procedure		•		•		•			
Deformation					•			•	•
Other	1						2	3	4

Abbreviations in table: AC—Asbestos cement, Br—Brick, C—Concrete, CI—Cast Iron, CL—Clay, HDPE—High Density Polyethylene, I/I—Infiltration/inflow, PCCP—Pre-stressed Cylindrical Concrete Pipe, PVC—Polyvinyl chloride; PVC Plastic, S—Steel, 1 = Seal defect, 2 = Missing bricks, 3 = House connections, 4 = Pressure testing.

As can be seen in Table 2, for example, PVC pipes are more resistant to root penetrations, while concrete, asbestos cement, clay, etc., pipes are more susceptible to root damage. Moreover, the cracks are more susceptible to concrete, asbestos cement, and clay pipes. For each type of pipe, the most frequent damages and defects are given in Table 2.

In order to restore/repair the sewer pipe, normally this type of work consists of six phases:

1. Removal of asphalt layer and disposal of materials;
2. Trench excavation;
3. Removal of the old pipe;
4. Installation of new pipes;
5. Backfilling the trench;
6. Relaying the asphalt layer [100].

Since the sewer pipe is underground, its replacement requires excavation which creates problems in the normal flow of walking and road traffic (Figures 7 and 8), undermines the appearance of the environment, damages (Figure 9) final coverings (asphalt, concrete, pavements, etc.) and is expensive [92].

Figure 7. Formwork for sewer control shaft—manhole (Photo by D. Obradović).

Figure 8. Sewer pipes delivered for installation (Photo by D. Obradović).

Figure 9. Destroyed asphalt pavement (Photo by D. Obradović).

Certain phases of the construction of the sewer control shaft (manhole) are shown in Figures 10–12.

Figure 10. GRP manhole delivered for installation (Photo by D. Obradović).

Figure 11. Installed manhole (Photo by D. Obradović).

Figure 12. Manhole cover (Photo by D. Obradović).

4.4. Trenchless Sewer Rehabilitation

Especially when renovating a sewer, there is a wide range of currently available technologies, starting from classic technology (excavations) to modern technology without excavations, i.e., the trenchless technology (Figure 13). Trenchless technologies have great advantages. Moreover, trenchless methods have great potential in reducing the disturbance of areas with dense traffic, historical buildings, valuable trees, etc. Furthermore, in the case that the pipes are located below the surface, the trenchless methods ensure a significant reduction in the cost of excavation. The application of trenchless technologies for the renovation of a sewer can result in significant savings in the economic and social sense, as well as environmental protection and time savings needed for the renovation of pipes. Due to the numerous modern technologies of pipe replacement without excavation, pipe renewal does not necessarily mean new construction, i.e., construction works in the space.

Some methods of trenchless reconstruction and repair of sewer pipes are as follows:

- Punching or line expansion method (In-Line extension; Pipe Bursting);
- Inserting a new pipe into an existing, slip lining method (Sliplining);
- The Cured-in-Place Pipe method (CIPP);
- The Modified Cross Section Liner method [101].

In Figure 13, the Cured-in-Place Pipe Method for sewer pipe trenchless rehabilitation is presented. The first figure on the left shows liner in a sewer pipe; the figure in the middle shows only one part of the equipment needed for the CIPP method. Finally, the figure on right shows a renovated sewer pipe with CIPP method.

Figure 13. Renewal method—the CIPP method. Adapted with permission from ref. [102]. Copyright 2022 Solmex d.o.o.

Table 3 shows a comparison of trenchless techniques according to the pipe diameter, installation lengths, liner material and costs.

Table 3. Comparison of trenchless techniques according to the pipe diameter, installation lengths, liner material and costs. Adapted from ref. [68,101,103].

Method	Pipe Diameter [cm]	Installation Lengths [m]	Liner Material	Cost Range [$/m]
Pipe bursting	10–60	230	PE, PP, PVC, GRP	130–260
Sliplining	10–400	300	PE, PP, PVC, GRP	260–550
Cured in Place Pipe	10–275	150–900	Thermoset Resin/Fabric Composite	80–215
Modified Cross Section Liner	10–40	760	HDPE	58–162

Abbreviations in table: GRP—Glassfiber Reinforced Polyester, HDPE—High Density Polyethylene, PE—Polyethylene, PP—Polypropylene, PVC—Polyvinyl Chloride.

The technology of the trenchless pipe renovation has the following favourable characteristics compared to the traditional method of excavating trenches for laying pipes, i.e., the replacement of pipes:

- No excavations are needed between the access points (often existing manholes) that are mainly set at a considerable distance.
- It is necessary to have a certain, smaller number of construction machinery, and activities are concentrated only in the places where it works, i.e., access points where new pipes are usually introduced.
- A continuous operating environment of 24 h is possible, with minimal interference in the work of the surrounding buildings or obstruction of the neighbourhood where it works.
- The visibility of construction activities is significantly reduced, which can lead to a smaller number of insurance claims and complaints from citizens.
- The result of the completed and restored sewer system (pipe) is in some cases better and stronger than the original.
- The final restored sewer system can have better flow characteristics than the original sewer system before rehabilitation [104].

5. Conclusions

The sewer system is one of the leading municipal infrastructures in urban areas. It has a significant impact on the quality of life of people, especially on health. Continuous monitoring and maintenance are necessary for the successful functioning of the sewer system. Maintenance methods and frequency depend on sewer type, pipe diameter, material from which it was built, age and, often, population habits. Due to the sharp increase in population and the increasing quantities of wastewater before sewer maintenance activities, more and more challenges are being posed. In dense urban environments with limited space for communal infrastructure, a sewer is, due to its specific content, placed at the maximum depth, under other installations, which makes its management and maintenance even more difficult. In addition to the classic maintenance methods, new methods of trenchless rehabilitation (maintenance) are being developed today, which are faster, more economical and more environmentally friendly. The amount and quality of maintenance to a significant extent are conditioned by financial resources; therefore, it is necessary to include maintenance costs in the sewer price already at the stage of its design.

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