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RESEARCH ARTICLE

The Approach and Importance of Urban Drainage from The Past to The Present

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ABSTRACT

Urban drainage and basic infrastructure systems, including the collection and controlled management of rainwater and wastewater, have been important throughout history. The origin of well-designed systematic drainage systems dates back to the Bronze Age. This systematic drainage design has continued to evolve over time. The common denominator of these systems is the efficient use of natural resources and the creation of liveable and resilient living spaces, which form the basis of the urban drainage technologies used today. It is clear that sewerage and drainage systems in cities are very important and will be an important part of future urban planning. Today, urban drainage and water management has to meet expectations beyond its historical importance due to concepts such as urbanisation, climate change, and energy conservation. Therefore, sustainable drainage systems are gaining attention for their ability to reduce carbon footprints, improve surface water runoff, and control flood risk. This article discusses the basic principles of drainage and assesses how important it has been for settlements throughout history and how it should be dealt with in the future using new concepts.

Keywords: Drainage, water management, sustainable drainage systems

Introduction

Throughout history, all successful civilisations have focused on efficient drainage systems that facilitate land reclamation, separate wastewater from drinking water and allow rainwater to be used for agricultural irrigation. Many historic excavations have uncovered earthen reservoirs, cisterns, manhole covers, in situ drainage channels, and ditches dating back to ancient times. The wetlands irrigated by the Nile in ancient Egypt were drained and used for agricultural production 6,000 years ago (Whalen & Sampedro, 2010). In DeAgri Cultura, written by Marcus Porcius Cato in the 2nd century BC, the drainage methods used by Roman farmers were described in detail (Cato, 2010). There is no doubt that drainage is essential for human life.

Historical evidence shows that factors such as climate, topography, local conditions, and materials have influenced urban drainage techniques. The first applications, which began with trial and error, evolved over time with experience, leading to the current drainage systems and water management principles used today (Burian & Edwards, 2002). Throughout history, storm water and wastewater have been considered in urban drainage systems, and these water types have either been combined in a single channel or kept separate during collection and disposal.

Historical Background

Archaeological evidence shows that humans have needed drainage systems since the moment they began to control their environment, and that the collection of rainwater and storm water from urban areas was at the heart of this need. As Cun et al. (2019) stated in their article, the world's first urban hydraulic systems date back to the Bronze Age (ca. 2800–1100 BCE) (Mays et al., 2007), and urban storm water management systems have existed since 3500–1100 BCE (Angelakis, 2017).

Mesopotamian cities are characterised by well-designed drainage systems. In the ancient cities of Ur and Babylon, for example, rainwater was controlled by gutters and drainage systems, while domestic waste was controlled by vaulted sewers. It is noteworthy that bricks baked with asphalt sealants were used in these systems. Rainwater was also collected and used for irrigation and

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domestic purposes (Burian & Edwards, 2002). In Habuba, wastewater was collected through U-shaped terracotta pipes that ran under the streets and drains lined with stone slabs and transported outside the city walls (Angelakis, 2016).

The most striking examples of a drainage system coordinated with the layout of urban areas and organised according to a plan can be found in the Indus civilisation. For example, in Harappa and Mohenjo-Daro, most dwellings were connected to open channels built in the middle of the streets. The channels are known to have been constructed either by excavating earth or by using burnt bricks above ground and sealing them with mud mortar. The fact that sewage was not discharged directly into the street sewers indicates that urban drainage systems were used to convey waste and rainwater (Burian & Edwards, 2002; Possehl, 2002). These settlements used reservoirs to collect rainwater.

The remains of the Minoan civilisation in Crete show extensive drainage systems. This evidence suggests that advanced water management and sanitation techniques were used in Minoan settlements; therefore, the architectural and hydraulic functions of rainwater and sewage systems were of great importance (Angelakis & Spyridakis, 2010). The remains of Minoan civilisation show that rainwater was conveyed by terracotta pipes and that there were stone drainage systems for sanitary sewerage, roof drainage and surface drainage. Rainwater was collected via both roof and surface collection. Wide-branched stone channels and terracotta pipes were used to convey water to the cisterns (Charlesworth et al., 2016; Burian & Edwards, 2002; Gorokhovich, et al., 2011). As Yannopoulos et al. (2017) pointed out, in Hellas, as in other ancient civilisations, drainage and sewerage systems were combined. Figure 1 shows the drainage pipe used in Ephesus, Turkey.

Figure 1. Pipes used in Ephesus, Turkey (Photo by N.P.Seçkin).

The collection of rainwater for later use in urban drainage systems has been widely used in past civilisations. The use of cisterns dates back to the Neolithic period; rainwater and urban runoff are known to have been collected in cisterns in Persia, and surface water storage technology was developed and used for a long time in ancient Crete. In the Hellenistic period, most cisterns were fed by rainwater, while some were fed by spring water. In Roman times, water collected on roofs was transferred to a cistern inside the house (Burian et al., 2002; Mays et al., 2013).

Aqueducts, which transport water from the source to the main distribution point, were widely used by ancient civilisations to supply water to cities and agricultural areas. The first example is the Nineveh aqueduct built by the Assyrians at Jerwan to supply water to the city of Nineveh. Some of the aqueducts, the most spectacular examples of which can be seen in the Hellenistic and Roman periods, were fed by surface water; most of them were reinforced by springs. The aqueducts in the Roman city of Timgad in North Africa were known to have been fed by qanats, a kind of underground tunnel that carried water from a well to the surface. Wings are known to have appeared in the Middle East at the beginning of the first millennium BCE and are still used in arid regions (Britannica, 2022; 2024; Deming, 2020).

Herculaneum, a Roman city, had a systematic sewage system. The drainage of rainwater and sewage from the city through cobbled streets, the presence of drainage holes in the pavement, and a sewer system under the street indicate the existence of a system for the disposal of sewage and rainwater (De Feo et al., 2014). This observation has been confirmed in Pompeii. The street drainage system consisted of openings on the vertical surface of the kerbstones or openings in the pavement, channels, and manholes to which the drain was connected. Drainage followed the gradient of the road, and the collected water was discharged into the main street sewer, to which the water draining from the buildings was also connected (Mays, 2001). However, stepping stones were used to allow pedestrians to cross the streets without stepping on wet ground caused by rain, flooding, bath water, or fountains (Figure 2).

Figure 2. Stepping stones in Pompeii (Photo by H.Kayan).

The concept of the urban water cycle, first encountered in Roman times, became widespread in Europe and the United States in the late nineteenth century, with the construction of piped water supplies and water-carrying sewer systems. The installation of kerbs and gutters or the levelling of roadbeds to divert surface runoff from streets to drainage channels are important findings (Burian & Edwards, 2002).

Historically, the fact that settlements in ancient China were built near large rivers provided both a source of water and an opportunity to control storm water. The basic principle in the design of drainage systems is to utilise the natural terrain, reduce surface runoff from the site, and effectively recycle rainwater, in short, to integrate the urban and natural environment (Che et al., 2013). In addition to a sewerage system that forms a perfect network, structural solutions that prevent surface runoff, pavements that act as both aesthetic and infiltration can be given as examples. The courtyard complex of individual buildings represents traditional dwellings. As Cun et al. (2019) explains, 'Micro drainage systems in courtyard complexes collect rainwater and convey it via minor drainage systems to the architecture-community-level drainage system. Rainwater gathered in community sewers is then transported to the main urban sewers for discharge into the major drainage system. All of these rainwater management practises at different scales, including natural retention, natural infiltration, and natural treatment, are consistent with the Sponge City concept. Water cellars are also widely used, especially in areas with erratic rainfall and water shortages during dry periods. In this method, rainwater collected from the ground and roof is combined and stored in a settling tank (Zhou et al., 2021).

The rapid growth of urbanisation in the 18th and 19th centuries, coupled with serious public health problems, led to the search for solutions and the development of urban drainage practises. For example, the cholera epidemic in London in the 19th century was solved by the construction of a series of combined preventative sewers north and south of the Thames. However, in the absence of a treatment system, the Thames estuary and its banks were polluted. Since the introduction of biological treatment in the 1920s, urban drainage systems have evolved in line with technical requirements (Butler et al., 2018).

The most significant change in drainage from ancient times to this day has been the choice of materials used to make pipes. Initially made of earth, pipes have been made of lead, wood, stone, and even bamboo; in the present day, copper, brass, concrete, and plastic pipes have replaced the materials of the past to facilitate the flow of water (Seçkin et al., 2017).

Principles of urban drainage

As technology has progressed, drainage systems using high-pressure pumps have been developed alongside traditional systems based on the attraction of water. The aim is to make good use of water, control erosion, and remove water quickly and safely from the foundation, roof, and perimeter of buildings.

Rainwater, in particular, is the main cause of erosion. The aim of drainage is to collect, control and channel water to prevent flooding and erosion, to prevent stagnant water and frost damage to the soil, to maintain the bearing capacity of the soil and to ensure the sustainability of effective waterproofing in buildings. This can be achieved by using surface and subsurface drainage systems or a combination of these. Surface drainage is an open system, whereas subsurface drainage is a closed system. In storm water drainage systems, a number of system elements such as natural drainage beds, open ditches, channels or gutters, culverts, drains, above- and underground pipes, and manholes are used to control and render harmless surface runoff. For example, rainwater falling on the roof of a building flows from the roof surface to the gutters. Rainwater flows from the gutters into the downpipes. These pipes are either poured onto a terrace or concrete or grass surface for wall base protection. If the rainwater downpipes are connected to the underground drainage pipes, the water is drained away from the building site via the underground drainage system and is harmless. However, if there is no such connection, the water that falls from the downpipes onto the ground surface will flow down the slope and away from the wall if this surface slopes away from the building wall. Otherwise, it will collect at the base of the wall, be absorbed by the soil, raise the water table, and potentially damage the structure if there is no drainage system at the base of the building wall.

As mentioned earlier, two types of sewer systems can be conventionally defined: a combined system, in which wastewater and storm water flow together in the same pipe, and a separate system, in which wastewater and storm water are kept in separate pipes. The combined system carries wastewater when it is not raining. When it rains, storm water is added, and the flow of water in the sewer increases. This large volume of wastewater is minimally treated and discharged into the environment, thereby causing pollution. In a separate system, rainwater and wastewater do not mix and can be discharged at an appropriate time. However, rainwater can be polluted for several reasons, such as washing pollutants from the catchment surface, and is slightly more expensive than a combined system (Butler et al., 2018).

Storm water drainage systems are more important in areas where development or settlement is intensively intercepted by storm water runoff. In fact, while under natural conditions about 20-30 per cent of annual precipitation is surface runoff, in areas of high density development this proportion increases to 90-95 per cent (Untermann, 1973). Increased density means an increase in surfaces such as vehicular and/or pedestrian roads, car parks, roofs, and terraces, which causes rapid surface runoff immediately after rainfall. This situation increases the importance of drainage systems.

In a good drainage system, gravity is the main factor governing the formation of surface runoff. The slope of the surface plays an important role. Erosion is the main drainage problem. Both fast and slow movement of water on the ground is harmful. The former leads to erosion and unwanted potholes, while the latter causes formations such as wet soils and swamps. This creates risks that negatively affect the sustainability of waterproofing. In this context, the success of waterproofing in buildings depends on the selection of the appropriate waterproofing material, the correct and faultless application of the waterproofing, and, where necessary, the installation of an adequate drainage system (Seckin et al., 2017).

Land drainage, foundations, floor slabs, walls, wall cavities, wallvoids, ceiling slabs, roofs, plumbing, heating, ventilation, and cooling systems are very important in the design development process to remove water from buildings. These need to be analysed separately. The starting point is the site drainage. Topography, soil type and soil structure are important. Groundwater levels, average rainfall, existing infrastructure, and irrigation systems are also critical to the design of land drainage. All this is important for the correct design of the land drainage, as well as for determining the location of the structure on the site and the finished ground elevation.

Land drainage and levelling are inextricably linked. Grading is the most important solution for reducing runoff velocity and achieving a good infiltration rate, and it should be performed in accordance with the existing topography without disturbing the shape of the existing contour lines. The grading plan and implementation should take into account the collection and removal of water before it reaches the building, allow water to flow without ponding in specific areas, and ensure that perimeter elevations are at least 15 cm below the finished floor level of the building. This will control runoff water from buildings, which can be controlled by rapidly removing runoff from the project area using drainage structures such as channels, aggregate-filled infiltration trenches or tunnels, and detention and retention ponds (Seckin et al., 2017).

Sustainable Drainage Systems

Mays (2007) defined the sustainability of water resources as the ability to use water in sufficient quantity and quality, from the local to the global scale, to meet the needs of people and ecosystems for the present and the future, to sustain life, and to protect people from damage caused by natural and man-made disasters that affect the sustainability of life.

Urban drainage techniques and surface water management strategies can be traced through historical records and archaeological remains. Similar source control methods, such as infiltration, storage, and conveyance in sustainable drainage systems (SuDS), are well known and effectively used in old settlements (Charlesworth et al., 2016). However, similar examples of sustainable rainwater harvesting systems can be found in traditional settlements. The main source of urban water in ancient Egypt was rainwater, and it was associated with structures such as canals and aqueducts (Mays, 2008). As noted by Charlesworth et al. (2016), rainwater collected from roof basins is sometimes conveyed through terracotta pipes to underground cisterns where it is stored. The use of sand filters where water supply was dependent on rainfall, reservoirs to store retained surface and rainwater, and floating aquatic plants in areas where evaporation was likely to significantly reduce volume, such as the ancient Maya, are practises found in antiquity. The use of a coarse sand filter at Phaistos in Crete to remove silt and other pollutants before water was stored in cisterns; the use of infiltrating pavements, meandering swales, and water harvesting at Machu Picchu are good examples of a sustainable drainage strategy (Charlesworth et al., 2016). However, traditional methods such as steels, ponds, and agricultural land used for rainwater harvesting in India are remarkable.

The climate, topographical features, and natural resources of a region, density of urbanisation, the wealth of the communities, history, legislation, and policies determine the scope and quality of urban drainage systems (Butler et al., 2018). Looking at the information that has survived from the historical record to the present day, changes in the understanding of urban water management over time can be constructed as an evolution of the previous stages. Brown et al. (2009) explained this situation in terms of a network of relationships (Figure 3). Based on a historical analysis of technical and institutional arrangements in urban water management, this network identifies six different stages of urban development that cities have gone through in achieving water sensitivity.

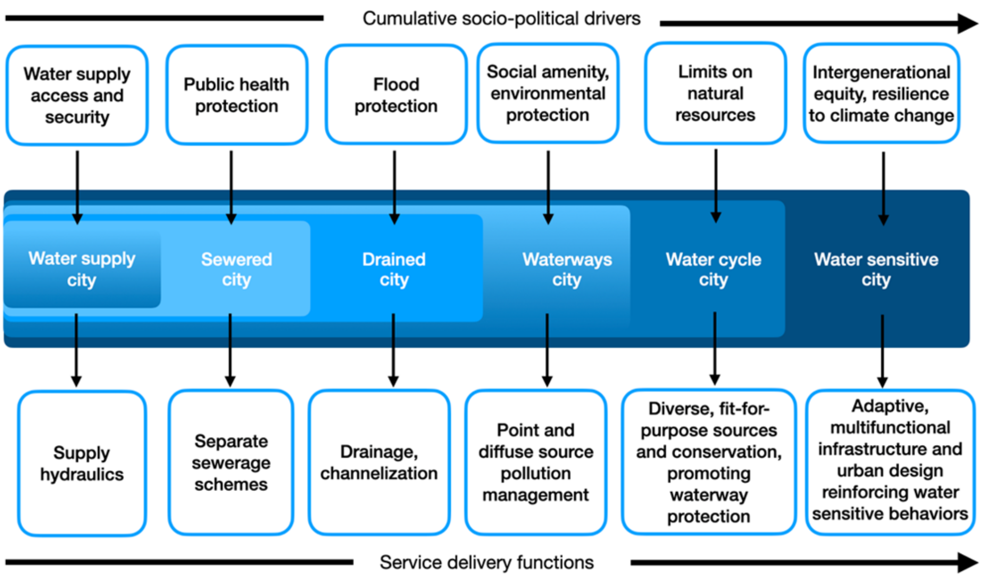

Figure 3. Urban water management transition states (Reproduced from Brown, et al., 2009).

Traditional urban water management is concerned with meeting water needs and removing surface runoff and wastewater from the city. Today, however, the recycling and reuse of rainwater and wastewater are gaining importance in line with cities' sustainability and development goals. Therefore, urban water management requires an integrated system that meets water demand, reuses wastewater, and controls storm water (Wen, 2019).

Due to climate change, the management of flood risk and extreme rainfall in urban areas is becoming increasingly important. Sustainable drainage systems (SuDS), includes 'technical solutions for transporting surface water, slowing down the runoff before it enters watercourses, storing or reusing water at the source, or allowing water to fall on permeable surfaces and soak into the ground' (EPOA, 2024). The systematic use of green roofs, permeable pavements, rain gardens, and canals as part of SuDS can help urban areas become more resilient to flooding and improve the quality of source water (Figure 4).

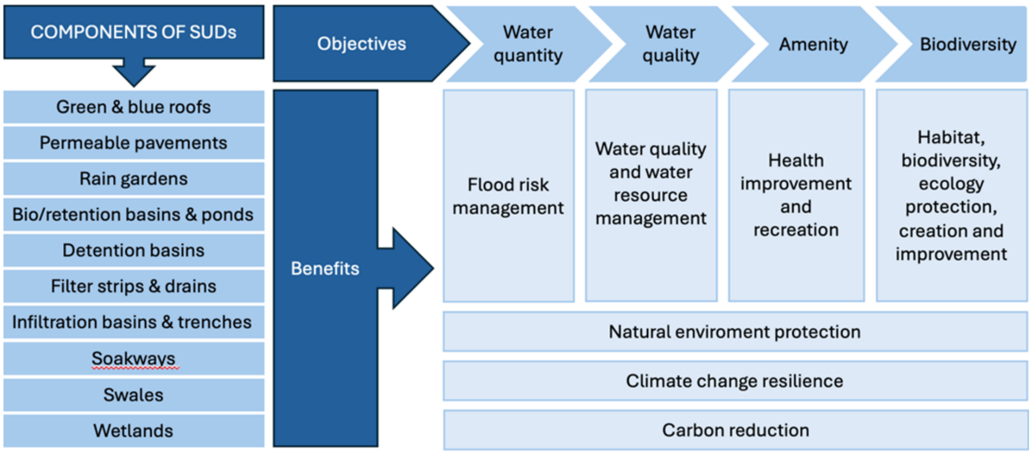

Figure 4. Components, objectives, and benefits of Sustainable drainage systems.

Rainwater harvesting should be the main principle for rainfall management in urban areas. This allows water collected from roofs and other surfaces to be reused. The SuDS network should take into account natural drainage paths, infiltration, and discharge rates. The best example of a sustainable urban drainage system that can filter pollutants through natural treatment is the use of vegetation. Water infiltrates through vegetation, and pollutants in the water decompose and are removed from the water. Vegetated water storage solutions include dry attenuation basins, balancing ponds (wet systems, and shallow vegetated or bio-swales.

Conclusion

The concept of drainage and road use dates back to the early Mesopotamian Empire. However, as we know from De Feo et al. (2014), well-organised and operated sewerage and drainage systems were first used in the Minoan and Harappan civilisations of Crete. The use of hydraulic systems for water supply, distribution, and the transfer of rainwater to the sewers was evident from Minoan remains. These drainage designs, which began with the Minoan and Indus Valley civilisations and were further developed during the Hellenistic and Roman periods, formed the basis of sewerage and drainage technologies in urban environments. The main purpose of these systems is to efficiently use natural resources, making civilisations more resilient to disasters and improving living standards (Angelakis, 2017; Angelakis & Spyridakis, 2013; De Feo et al., 2014).

There is no doubt that urban drainage and sanitation systems will be an important part of future urban planning. Urban drainage and water management must meet today's expectations far beyond its historical importance due to concepts such as urbanisation, climate change and energy saving, which have gained importance today. Population growth and urbanisation can lead to further depletion of already insufficient water resources, increased pollution and health risks in urban areas and negative impacts on wastewater infrastructure. The inadequacy and obsolescence of the infrastructure systems of existing buildings and facilities, combined with new growth and urbanisation rates and increasing environmental expectations, may require costly new investments (De Feo, et al., 2014).

Infrastructure systems that are renewed or built from scratch should be developed in a way that does not contribute to the carbon footprint and therefore does not contribute to climate change and that supports natural life. Sustainable drainage systems (SuDS), which provide a natural approach to rainfall management in urban areas, slow water runoff and improve water quality and storage capacity. The main principle of SuDS is the treatment and management of storm water, which helps to achieve sustainable development goals. This approach avoids the need for extensive surface water conveyance infrastructure, reduces capital costs and carbon footprint, and controls flood risk. In addition to these technical benefits, it provides an aesthetic appearance to the area where it is used by increasing green open space. The functional impact of a smart city building can be enhanced by integration with urban facilities. Some SuDS techniques, such as green roof rain gardens, support biodiversity and ecosystems while providing water management.

Urban drainage has evolved and progressed throughout history, but its basic purpose and principles have not changed. Today, urban drainage has become even more important because of global warming and climate change, which have become a threat to the whole world. By controlling water using methods that are in harmony with nature, it will meet environmental, climatic, and aesthetic requirements and allow cities to maintain their unique value.

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